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ABSTRACT

This publication is a collection of selected papers from the conference on science education in developing countries. The goals of this conference were to review past experiences about theory and practice in science education in both developed and developing countries, identify factors influencing successful practice around the world, distinguish priorities for science education in the 21st century, and develop a plan for action for achieving these priorities. The overview chapter which is based mainly on the Keynote addresses and Plenary sessions focuses on the following themes: goals and needs in science education, a look at the educational system, a look at the learner and the teacher, and assessment and feedback in science education. The papers included reflect a number of important issues relating to the nature of contemporary science education research and its implication for practice, whether in a developed or in a developing country. The chapters are organized around the main conference strands: The Learner, The Teacher, The Classroom, and the Curriculum. (JRH)

Science Education: from Theory to Practice

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Introduction

Bat-Sheva Eylon, Geoffrey Giddings, Avi Hofstein

Science educators from 55 countries met in Jerusalem, Israel, January 3-7, 1993, at an International UNESCO-sponsored Conference on issues of theory and practice in science education. The conference was organized by the Amos de-Shalit Israel Science Teaching Center. This book of readings is a collection of selected papers from the conference.

The goals of this conference were to review past experiences about theory and practice in science education in both developed and developing countries, to identify factors influencing successful practice around the world, to distinguish priorities for science education in the 21st century, and to develop a plan of action for achieving these priorities.

The overview chapter, which is based mainly on the Keynote addresses and the Plenary sessions, focuses on the following themes related to these goals:

Goals and needs in science education: Past and future
Fostering change in science education: A look at the educational system
Fostering change in science education: A look at the learner and the teacher
Assessment and feedback in science education

One of the key elements explored by the conference was how best to bridge the gap between theory and practice in science education. The important differences between the context of research and practice, the fact that research can only offer partial solutions, the dangers of generalizing research results from one context to another, and the difficulty of implementing change are all reflected in the papers.

The papers reflect a number of important issues relating to the nature of contemporary science education research and its implication for practice, whether in a developed or developing country. First, it is clear that a great deal more research is being performed in the context of real-world practice. Practitioners are realizing more and more the importance of research evidence in their thinking, and likewise, researchers, mindful of the need for research accountability and credibility, have more readily embraced the importance of collaboration. These changes have had the effect of producing more relevant and adaptable research information within a natural, rather than abstract, consideration of context. Second, the continuing focus on both process and product research has enabled the achievement of a much more effective balance between these two research paradigms. Finally, the change in grain size of data collection and subsequent analyses raises important methodological issues, which are discussed in a number of papers presented in this compilation.

The other chapters are organized around the main conference strands: The Learner, The Teacher, The Classroom, and The Curriculum. Each chapter begins with a summary by the strand leaders.

Each of these chapters highlights the above-mentioned themes with a different focus. The presentations, however, reflect the fact that these four aspects of the educational scene are inseparable and the discussion of one always involves also the others.

Important aspects of the learner were the subject of many presentations across the strands and focused on the following questions:

1. What are learners' needs, perceptions and motivation for science learning?
2. What do students actually learn? How do they learn? What are the students' conceptions and problem-solving strategies in the sciences?
3. How can learning be promoted? How can conceptual change be fostered?
4. How can students' scientific knowledge and progress be assessed? What is the role and method of assessment?

Driver's summary of the Learners' strand draws our attention to features of the everyday culture of students that may frame particular knowledge representations and that may differ markedly from the scientific culture into which they are being socialized. Driver notes that the contrast between everyday culture and science culture is not limited to the developing world. It is a feature of all societies and raises the important issue for science education of identifying those features of people's everyday culture that frame their "common-sense" knowledge about the world and what is involved when learners move from this to the culture of science. She also notes that some papers provided evidence that the search for the "best" instructional strategy may be a misguided one and that different strategies may need to be provided for different learners.

The main focus of studies of the learning process was on learning as conceptual change. In studying conceptual change, most studies focused on change in the content of students' conceptual schemes though some attention was also given to changes in students' focus of reasoning, for example in their casual reasoning. The picture of conceptual change in science which emerged was that of the evolution of knowledge representation with age and experience. A range of strategies were reported for promoting conceptual change, including the use of analogies, conflict strategies and bridging. The methods used by most researchers to study conceptual change involved detailed studies of the learning of a small number of students during a prescribed unit or topic of work within a specific learning context.

Papers in the Teacher strand dealt with the following issues:

1. Roles, competencies and needs of the teacher in the science classroom
2. Practical implications of studies on teachers' knowledge
3. Models for fostering teacher development
4. The role of the teacher in assessing the learning/teaching process

The papers identified problems related to teaching in developing-country environments as being associated with a variety of factors including: socioeconomic biases; community diversity; centralized decision-making; political instability; inadequate finances, resources, and facilities; limited levels of teacher preparation; inappropriate external exams; poor communication; and insufficient adaptation of curricula to local culture. They indicate that although some educational problems in developed and developing countries may look similar, the underlying causes may differ and mechanisms for solutions almost certainly would have to differ. Thus, the strand leaders, Van den Berg, Lunetta, and Feingold, suggest it is prudent to be cautious in generalizing about remediation strategies and solution alternatives. In short, the authors of this strand suggest that to narrow the great gaps between visions and realities, educational leaders must be sensitive to regional, cultural, and physical settings, while developing and examining more systemic, theoretical and practical conceptualizations of teaching and teacher development. Further, they recommend that databases need to be developed that can serve as bases for scholarly inquiry into the nature of complex educational problems and their resolution.

There was strong across-the-board agreement about the future directions of teacher preparation and its role in science teaching. The concept of lifelong integrated teacher education is widely accepted as a goal for most countries. Certainly it is part of accepted educational wisdom that in our rapidly changing world, teacher education should be a life-long process. This means that the various components of teacher education (pre-service, induction, in-service) should be planned as a whole and be widely available throughout the working life of a teacher. This, in turn, calls for considerable change in many of our systems of teacher education; the integration of in-service and pre-service efforts; engagement between science discipline specialists and those concerned with pedagogy; and the reform of schools to promote more active engagement and leadership for competent, professional teachers.

Presentations in the Classroom strand discussed the following issues:

1. New models and settings for learning science

2. The learning environment in the science classroom and its effects on learning

3. The effectiveness of particular instructional strategies

4. Language and communication in the science classroom

In a summary, Lazarowitz raises issues regarding the need for science teachers to use a variety of teaching strategies to satisfy students' different learning styles, the demands of different topics, the personalities of teachers, and the heterogeneity of students. There was agreement about the advantages of student-centered learning activities as opposed to teacher-centered instructional activities. Classroom life organization is an important factor in the process of constructing knowledge and must allow student interaction that is advocated as an effective strategy for increasing students' learning and conceptual changes. The learning environment and how it is perceived by students and teachers is another important factor in determining learning outcomes. Reports on research concerning classroom learning environment show that it is perceived differently by teachers and students. Also, there is a difference between actual and preferred learning environment by students, and there is better achievement when the two are more congruent.

Presentations about language and communication in the classroom were concerned with several important issues: the need to encourage students to use words that express their thoughts rather than just to report information; the need for students to listen to scientists and interpret what they hear; issues of quantitative communication skill development in students; the difference between home language and the language of discourse necessary to conceive and communicate concepts; and the need to help students communicate clearly, master science concepts, and express thoughts in full sentences. The fact that language is a social tool before it is a language of instruction is an important aspect in communication problems in developing countries.

New roles for teachers are essential so that they can implement alternative approaches in their classrooms that are different from the traditional ones. In his summary, Tobin claims that if we expect changes to occur in the classroom, we have to provide teachers with the autonomy to review for themselves what happens in their classrooms and to construct reasons for what is happening. Only through these activities will teachers be able to decide the needs and procedures to sustain changes in teaching practices.

From a curriculum perspective, a view held by many Conference participants was that science curricula should focus on conceptual change, contain different emphases on the goals of knowledge, methods, personal and social issues, and integrate teaching and assessment along with the content of science. Accordingly, papers in this strand of the curriculum dealt with the following issues:

1. Rethinking goals of science education in light of our current view of the learning teaching process
2. Critical issues in the design and development of new science curricula
3. Models and examples of curriculum development and implementation
4. Assessment and evaluation for curriculum modification.

Bybee and Ben-Zvi, in their summary of the Curriculum strand, reiterate the challenge that the reform of science education in both developed and developing countries has many common themes in addition to some clearly unique issues. Certainly the common goal of developing scientific literacy unites science educators from all countries. On the other hand, the form of particular curriculum in achieving this goal varies among the different countries as science educators accommodate the unique needs and aspirations of their respective countries.

On the general applicability of the reported research at the Conference, the strand leaders concluded that science educators from around the world can truly benefit from, and be informed by, the work of others, regardless of their culture and setting. Moreover, as suggested by Tobin, potential users can consider available research and determine whether or not particular findings are potentially applicable. In education however, the specific features of the particular educational system and practices have a major influence on the effective implementation of any change. For this reason, there is a pressing need to take account of the specific concerns and needs of third world countries in identifying priorities for research in such settings.

Interestingly, presentations across the various conference strands do not support the assumption that contemporary science education, as a whole, is proceeding from theory to practice either in developed or in developing countries. Van den Berg and Lunetta suggest that in a complex social science field like science education there is almost certainly a complex interchange between theory and practice, and although it is unrealistic to expect practice in such a diverse field to be discernibly informed by a unifying theory, it is appropriate for science educators to search for theoretical organizers that can guide practice, policy, and development. Yet, for the present conference, the preponderance of activity reported across the strands seems to have been driven more by perceived needs and practical constraints than by theories.

In discussing research priorities for the future, Kempa notes that several conditions need to be fulfilled for closing the gap between research and practice, the most important being the following:

1. In the choice of research topics, far greater attention has to be given than has been the case hitherto to practice-relatedness and applicability.

2. Closer cooperation needs to be achieved between researchers and practitioners, preferably in the form of a genuine communication between the two.

These conditions suggest the importance of research that is being carried out in the context of practice.

Several presentations stressed the importance of studying issues related to the needs and goals highlighted in the conference, namely producing science education for all and providing the needs of future citizens in a scientific and technological society. For example, Driver notes that most research on learning to date has focused on conceptual understanding (with emphasis on physics rather than life sciences). Little attention has yet been given to the study of the ways people develop practical problem-solving capabilities or the way in which their knowledge interacts with their action.

.Designing research that meets the previously mentioned goals suggest the importance of studying issues such as: providing baseline data on the existing situation relating to the provision of science education (teaching practices, level of resources, learning outcomes, etc.); making decisions about what science is appropriate to the needs of learners; researching the resources for learning science that exist within the culture (local environment, technologies, cultural practices, etc.) and investigating how these can be drawn upon in instruction; what strategies can be used to promote effective learning in realistic educational settings where effective learning may require significant changes in practice; and how science can be communicated effectively in an informal setting to people of all ages within a society.

In considering future research associated with teacher needs, an important direction is the investigation of processes involved in ". . .preparing teachers to teach the way students learn," discussed by McDermott and Gunstone. This kind of teaching involves a change in the role of teachers in the classrooms. Taking the view of "teachers as learners" requires the development of a research program on teacher learning involving the identification of what needs to be learned by teachers and what models of teacher development can meet the needs. Teacher stress, desirable goals of instruction (breadth vs. depth), models of teaching and learning, and roles of teachers as researchers are some of the issues involved in investigating models for life-long teacher education and development. Such models must also consider the systemic changes that need to be taken (e.g., licensing systems consistent with appropriate long-term teacher development, systems for recognition and enpowerment of successful teachers, etc.).

Some of the gaps between research and practice result from the different time scales involved. Usually the time duration of research studies is short, relative to the relevant time in practice. Consequently, in planning a meaningful research agenda that can inform practice, it is essential to allow enough time to develop meaningful research results. Short-term studies can inform practice only in a limited way.

Innovation is a slow process and it requires time. To foster innovation, a systems approach is required—one in which longitudinal, progressive refinement of program development, school and classroom organization, teacher development, assessment, and research are all considered and activated together. Coherence of theory and practice is a more natural outcome of such an integrated effort.

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Chapter 1

Overview

Goals and Needs in Science Education—Past and Future

Samuel Bajah

Introduction

In many developing countries, the enthusiastic but over worked classroom teacher of science is often concerned with short-term objectives with observable behaviours clearly stated. Goals often have been set by the larger national policy makers. However, national goals and classroom behavioural objectives must intersect. The education literature is very clear on the differences between goals and objectives—goals are long-term, broad statements of intention, and objectives are usually specific and relatively short-term. There is the normal assumption that classroom objectives are derived, by and large, from national education goals. There is also a strong belief that goals are determined by governments in policy papers:

> *Government prescribes the following curricular activities for the primary school: the inculcation of literacy and numeracy, the study of science. . . . Government will also make available materials and manpower for the teaching of science.*
> (National Policy on Education, 1981
> Federal Republic of Nigeria)

The arduous task of the classroom teacher is generally to translate goals into achievable objects.

The Curriculum Developers and Classroom Teachers

Many developing countries have placed a very high premium on the teaching and learning of science (Fafunwa, 1967; Bajah, 1977). That science is important and desirable is no longer the issue—what is perhaps still being debated is what science has done or can do for developing countries. Advancement in modern technology has been used as evidence for the need to support science, but when a scientific disaster occurs or when science is misused, the accusing finger is pointed at science. But as science educators, it is our task to present science to our students as an appropriate activity. Goals in science education are therefore translated into well-thought-out objectives by curriculum designers.

Curriculum developers and researchers in many developing countries have come to accept three types of curriculum that constitute the framework of a system in our education (Figure 1):

1. The intended curriculum
2. The implemented curriculum
3. The achieved curriculum

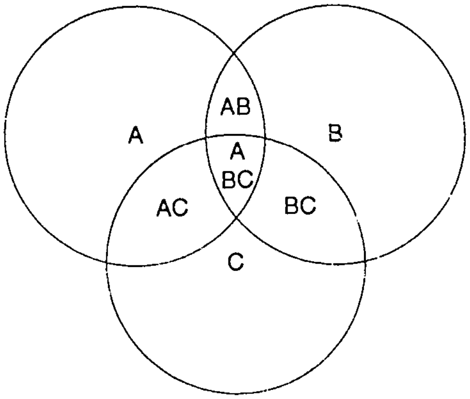

Figure 1. Tripartite Curriculum

These three aspects of the curriculum system should achieve the intended goal. In practical terms however, there has always been disparity between any one part of the system and the others.

Learner Needs

In considering the needs of the learner, two aspects become important —the perception of and the motivation for learning science. In many African countries, science has been portrayed differently. In Nigeria for instance, there was once a prevalent idea that science is *iro oyinbo*, which translates to mean *science, the white man's lies*. Science was perceived as a subject in schools brought from the outside, from a culture different from our own. Today however, science is seen more as the precursor of technology among a large proportion of school children (Bajah and Okebukola, 1984). Thus, classroom teachers have an up-hill task, not only to change the orientation of their pupils, but to teach science in a culture with a strong belief in "superstitions" (Awokoya, 1979). Perceived in its modern sense, science for many people in developing countries must not only be seen as an adventure of the human mind but as a discipline that enables the understanding of nature. But more than that, it must lead to the solution of problems, including disease, poverty, and under-development. The classroom teacher must therefore understand the cultural setting in which science is being taught.

Fortunately, in many developing countries, there is still a high density of school-age children who are anxious to acquire education, including the study of science. However, the motivation to pursue and sustain the study of science suffers some setbacks. Science is still seen with some suspicion as infringing on traditional beliefs brought from home. Science is perceived as a difficult subject, first to be studied only by the academically above-average student. If the study of science, as many believe, cannot readily take the student toward the goal of becoming a medical doctor, there is no need to study science. The classroom teacher therefore not only has to present science in the most interesting ways, but also has to be a career-guidance counsellor. The science teacher, supported by the society, must do everything to convince students of the worth of studying science. Many children will continue studying science if:

1. They are provided with the relevant science textbooks;
2. They can perform the experiments they study;
3. The examination system takes into consideration their classroom activities; and
4. Their traditional beliefs are examined through science sympathetically.

It is also important that, upon completion of the school science program, the students have bright prospects for job placement in science-related areas.

Roles, Competencies and Needs of the Science Teacher

The arguments advanced thus far put the science teacher in a commanding position. A student in a developing country once referred to the senior science teacher in the school as the "commander-in-chief of the unarmed forces." But certainly, that description does not fit the preferred role of the science teacher as a "facilitator of learning." The teacher is like a sales person with a commodity—science—and the prospective buyers are the students. The interplay between teacher and learner is such that a strong cooperative spirit is generated.

To enable the teacher to efficiently perform these roles, certain competencies must be acquired. The teacher must, above all, (a) have a thorough command of the science subject taught; (b) be able to manage the learners, and (c) be able to manage with the often limited material resources available. In both the initial training and the in-service training, the teacher must learn to be in control. Teachers lose respect of their pupils if there is any doubt about the competency of the teacher in the subject taught. For teachers to remain in control and be confident, they must know and display that knowledge of their subject.

Many teachers are being asked to teach a subject for which they are inadequately prepared. Volunteer teachers who have been sent to many developing countries face this problem, for instance, a geology graduate being asked to teach advanced-level chemistry in a sixth form school. Or as we now regularly find, a graduate in agriculture being asked to teach integrated science or physics to sixth-formers. Teachers must be given teaching assignments in areas in which they are trained. Trying to use "conventional wisdom" in teaching is not enough. And as the educational system in many developing countries continues to improve, teachers need regular INSETs to update themselves. They must learn how to best use the latest technology available in teaching science.

When discussing professionalism, there is always the caution to avoid any aspects of trade unionism—salaries and conditions of service. Yet it is the one single factor that we find affects the total performance and outlook of the teacher. The observation made about teachers' conditions of service is worth noting here:

> *Teachers have seen a massive decline in their status; they are asked to work long hours for a salary that has rarely kept up with inflation; they often work with only a few materials of very poor quality; contact hours with their students are reduced; and more and more time is spent on needless administration brought about by constantly changing government policies.*

New Models and Settings for Learning Science

Science teachers in developing countries have long been used to the "chalk and talk" approach to classroom teaching. This prevalent approach has largely been because of the limited resources and public examination pressure which with teachers are confronted. At the primary school level, the science teachers now try to teach science with some emphasis on experimentation and pupil activities. Figures 2a and 2b show how observed classroom transactions have been represented (Bajah, 1977) in one of our studies. The distortion in the observed teaching profile has been due to the various factors already discussed in this paper: the teacher factor, the pupil factor, and the classroom environment factor.

The classroom teacher is largely responsible for teaching-learning transactions, but a major aspect of present-day science education program rests with the curriculum developers. In many of the Curriculum Development Centres that now exist in developing countries, radical approaches to the delivery of science at both the primary and secondary school levels are being suggested: Flexibility has been brought into the prescribed syllabus. The integrated approach, with emphasis on society, is given considerable mention in curriculum development materials. To encourage primary teachers to use more of activities in their science teaching, the process approach to the teaching of science is being suggested.

The concept of the laboratory is now being revised to include the entire physical environment in which science can be studied. Thus, the four walls surrounding many conventional laboratories have been pulled down, especially at the primary school level. At the secondary level, laboratory use and management have been pursued to make all the laboratories cost-effective. The scarce funds available for building and equipping school science laboratories should be well spent.

Rethinking Science Education: Goals in Developing Countries

The twenty-first century will arrive with new technology. The entire world, including developing countries, will face the modern age, and unless everyone embraces science and technology, people will just exist—not live. Scientific literacy for all is therefore

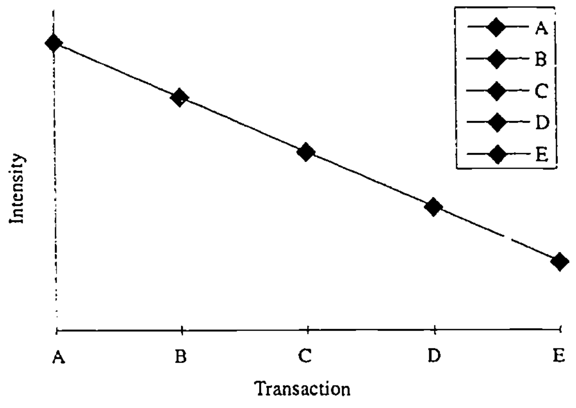

Figure 2a. Ideal Profile

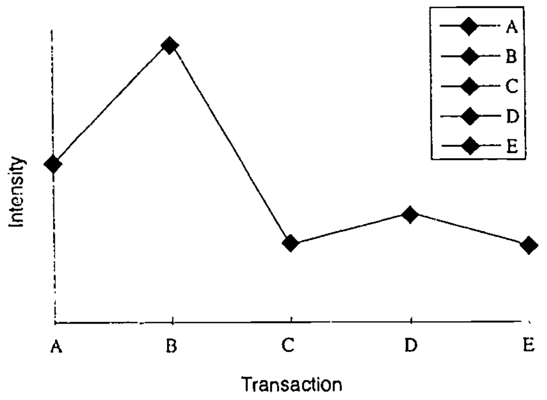

Figure 2b.

LEGEND: A = Individual or Group Activity
B = Whole Class Discussion
C = Transition (Handing out of materials or rearrangement of class)
D = Lecturing
E = Other (Note copying from chalk board)

a *sine qua non* for living in the twenty-first century. Science educators should, as much as possible, be familiar with *Project 2000+*, an international initiative of UNESCO and ICASE (International Council of Associations for Science Education). It is essential that we educate everyone through science. The relationship between science and society, highlighting environmental issues, should be underscored.

Two issues that now plague developing countries are health and politics. Life expectancy in many developing countries is relatively low (although rising) when compared with technologically advanced countries. The teaching of good science should make a positive impact on the health of people in developing countries. Another issue that plagues many developing countries is politics. How can education through science positively influence politics as they exist in the developing countries? When people enter politics, they tend to forget the ethics that science is meant to transmit. Science and politics—are these strange bedfellows in developing countries?

Conclusion

This paper should be read along with the global/national treatment of goals and needs. The science classroom to a large extent is a reflection of how much importance any nation gives to science. National goals, when properly conceived and implemented, will lead to a classroom environment conducive to science education.

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Dilemmas in Science Education: Solutions From Individuals

David Waddington

This conference examined in detail the goals and needs of science education, past, and future. Much of the discussion was about strategies, including many facets of education services at government and at local levels. However, I want to illustrate in this paper the efforts of individuals or individual groups in improving science education at all levels. This paper contains examples from India and Brazil, with which I have been involved, and finishes with work begun in the United Kingdom that has attracted international interest .

As you have read this paragraph, at least 100 children have been born, 6 in industrialized countries and 94 in developing countries (World Bank, 1991). Of these, more than 20 have been born into circumstances that most of us find intolerable even to consider, for as children or adults they will have to exist on less than one dollar a day. Many will have no formal education; they live in countries with a literacy rate of less than 70% and with a illiteracy rate double among women than men (Unesco, 1991; World Bank, 1991).

Some of the 94 children may live in a country where $250 are spent each year per pupil on education; those less lucky will be in a country that can afford less than $50. Industrial countries can spend $2000–$4000 per pupil annually. This must be considered as we discuss science education access world-wide.

Science education covers an enormous range of activities, in primary and secondary education and in teacher training. But it also covers technical education, university and college education, and specialized research courses, all subjects generally ignored when science education is discussed.

Where should countries put their resources in science education? Is it in basic education or in advanced training? The latter may bring quick results for the industrial base; the former may, in the long run, provide a better framework for sustained development. This dilemma is shared by industrial, as well as developing, countries. In the United Kingdom, the government has deliberately allowed the science education base at the university level to erode. Some universities have closed their physics and chemistry departments as they concentrate their remaining resources elsewhere; some government-funded research institutions of international renown have been closed or face closure. There are serious deliberations as to whether we should withdraw from one of the greatest international research laboratories—CERN.

Because university education may not get its fair share of attention in the conference, I will begin my examples with some work in India and Brazil. What follows are some small initiatives, highly focused, but from which we can learn for the future.

A venture in India began in 1977, inspired by a lecture at a conference in Ljubjana given by Emmanuel Apea, who had been teaching in his native country, Ghana, and who is now well known as a science education specialist at the Commonwealth Secretariat and UNESCO (Apea, 1977). Apea was stressing the need to rethink our teaching strategies if science were to remain an experimentally taught subject; I, as Chairman of that part of the meeting, asked IUPAC and UNESCO to help to bring practitioners together. Listening, unknown to us, was an internationally distinguished theoretical chemist, Krishna Sane, from the University of Delhi. He met me 2 years later and said he would like to join the network. As the network did not exist, he became the network. He brought together volunteers—colleagues, students at the University of Delhi, and local teachers to analyze the problem.

The Problem

The laboratory component of chemical education in developing countries is deteriorating because of a continual rise in the cost of equipment and chemicals and the black box attitude toward instruments, resulting in poor maintenance. The diminishing quality of laboratory work prevents learning of manipulative skills and produces chemists ill equipped for research, teaching and industry. This has led, at worst, to no experimental work being performed, or at best, to experiments irrelevant in terms of content and experience for the course itself and for the students' careers on leaving the university.

A Solution

Modern technology, particularly in electronics, offers many products that are cheap, versatile, long lasting; they are now made or are available in developing countries and are usable as building blocks for the design of simple equipment.

Krishna Sane insisted that equipment such as pH meters, conductance bridges and other electrochemical devices, had to be made by the teachers themselves so they could learn to maintain them and not add to the ever increasing graveyards of broken equipment that litter universities world-wide. This is, of course, teacher training with a hidden agenda.

An Approach

A problem, however, can seldom be solved by technology only. Methodology is equally important. If reliable low-cost equipment (i.e., equipment low in cost but not in quality) is to become a means of improving chemical education, it is essential that teachers and students are involved in the developmental process, that is, in the design, fabrication and testing of prototypes. This will ensure that the equipment is tailor-made for different requirements, confidence and expertise in instrumentation is generated, overheads are negligible, and maintenance is satisfactory.

In the first 10 years of the project, many teacher workshops were held. The first few were devoted to developing and testing the equipment. Others were used to help start or to encourage the development of similar centers in other countries (Table 1). Others, for example in Denmark (Sane, 1983) and Germany, brought together the leaders of these other groups (such as Professor Ram Lamba of the University of Puerto Rico, Dr. Zaghul of the University of Jordan, Dr. Edward Gabrowski at the University of Lyon and Professor Danielle Cros at the University of Montpellier, and Professor Reiko Isuyama at the University of São Paulo) to review past work and to discuss initiatives.

Professor Sane has published many texts to help individuals who are unable to come to the workshops to benefit from the work, and examples are given at the end of this paper (Sane 1981, 1984, 1987; Sane & West 1991). Recently, the Indian University Grants Committee asked him to supply equipment to students at the Indira Gandhi Natural Open University and to organize a large national program of college teacher development based on his work.

Another individual assisting in more relevant teaching of chemistry at the university level is Professor Reiko Isuyama at the University of São Paulo. Two reasons for the work are similar to those seen by Professor Sane. One is the lack of student-centered learning; the second is the irrelevance of much of what is taught. These two were starkly demonstrated in courses in industrial chemistry at São Paulo that were based on texts produced in the United States and United Kingdom. Thus, students were learning about industrial processes that were not used in Brazil. Furthermore, they had no idea why the particular process used in Brazil had been chosen. Professor Isuyama now has a group at São Paulo producing interactive case studies on Brazilian industry (Table 2).

The knowledge generated through the project has been transferred to teachers through workshops. The following training workshops were held by the Electron-

Table 1. The IUPAC/UNESCO Project in Delhi: Propagation

Madras	India (April 81)	Delhi	India (April 92)
Mysore	India (October 81)	Indore	India (July 92)
Delhi	India (November 82)	Reduit	Mauritius (August 92)
Hyderabad	India (November 82)	Rewa	India (December 92)
Chandigarh	India (January 83)	Trivandrum	India (January 88)
Delhi	India (June 83)	Jaipur	India (April 88)
Sao Paulo	India (July 83)	Iloilo	Philippines (May 88)
Georgetown	Guyana (August 93)	Hong Kong	Hong Kong (May 88)
Copenhagen	Denmark (August 83)	Uberlingen	Germany (July 88)
Montpellier	France (August 83)	Lisbon	Portugal (August 88)
Dhaka	Bangladesh (June 84)	Delhi	India (December 88)
Bathurst	Australia (September 84)	Delhi	India (April 89)
Talwakalle	Sri Lanka (December 84)	Bharuch	India (April 89)
Singapore	Singapore (April 85)	Mayiladuturai	India (May 89)
Ljubljana	Yugoslavia (June 85)	Dhaka	Bangladesh (June 89)
Puerto Rico	USA (October 85)	Waterloo	Canada (August 89)
Amman	Jordan (October 85)	Reduit	Mauritius (December 89)
Bombay	India (December 85)	Delhi	India (February 90)
Rajshahi	Bangladesh (April 86)	Delhi	India (March 90)
Bangkok	Thailand (October 86)	Bangalore	India (May 90)
Islamabad	Pakistan (December 86)	Bangalore	India (June 90)
Kathmandu	Nepal (February 87)	Delhi	March (March 91)
Serdang	Malaysia (April 87)	Delhi	India (January 92)
Kabul	Afghanistan (October 87)	Delhi	India (March 92)
Hyderabad	India (December 87)	Bhopal	India (May 92)
Delhi	India (February 91)	Uberlingen	Germany (August 92)
Delhi	India (August 91)	Gwalior	India (September 92)
Delhi	India (February 92)	Johannesburg	South Africa (September 92)

ics Group under the auspices of UNESCO, UGC, IUPAC, and DST, in association with global, regional national agencies[1], and host institutions.

As can be seen from Table 2, students work, either as individuals or in groups, on exercises that introduce the scientific principles needed to understand the process and the economic factors which must be taken into account in choosing the starting materials and the process used. Students can compare their choices with those actually used and determine other reasons (social and political) that may have come into play in making the choice. They see that there may be no right answers, something as scientists they must appreciate. Economic, technological, social issues are woven into the chemistry course, but the chemical concepts still remain essentially what drive the case studies.

One particularly pleasing aspect of the work has been the interest from industrial companies in Brazil, both international and national, and the help they have given

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[1] These include: ICSU, Commonwealth Foundation, COSTED, IDRC, ADAB, and AUIDP (Australia), UGC (Pakistan, Bangladesh), NCERT (India), All India Science Teachers Association, RONAST (Nepal); and the British Council.

Table 2. University of São Paulo: Case Studies in Industrial Chemistry

The Units Produced So Far in This Project

Hydrogen Production in Brazil
R. Isuyama, P. W. Tiedermann, and C. J. Garratt

A decision making exercise where the student has to play the role of a consultant chemist to a company wishing to make hydrogen to produce nylon salt. Students analyze the processes available in Brazil and through comparison of the inputs and outputs of different processes decide which is the most suitable.

Paints, an Application of Polymers
P. W. Tiedemann, R. Isuyama, and G. C. Fettis

The substitution of one raw material for a less toxic one for the manufacture of a polymer in latex paints is examined in terms or the economics of the process. The glass transition temperature of the new polymer, an important physical property of polymers, is compared with that of the previously used polymer.

Ammonia, Fertilizers and the Fixation of Carbon Dioxide
J. A. Pontin, E. M. Aricô, J. Pitôscio Filho, R. Isuyama, P. W. Tiedemann, and G. C. Fettis

Ammonia production is approached in the context of reduction of atmospheric CO2 . There is a quantitative comparison of carbon dioxide absorption by forests and by crops to investigate whether the application of fertilizers for food production is recommended from the point of view of the amount of CO_2 released to the atmosphere.

Production of Chlorine: Present Status in Brazil
S. B. Faldini, W. de Oliveira, R Isuyama, P. W. Tiedemann and G. C. Fettis

Students examine the possibility of using a membrane cell for the manufacture of chlorine instead of a mercury cell, in terms of energy consumption and other economic and environmental concerns. The unit also examines how the Brazilian industries are reacting to the Montreal Protocol of 1989 to diminish the emission of CFCs.

Production of Titanium Dioxide
J. Pitôscio Filho

The supply of raw materials, available in Brazil and the disposal of by-products for the production of titanium dioxide, is investigated in terms of technology, economics and the environment.

Production of Aluminium
E. M. Aricô, R. Isuyama, P. W. Tiedemann, and G. C. Fettis

Students look at the specific primary energy consumption in the production of aluminum in Brazil. The analysis of the production of a can shows that a large amount of energy is needed to produce aluminum, which is then compared with the energy consumption for the production of steel cans.

Quality Control of Vitamins
M. Escudeiro and E. de Oliveira

This investigates a modern statistical concept of quality control. Production and sampling are used to understand quality control processes now used.

Table 2. University of São Paulo: Case Studies in Industrial Chemistry (cont.)

Plastic Waste -- What Should be Done?
J. A. Pontin

The various processes of recycling plastics - mechanical, physical and chemical - are analyzed, in particular emphasizing possible environmental problems each of the processes may cause.

Recycling Paper—Is It Worthwhile?
S. Corner

The advantages and disadvantages of recycling paper are evaluated by comparing the amount of energy used to produce and to recycle paper.

Recycling Aluminium
R. Isuyama, P. W. Tiedemann, and G. C. Fettis

This is an exercise involving energy calculations on recycling aluminum and producing primary aluminum.

Ammonia Syntheses: An Economical Alternative
P. W. Tiedemann, R. Isuyama, and G. C. Fettis

Students examine the effects on the operating conditions for the manufacture of ammonia, investigating the substitution of refinery gas for naphtha as a raw material.

in the production of the case studies. A real partnership between industry and education has grown, which has so far involved 15 of the leading companies in Brazil and ABIQUIM, the leading association for the chemical industry.

The third example concerns a large effort in Brazil, PADCT, to bring their science base, in carefully selected areas, up to international standards so they can compete successfully on equal terms with highly industrialized countries. The World Bank and the Government of Brazil, with matching funds, have a program of some $800 million over 10 years, to update university departments in chemistry, biochemistry, environmental services, and geosciences.

These are called the vertical sub-programs; there are horizontal sub-programs to support the vertical programs. These horizontal programs exist in instrumentation and maintenance, to ensure that the equipment is in good order; in consumables, to ensure that the program is not held up for lack of materials that have to be imported; in science policy, to ensure that Brazil has the necessary infrastructure for its scientific research; and in information, to ensure that the libraries and information systems are adequate, nationally, for this drive. But there is one extra ingredient which I believe will, in the long term to be the most significant. About 15% of the total funding is going to it another horizontal sub-program, science education, entirely devoted to primary and secondary education. Resources for university and college education—highly necessary if the vertical sub-programs are to succeed—come from the vertical sub-programs themselves. Much of the science education program is being devoted to in-service training, in an attempt to secure a sure foundation later on for innovation.

Thus, one of the dilemmas discussed—whether to invest in primary and secondary or in tertiary education for development—is being answered in this imaginative program. What is less clear is whether the scheme is supportive enough of the poorer parts of the country. There is a considerable disparity in wealth between the relative prosperous South and Southeast of Brazil and the rest of the country.

The World Bank has reversed its policy of investing so much of its educational resources in technical education at the secondary and tertiary levels, believing that it was unable to gauge accurately enough the needs of individual sectors of the economy. Instead, it is encouraging more investment in basic and secondary education, and the initiative in Brazil is an example. Further, it helps to reverse an unhealthy trend in the proportion of educational resources going to a minority of the population. For example, it is estimated that 50% of the educational budget in India goes to the 10% most highly educated; Bangladesh has a higher proportion, with about 75% of the budget being spent on 10% of the population (World Bank, 1991).

Indeed, the message coming from the World Bank and other agencies such an UNESCO is that science education is needed for everyone (Bowyer, 1990; UNICEF, 1990). To this, one should add the words appropriate and understandable.

One such appropriate and understandable initiative in the PADCT science education program is that of Dr. Dietrich Schiel. He has created a center, which can act as a model for others both in Brazil and in other countries, for producing low-cost equipment for experimental work for new primary science courses being introduced into Brazilian schools from his own base at the University of São Paulo, the São Carlos campus, into centers all over Brazil (Schiel, 1993). It is an imaginative program that deserves careful evaluation and study.

There are common characteristics in these three examples. All three have individuals who have a strong belief in the work and are resolute in bad times; are doing the work in addition to their normal duties; have built strong teams around them and have a powerful infra-structure; have focused on specific work of amenable proportions; have done market research to ascertain demands; have, in harness with curriculum development, initiated an intensive program of in-service teacher training; have developed interactive student-centered learning materials; and have brought in other scientists as advisors, and industrial companies

Table 3. The Salters Approach

Project	Age Range	References
Salters' Chemistry	13 - 16	Frazer, Garforth, Lazonby, & Waddington, 1984; Garforth, 1983; Hill, Holman, Lazonby, Raffan, & Waddington, 1989;
Salters' Science	11 - 16	Campbell, Lazonby, Millar, & Smyth, 1991; Edwards, 1989; Ramsden, 1990
Salters' Advanced Chemistry	16 -19	Holman, 1991; Lloyd, 1992; Ramsden, 1992; Waddington, 1992

Table 4. Salters Chemistry Project: Units

Metals
Drinks
Warmth
Food
Clothing

Buildings
Food Processing
Growing food
Keeping clean
Minerals
Plastics
Transporting chemicals

Burning and Bonding
Energy
Fighting disease
Making and Using
Electricity

Table 5. Salters Science Project: Units

Restless Earth
Construction Materials
Energy Matters
Food for Thought
Keeping Healthy
Moving On
Transporting Chemicals
The Atmosphere
Balancing Acts
Communicating Information
Mining and Minerals

Electricity in the Home
Burning and Bonding
Controlling Change
The Earth in Space
Energy
Evolution
Making Use of Oil
Seeing Inside the Body
Sound Reproduction
Sports Science
Waste Not Want Not

Table 6. Salters Advanced Chemistry Project: Units

Title	Storyline	Main Chemical Principles Developed
1. The Elements of Life	A study of some elements, in the human body, the solar system and the universe	Atomic and nuclear structure; bonding; periodicity; Group II chemistry; chemical calculations
2. Developing Fuels	A study of fuels and the contributions that chemists make to developing better fuels	Homologous series; alkanes; isomerism; thermochemistry; catalysis
3. From Minerals to Elements	A study of the extraction and uses of three elements, used to introduce major classes of chemical reactions	Halogen chemistry; major classes of chemical reactions: acid-base, redox, complex formation, precipitation
4. The Atmosphere	A study of chemical processes occurring in the atmosphere which have important influence	Interaction between radiation and matter; free radicals; halogenoalkanes; equilibrium (qualitative)
5. The Polymer Revolution	The story of the development of polymers, from the first discoveries to the present day	Polymerization; alkenes; intermolecular forces
6. What's in a Medicine?	A study of aspirin, its chemistry and synthesis, illustrating some of the features of the history of pharmaceuticals and the pharmaceutical industry	Spectroscopy; alcohols, phenols, carboxylic acids and derivatives
7. Using Sunlight	An account of the ways that chemicals can trap the energy of sunlight and make it available for useful purposes	Photochemistry; redox; electrochemistry
8. Engineering Proteins	The story of proteins and enzymes, the role of DNA in protein synthesis and the use of chemistry to 'engineer' proteins with particular properties	Amino compounds; enzyme catalysis; reaction kinetics (effect of concentration)
9. The Steel Story	Steel as a material, and the processes used to make it and prevent its corrosion;	Electronic structure; d-block elements; complex formation
10. Colour by Design	The chemical basis of colour and the use of chemistry to provide colours to order	Aromatic compounds; analytical techniques
11. Medicines by Design	An account of the way chemical principles and techniques are used to investigate the effects of chemicals on the body, and to design and make pharmaceuticals	Carbonyl compounds; synthetic routes; molecular recognition
12. Aspects of Agriculture	A study of the contribution that chemistry makes to ensuring a safe and sufficient food supply	Group IV and Group V chemistry; equilibrium constants; reaction kinetics (effect of temperature)
13. The Oceans	The story of the oceans: their role in regulating the climate, in forming rocks and in supporting life	Solvation and solutions; acid-base equilibria; solubility products; entropy

Visiting the Chemical Industry: A structured industrial visit leading to a study of the way that chemical principles can be applied to optimize efficiency and safety and to minimize environmental damage and economic cost.
Individual Investigation: A practical investigation of a topic chosen by the student.

as collaborators. They are models for future development.

The final example in which all these characteristics are present is from an industrial country—my own. These are the Salters projects. So far, three curricula have been developed (Table 3). All have similar criteria. They are courses which are designed to address the needs of students who wish to resume the subject at a higher level; inspire students to think about science and technology in terms of their future courses; and educate others, to enable them to work and live enjoyably and effectively in a society increasingly dominated by science and technology.

To achieve this end, we did not define what we expected of students when they completed the science course. Instead, having chosen themes, we then developed them by introducing science concepts only when they are *needed* to understand the work. The concepts are linked to a context that students see as important. We encouraged active learning and exploration, for example, with student practical work, small group discussions, class discussions creative writing and reporting, role-playing exercises for discussing value-related issues, and applications of information technology techniques.

The choice of topics in the Salters Science and Salters Chemistry courses (for 11- to 16-year-olds) was governed by consideration of what students might bring to the course in that age range and by basing the content on things in their lives that they have experienced either first-hand or through the media.

The Salters Advanced Chemistry Course (Table 6), like the earlier projects, provides a rigorous course of study that stimulates and challenges students. It lays the foundation for future studies, yet provides a satisfying course for those who will take their formal study of the subject no further. We want to lift the eyes of these 16- to 19-year-olds to the horizon, to where chemistry is.

We also wanted our students to understand something of the many and varied jobs chemists do and the roles they play in modern society. The titles of the course units (Table 6) give some of the flavor of the course. The table shows what chemical principles are introduced.

In this paper, I have described several projects that have been inspired by and performed by individuals or small groups. In the end, it is science educators, often working on their own and in difficult circumstances, that effect real changes in what students are taught. Governments and institutions can create the climate for change; individuals are much more important in making the changes.

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The Science/Technology/Society Movement: Views, Practices and Results

Robert Yager

Introduction

Science/Technology/Society (STS) has become a major reform effort across the world as many search for new ways of resolving the serious problems in science education. Many find reforms in science education related to national superiority, the differences between developed and developing nations, worldwide economic competitiveness, and environmental degradation. The seriousness of the problems suggests the reasons that politicians, business leaders, military personnel, humanitarians, and environmentalists are united in calling for science education reforms at all levels and in all nations.

John Ziman is credited with providing the name "STS" to describe worldwide efforts to broaden the nature of science courses in elementary and secondary schools (Ziman, 1980). Ziman sees the STS movement as a focus upon the nature of science, its relationship to technology, and the use of science in people's lives. Ziman and others in the U.K. popularized the movement with Lewis' *Science in Society* series (1981) and later the *Science in a Social Context* Program (Solomon, 1983). Efforts were also undertaken in The Netherlands with PLON (Physics Curriculum Development Project), and a number of other European nations illustrate other STS initiatives designed to improve student learning as they deal with real problems that require science concepts and skills.

STS was popularized in the U.S. by Harms, who used STS as one of the five focus groups for his Project Synthesis (Harms, 1977). Suddenly STS became an area for study, concern, and trial in U.S. secondary schools, where there was interest in innovation and reform. Many saw STS as a means of responding to the Goal Clusters that Harms used as a basis for Project Synthesis, one of the largest NSF projects funded to analyze the current status of science education in the U.S. Project Synthesis analyzed the current states and the desired/visionary states, contrasted the two, and made recommendations for moving the current to the desired state. The Goal Clusters were:

1. *Science for Meeting Personal Needs.* Science Education should prepare individuals to use science for improving their own lives and for coping with an increasingly technological world.

2. *Science for Resolving Current Societal Issues.* Science education should produce informed citizens prepared to deal responsibly with science related societal issues.

3. *Science for Assisting with Career Choices.* Science education should give all students an awareness of the nature and scope of a wide variety of science and technology-related careers open to students of varying aptitudes and interests.

4. *Science for Preparing for Further Study.* Science education should allow students who are likely to pursue science academically as well as professionally to acquire the academic knowledge appropriate for their needs (Harms, 1977).

Many saw STS as a way of providing a means of realizing the first three goal areas—places where typical science courses were found to be wholly deficient.

In addition to goals that were not being met by traditional science programs, many identified specific problems which were causing alarm. Unfortunately, these basic problems were not being addressed, as leaders called for students who possessed fewer misconceptions, who could score higher on student examinations, and who would remain in the science "pipeline" beyond required courses and programs. The following were chief among these serious problems needing funding and direct attention.

1. Although a focus on science process skills (inquiry, critical thinking, problem solving) has been a goal of science education reformers for over 50 years (NSSE, 1932; Welch, 1981), there is virtually no evidence that typical science courses have been successful in stimulating growth across grade levels in student mastery of such skills (Hurd, 1978; Welch, 1981). This is alarming in view of the supposedly great attention to "science as inquiry" during the past 30 years in NSF-supported projects.

2. Students in science classes are more interested in, and more knowledgeable about, technology than they are of basic science concepts and processes (Miller, Suchner & Voelker, 1980; Voelker, 1982). This may come as a surprise as technology was consistently deleted from K-12 science curricula during the two decades after the Soviet launching of Sputnik (Harms & Yager, 1981). Yet technology provides a tie to most current problems and can provide the link between science and people's lives.

3. Although curiosity is the starting place for science (and technology), typical school science programs destroy natural curiosity. The longer students study science, the less curious they are about the natural world. Students in lower elementary school are very curious; by the senior year it is hard to find curious students—even in those students who enroll in advanced placement courses. Success of such science students is too often determined by repeating what they are told, verifying the "experimental" results in the laboratory, and producing calculations and explanations merely to satisfy their teachers (Hueftle, Rakow & Welch, 1983; NAEP, 1978, 1988).

4. Dealing with cause-and-effect relationships is basic to the scientific enterprise. Again, however, school science tends to diminish the ability of students to understand such relationships (Helgeson, Blosser & Howe, 1977; NAEP, 1978). Successful students learn to act and to speak by mimicking what teachers think scientists do and know. Unfortunately, one rarely finds a student who can apply science elsewhere after mastering concepts and process skills in science classrooms (Mestre & Lochhead 1990; Weiss, 1978, 1987). Producing students who merely appear to know basic science concepts and process skills but who cannot use those concepts and skills provides evidence of a serious instructional problem (Champagne & Klopfer, 1984; Mestre & Lochhead, 1990).

5. Nearly all students see science in school as unrelated to their daily lives, seeing few ties between the science they study and such personal concerns as diets, hobbies, work experiences, and consumer decisions. The highest achieving students see school science as merely preparation for enrolling in more courses (Harms, 1977; NAEP, 1978, 1988; Yager & Penick, 1986).

6. Most students elect to halt study of science as soon as they are permitted to do so (Harms & Yager, 1981; Weiss, 1978, 1987). (Requiring more years of the same kind of study, a corrective that has been tried in many places, seems not to produce more scientifically/ technologically literate graduates.) The longer students are enrolled in school, the more the students report an intensified lack of interest in science careers, science study, science classes, and more negative views of science teachers (NAEP, 1978, 1988; Yager & Penick, 1986). The evidence documents failure of the current situation.

7. Science study seems, to most students, unrelated to the world of work and that facet of their daily lives (Harms & Yager, 1981; Weiss, 1987). School science provides no assistance with careers/occupations for which elementary and secondary schools prepare students.

8. Newspaper reports and summaries of special studies have provided ample evidence of common misconceptions that students have of the natural world. These misconceptions are seemingly held by most students—even the most interested and successful students who enroll in advanced college preparatory courses (Champagne & Klopfer, 1984).

STS as reform was seen as a major effort to address these basic problems. It was not a movement designed to raise standard test scores, to illustrate a new kind of course, to provide "add-on" topics and perspectives to units, chapters, or courses, to offer a new kind of content, or to provide a new curriculum framework.

STS was popularized in the U.S. by the official Position Statement of the National Science Teachers Association (NSTA) for the 80s. This statement began:

> *The goal of science education during the 1980s is to develop scientifically literate individuals who understand how science, technology, and society influence one another and who are able to use their knowledge in their everyday decision-making. The scientifically literate person has a substantial knowledge base of facts, concepts, conceptual networks, and process skills which enable the individual to continue and learn logically. This individual both appreciates the value of science and technology in society and understands their limitations.*
>
> (NSTA, 1982)

NSTA also drew attention to STS with its Search for Excellence program that was administered from 1983-1988. Searches for exemplary programs that best fit criteria established by national panels were conducted; two were national searches for exemplary STS programs.

As STS became a popular new direction in the U.S., NSTA embarked on an effort to define STS as a national reform. A Task Force was appointed in 1988 and worked 2 1/2 years to prepare a Position, which was unanimously adopted as policy in 1990. The NSTA definition for STS identifies it as "the teaching and learning of science/technology in the context of human experience" (NSTA, 1990-1991, p. 47). It was recognized that STS provides a rich view of new goals for science education (e.g., a means of reaching the first three goals areas of Project Synthesis). Further, it provides an expanded view of the curriculum—with more and more text series, state frameworks, and distinct curricula including STS. Some have written of STS themes, organizers, content (Bybee & Bonnstetter, 1986, 1987; Hickman, Patrick & Bybee, 1987). Many reformers think primarily in terms of curriculum reform. Perhaps such thinking is a remnant of the 1960s when most thought of reform in terms of new course materials. Some even spoke openly of producing teacher-proof curricula with the NSF "curricula" of the 1960s and early 1970s.

But STS also focuses on instruction as well as assessment and evaluation. In fact, the NSTA definition focuses more on instruction (note teaching and learning in the definition) than any of the other critical ingredient of the educational process. This focus allows many to refer to STS as an approach to teaching. Such a view emphasizes STS as potential for such gigantic reform efforts in the U.S., such as Project 2061 of the American Association for the Advancement of Science (AAAS) and the NSTA Scope, Sequence, and Coordination (SS&C) Project.

It is important to note that STS includes "technology." In 1990, many are convinced that a major error was made in the 1960s to separate science from technology. It is ironic that Sputnik—a major technological achievement of all time—sparked a renewed focus upon basic science in K-12 courses. The cry was to rid science courses of all such applied material—to send radio and television to industrial technology, health to physical education and home economics, transportation and communication to social studies. All applications and all approaches and ideas related to the lives of learners were sent to other facets of the curriculum. Science was to be a look at the conceptual schemes, unifying themes, and/or the big ideas of the science disciplines, along with a consideration of the skills and procedures used by scientists to advance their understanding of concepts. This separation of science and technology seemed to be a major factor in making science unrelated to living and unreachable in terms of abstraction and usefulness. Neither the concepts nor the process skills seemed relevant to the lives of most learners. STS is an attempt to reverse the situation. STS represents an attempt to define science more broadly, that is, in ways that make sense in people's lives. George Gaylord Simpson has offered such a definition that STS researchers are quick to embrace.

> *Science is an exploration of the material universe that seeks natural, orderly relationships among observed phenomena and that is self-testing.*
> (Simpson, 1963, p. 82)

The second "S" in STS is Society. A focus on society is an aspect that many abhor, especially classical physicists. Aldridge (1992), for example, finds STS as a term for reform to be lacking because "society is not science; it is social studies." Of course, one can argue that sociology is a social science. Or one can argue that society is one level of biological organization. To most people in the STS movement, society simply provides the link to people. It is the experience and thinking of people that produce science—in other words, science is a human enterprise. To others, "society" in STS illustrates the link between the natural and social sciences and a way of integrating more fully the total school program.

STS also provides a link to our latest thinking and research about learning. The Constructivist Learning Model is attracting much attention today because it suggests ways that learning can be enhanced and the changes in teaching that are essential for it to occur. Constructivism indicates that each human being (learner) must put together ideas and structures that have personal meaning if he/she is to learn. The model suggests that knowing means being able to do or to construct something. Research concerning the Constructivist Model continues today at an ever faster rate as educators attempt to apply what we know about learning to instructional strategies and curriculum materials in attempts to meet goals better.

The Constructivist Model explains that knowledge can never be observer-independent. In fact knowledge must be attained in a personal sense; it cannot be transferred from one person to another like filling a vessel. It is not like other physiological processes, which can be described chemically. Instead, it requires a personal commitment to question, to explain, and to test explanations for validity.

Although the model indicates that each learner constructs meaning for him/herself, it does not always mean in isolation. Nonetheless, it often occurs without teachers, textbooks, and schools. The classroom must become a place where students offer *their* personal constructions. These can then be applied to new situations where they are useful, adequate, and/or altered. Teachers, other adults, and, even more often, peers can enhance learning by challenging conceptions of a given learner.

Constructivist practices result in students who attain more of the goals typically cited by teachers. Among these are demonstrated mastery of basic concepts (in ways other than repeating or recognizing standard definitions); use of basic process skills (again, in new situations); ability to apply, interpret, and synthesize information; enhancement of creativity skills (questioning, proposing causes, predicting consequences), and improved attitudes toward science study, schools, classes, teachers, and careers.

Constructivist practices require teachers to place students in more central positions in the whole instructional program. They must question more and their questions must be used as the basis for discussions, investigations, and actions in the classroom/laboratory. They must propose solutions and offer explanations, and these proposals must be used in the classroom and form the basis for seeking and using information and for testing the validity of all the explanations offered. This suggest a progression of involvement that starts with the student, moves to pairs and/or small groups of students for more questions and eventually consensus, then to the whole class for similar processing, and finally to the professional (scientific) community views. This progression is just the opposite of what typically happens. In traditional classrooms where traditional strategies are used, the textbook, teacher, or professionals (scientists) define what students should know. Typically they are expected to read, to listen, and to repeat the desired information. If students read, listen, and repeat, they are said to have learned. However, this definition of learning is simply not adequate.

As indicated earlier, the NSTA definition of STS focuses primarily on instruction. The richness of the "movement" is what it means in teaching. Teachers must view their repertoire of strategies for use in teaching differently. The student must be the center of the process because it is the student's mind that must be engaged—each one in a given class setting. Teachers can not merely go over material they think is important, insist that students take notes, do verification-type laboratories, and have students recall information and repeat skills that were all taught directly and for their own sake for periodic examinations. STS demands a focus upon students—their prior experiences and those they are encouraged to have in and out of the classroom because of current enrollment in a science class.

In the U.S. several states have developed statewide in-service efforts to promote wide use of the STS approach in K-12 science classrooms. These states are Arizona, California, Florida, Iowa, Missouri, New Jersey, New York, North Carolina, Pennsylvania, South Dakota, and Wisconsin. Perhaps the Iowa Chautauqua Program characterizes best an in-service model used to introduce up to 300 new K-12 teachers to STS teaching strategies each year. It is a program proclaimed as effective by the National Diffusion Network. Table 1 provides an indication of the model. The list provides a contrast between typical instruction and what an STS teacher does.

Important features of this program are:

1. A two week leadership conference for 30 of the most successful teachers from previous years who want to become part of the instructional team for future workshops.

2. A two week summer workshop at each new site for 30 new teachers electing to try Science/Technology/Society (STS) modules and strategies; the workshop provides experience with STS (teachers as students) and time to plan a five day STS unit to be used with students in the fall.

3. A 2 1/2 day fall short course for 30-50 teachers (including the 340 enrolled during the summer); the focus is upon developing a month long STS module and an extensive assessment plan.

4. An interim communication with central staff, lead teachers, and fellow participants, including a newsletter, special memoranda, monthly telephone contacts, and school/ classroom visits.

5. A 2 1/2 day spring short course for the same 30-50 teachers who participated in the fall. This session focuses upon reports by participants on their STS experience and the results of the assessment program.

Since its inception in 1983, the Iowa Chautauqua Program has enrolled nearly 1,700 teachers and introduced them to STS. With 10 years of work with a leadership

Table 1. Iowa Chautauqua Program

Typical Science Instruction	STS Instruction
The teacher directing all aspects of the class and laboratory	The student acting as active partners in defining problems, finding information, seeking solutions, and taking action
Group instruction geared for the average student	Individualized and personalized, recognizing student diversity
Directed by the textbook	Directed by student questions and experiences
Uses basic textbook almost exclusively	Uses a variety of resources
Some group work, primarily in laboratory	Cooperative work on problems and issues
Students seen as recipients of instruction	Students considered active contributors to instruction
Teachers do not build on students' experiences, assuming that students learn more effectively by being presented with organized, easy-to-grasp information	Teachers build on student experiences, assuming that students learn best from their own experiences
Teachers plan their teaching from the prescribed curriculum guide and textbook	Teachers plan their teaching around problems and current issues (many indicated by student)
Learning confined to textual materials	Learning goes beyond classroom and school
No emphasis on career awareness	Emphasize career awareness related to science and technology

cadre and a new group of 250 to 300 teachers over an entire calendar year, it has been possible to amass information which illustrates the advantages of the STS approach.

In Iowa, six assessment domains have been identified to provide information about the effectiveness of STS instruction. The domains are a modification of those described by Yager and McCormack (1989). A brief elaboration for each of the six domains includes:

1. Concept Domain (mastering basic content constructs);
2. Process Domain (learning the skills scientists use to do science);
3. Application and Connection Domain (using concepts and processes in new situations);
4. Creativity Domain (improving in quantity and quality of questions, explanations, and tests for the validity of personally generated explanations);
5. Attitudinal Domain (developing more positive feelings concerning the usefulness of science, science study, science teachers, and science a-reers); and
6. World View Domain (how the efforts assist students with an understanding of and ability to use basic science; questioning, explaining, and testing).

The Iowa Chautauqua Program improves teacher's confidence to teach science, expertise in using the nature of science in their science teaching, and successes with their students as they move to STS instruction and assess student progress in domains that are closer to their own stated instructional goals. Basically, the Chautauqua model aims to improve all critical incidents in science teaching that will change the existing conditions in science education to more desirable ones. These newer goals will lead to better student learning outcomes (see Table 2). These critical incidents that effect learning include goals, teaching strategies, curriculum materials, and models for assessing success.

Teachers and their students who were involved from the 1989-90 program were selected to provide evidence for the success of the Iowa Chautauqua Program. To determine the effect of the Chautauqua Program in terms of making teachers more confident to teach and helping them to understand the nature of science better, participating teachers and a sample of applicants who did not participate were asked to complete a Likert-scale that provided information concerning their confidence to teach science and a second that indicated their understanding and use of the basic ingredients of science. The same scales were administered at the end of the spring workshop and again 1 year later (thereby collecting information concerning the longevity of perception change). Some items in all scales were included to provide a cross-check for reliability. Further, observation and interviews with a school principal and a member of the Chautauqua staff were used to validate the self-reporting scales.

To determine the success of the STS approach in terms of student learning, pre- and post-tests were administered to all students of 15 Lead Teachers in 1989-90. Assessment information in six domains was collected from 722 students for the particular year (where two sections were selected for Lead Teachers—one with conventional instructional procedures and one with STS approaches for instruction by Lead Teachers). Classes were randomly assigned to treatments.

The sample used to establish the effectiveness of the Iowa Chautauqua Program in assisting teachers to move to STS were teachers enrolled in the 1989-90 sequence and the 15 Lead Teachers who also participated in the experiment for the year and assisted as part of the staff for new teachers. Both the Lead Teacher group and the 1989-90 new enrollees were representative of all teachers in Iowa. No evidence was found to suggest that the sample did not represent all 50 Lead Teachers and the 250 new teachers for any other year. Further the initial results in other states with other teachers are producing very similar results. The Lead Teachers used in this study taught both an experimental section and another section with the existing curriculum, where textbooks were frequently the determiner for topics, examples, and activities. To determine changes in teacher confidence and understanding and use of the nature of science in their science teaching, all teachers were polled. A total of 132 applicants who were fully qualified were invited to serve as a control group. Fifty-six accepted the invitation and agreed to participate in the study. Thus, they were similar in that they were teachers in the same schools as the participants and had similar levels of experience and preparation. Because they were drawn from a field of applicants with no obvious differences, it was judged that the 56 would serve as an appropriate and comparable control group of teachers.

For the student data all students in two class sections for all teachers were involved. Care was taken to assure that each class group was representative of the school and that the larger number of schools involved for the year provided a representative group of Iowa students at each grade level.

Six domains were used as a focus for instruction and assessment: Concepts (content), Process Skills, Applications, Creativity, World View, and Attitude. Because a variety of lessons and students of different ages were used, different items had to be used by different teachers for the concept and application domains. Standard items and instruments were used in the other four domains. However, all six domains were assessed in each class with pre- and post-measures. The instruments were taken from *The Iowa Assess-*

Table 2. Contrasts Between Typical and STS Classrooms

Typical	STS
Goals	
1. Minimal consideration given to human adaptive capacities	1. Human adaptation and alternative futures emphasized
2. Marginal emphasis on current societal problems and issues—and then only as an after thought (i.e., if there is any extra time at the end of a unit)	2. Dealing with societal problems and issues as goals, which creates a need for learning science concepts
3. Inquiry skills, if present, characteristic of a generalized model of science (often follows direction-type activities)	3. Inquiry processes unique to each problem
4. Uncovering a correct answer to discipline-bound problems	4. Decision-making using scientific knowledge in social contexts
5. Minimal attention to careers; only historical personages highlighted	5. Career awareness an integral part of learning
6. Value-free interpretations of discipline-bound problems	6. Value, ethical, and moral dimensions of problems and issues considered
Curriculum	
7. Curriculum is textbook-centered, inflexible; only scientific validity is considered	7. Curriculum is problem-centered, flexible; culturally as well as scientifically valid
8. Humankind incidental	8. Humankind central
9 Textbook controlled; local relevance fortuitous	9. Multiple sources of information; local and community relevance emphasized
10..Contrived materials, kits, and classroom-bound resources; use of hands-on materials—often only for the sake of keeping students involved	10. Use of the natural environment, community resources, and the students themselves as foci of study
11. Information is in the context of the logic and structure of the discipline	11. Information is in the context of the student as a person in a cultural/social/technological environment
12. Distorts the nature of science by portraying science solely from an internalist position	12. Portrays a more accurate view of the nature of science by explicitly making connections between science and society (externalism) as well as the isolated workings of science (internalism)
Instruction	
13. Teacher-centered	13. Student-centered
14. Group instruction geared for the average student and directed by the organization of the textbook	14. Individualized and personalized, recognizing student diversity
15. Some group work, primarily in laboratory	15. Cooperative and experiential work on problems and issue

Table 2. Contrasts Between Typical and STS Classrooms (cont.)

Typical	STS
16. Students seen as recipients of instruction.	16. Students are considered important ingredients in instruction, i.e., active partners
17. Weak psychological basis for instruction in the sciences: behavioristic orientation	17. Methodology based on current information and research in developmental psychology involving cognitive, affective, experiential, and maturational studies
18. Teachers ignore students in terms of what they might bring to the instructional process; use of information where success can be measured by rote learning	18. Teachers build on student experiences, assuming that students learn only from their own experiences

ment Handbook (McComas & Yager, 1988; Yager, Blunck & Ajam, 1990; Yager & Kellerman, 1992). This *Handbook* also provided samples in the concept and applications domains and other information to assist teachers in developing valid tests In most cases, chapter and unit tests provided by textbook publishers served as instruments in the concept domain. This could have given preference to students in textbook sections.

Data Analysis

The pre- and post-test scores for each of the scales used for confidence of nature of science were computed in terms of percentage reporting given levels of confidence and for reports of their understanding of basic science features. The analysis of variance with repeated measures was used to determine significant changes between pre- and post-test scores.

For the student data, only scores from the 15 teachers who were active instructors were used. Rather than pooling the results of all students and teachers, the data from the classrooms of Lead Teachers were treated as 15 replications and for each dependent variable the students in the two classes of each teacher were compared separately . The analyses of covariance were used to determine significant changes between student post-test scores in STS classes and non-STS classes with pretest scores used as the covariant.

The figures reported in Table 3 are for 160 K-12 teachers who completed the Chautauqua series in 1989-90 and 56 non-Chautauqua participants. The analysis of variance with repeated measures was used to examine the difference of teachers' ratings.

In a study involving 160 Chautauqua new teachers and 56 non-Chautauqua teachers, it was shown that the significant difference occurred between teachers in the Chautauqua group and teachers not in the Chautauqua group (see F and P values in Table 3). This means that the teachers who participated in the Iowa Chautauqua Program and moved to STS instruction increased their confidence to teach science significantly more than did teachers not enrolled in the Iowa Chautauqua Program. This is evidence that the program is successful in encouraging greater confidence on the part of teachers moving to STS.

In a study involving 160 Chautauqua new teachers and 56 non-Chautauqua teachers, it was shown that the significant difference occurred between teachers in the Chautauqua group and teachers not in the

Table 3. Average Scores Indicating Teacher Confidence to Teach Science

	Chautauqua Group Mean*			Non-Chautauqua Group Mean*				
Grade Level	N	Pre	Post	N	Pre	Post	F	P
K-3	24	37.1	19.0	8	36.3	33.9	109.7	0.00
4-6	61	34.2	18.2	20	34.9	34.7	123.4	0.00
7-9	61	33.5	20.4	16	35.2	34.8	115.3	0.00
10-12	14	35.8	21.3	12	34.2	33.5	98.9	0.00

*lower means represent greater confidence

Table 4. Teacher Responses Indicating Their Understanding of Basic Science

	Chautauqua Group Mean*			Non-Chautauqua Group Mean*				
Grade Level	N	Pre	Post	N	Pre	Post	F	P
K-3	24	37.4	19.5	8	37.9	38.2	177.2	0.00
4-6	61	36.5	20.6	20	38.6	38.4	165.4	0.00
7-9	61	36.0	20.9	16	37.7	37.8	159.3	0.00
10-12	14	37.3	19.7	12	38.0	37.4	190.7	0.00

*lower means represent greater understanding of basic science

Chautauqua group (see F and P values in Table 4) with respect to their understanding of the nature of basic science. The results indicate that the teachers who participated in the Iowa Chautauqua Program to learn about STS increased their understanding of basic science features significantly more than did teachers not enrolled in the Iowa Chautauqua Program. This is evidence that the program is successful in altering teachers' understanding of basic science features as they use STS approaches.

The 15 Lead Teachers used the strategies and modules from Chautauqua with one class and the usual textbook dominant mode for a contrast group. Such a research project provides contrasting information in each of six domains. To assure fidelity of treatment in the two class sessions, frequent video recordings of both class sessions were collected and analyzed independently. Table 5 provides an indication of differences revealed by analyzing three pairs of video tapes for each of the 15 teachers.

The consistency of these results for all teachers in all six domains is impressive. It may be concluded that even though the STS approach follows the local interests and preferences of students, it is much less structured, and does not enjoy the benefit of textbook material that can easily be memorized, student perform-

Table 5. Average Scores and Standard Deviations of Teacher Behaviors in STS and Non-STS Classes

Indicator	STS Periods 1	2	3	Non-STS Periods 1	2	3
Asks more questions	13.80	15.67	16.20	3.80	3.93	4.33
Dispenses less information	5.00	7.20	5.13	20.67	20.40	18.13
Uses student questions to drive discussion:						
(a) number per period	9.93	12.13	14.13	0.27	0.80	0.53
(b) time during period (in minutes) for such activity	22.67	28.53	28.98	1.53	3.73	2.53
Spends less time at front of classroom "before" students	9.20	10.00	9.73	36.93	35.13	38.20
Spends more time interacting with individual students or cooperative groups	35.80	36.13	34.53	4.93	7.73	6.47

Table 6. Values of Analysis of Covariance (ANCOVA) Between Student Post-test Scores in STS Classes and Non-STS Classes With the Pre-test Scores Used as the Covariant

	STS		Non-STS			
Domain	X	S.D.	X	S.D.	F	P
Concept	11.71	3.00	11.80	3.00	0.09	0.76
Process	8.83	2.43	4.20	1.97	1580.08	0.00
Application	11.20	1.89	4.30	1.99	1459.89	0.00
Creativity	103.47	30.43	61.47	23.27	1462.37	0.00
Attitude	20.00	3.90	13.42	4.02	5465.29	0.00
World View	9.83	1.91	11.16	1.70	393.72	0.00

ance in the concept domain is as high as that of non-STS students. Apparently, the student-centered activities result in as much meaningful learning, which is reflected in the performance on knowledge tests for students of all ability levels. And the STS approach is *significantly more effective* in producing changes in students regarding process skills, applications of concepts and processes, creativity skills, world view of the nature of science, and more positive attitudes. Student growth in the other five domains is significantly better in classrooms where the STS approach is used. Promulgating the use of the STS approach to teaching is a major goal of the Chautauqua Program. The Chautauqua Program produces teachers, especially Lead Teachers, who can utilize STS strategies that result in significantly greater achievement (growth) and more positive attitudes than students in classrooms where such strategies are not used.

Table 6 presents the average scores for all 15 teachers in all six domains, namely concept, process, application, world view, creativity, and attitude. The data in

Table 5 indicate that, without losing in concept mastery, STS students have gained substantially more than their non-STS counterparts in the five other domains. Although many action research projects have focused on middle-school teachers and their students (grades 4-9), similar results have been secured for all teachers K-12.

Summary

The NSTA rationale for STS makes it an attractive vehicle for reforms in science education. All of the features that NSTA uses to describe STS coincide with strategies that characterize constructivist practices. NSTA has offered these features for STS:

- Utilizing student-identified problems with local interest, and scientific and technical components as organizers for the course;
- Using local resources (human and material) as original sources of scientific or technical information that can be used in problem resolution;
- Involving students in seeking scientific or technical information that can be applied in dealing with real-life problems;
- Extending science learning beyond the class period, the classroom, the school;
- Focusing upon the impact of science and technology on each individual student;
- Viewing science content as more than something that exists for students to master for tests;
- De-emphasizing science process skills for students to master by mimicking skills used by practicing scientists;
- Emphasizing career awareness—especially current careers related to science and technology;
- Providing opportunities for students to perform in citizenship roles as they attempt to answer questions about the natural world and to deal with problems they have identified; and
- Demonstrating that science and technology are major factors that will impact the future (NSTA, 1990-1991).

Constructivists identify these points as recommended teaching strategies:

- Encourage and accept student autonomy, initiation, and leadership;
- Allow student thinking to drive lessons and shift content and instructional strategy based on student responses;
- Ask students to elaborate on their responses;
- Allow waiting time for asking questions;
- Encourage students to interact with each other and with you;
- Ask thoughtful, open-ended questions;
- Encourage students to reflect on experiences and predict future outcomes;
- Ask students to articulate their theories about concepts before presenting your understanding of the concepts; and
- Look for students' alternative conceptions and design lessons to address any misconceptions (Yager, 1991).

STS seems to be a reform movement that broadens the scope of the problem, enlarges views of science, and utilizes the most recent thinking and research about learning. In addition, emerging research provides information about successes with STS in K-12 classrooms. Basically these experiments permit the following generalizations:

1. STS encourages student mastery of basic concepts—but no better than do traditional approaches to teaching. However, emerging observation suggests that the learning in STS classrooms may be better in terms of long-term learning because it arises from direct experiences of students.
2. STS approaches seem to solve problems related to women in science, minorities in science, and students with low abilities in heterogeneous classes. Initially, high-ability students (those who have experience with note taking and following directions in typical classrooms) resent their lack of success with different classroom behaviors and skills they need.
3. STS is superior in terms of student mastery of basic process skills and high-ordered thinking.
4. STS is superior in terms of helping students to apply basic concepts and process skills.
5. STS enables more students to understand the nature of science.
6. STS results in more positive student attitudes about science, science classrooms, science teachers, and science careers.
7. STS provides a focus on the teaching process and helps develop confidence that teachers can learn about issuing questions about situations, objects, and events in their own environment.

STS represents a worldwide reform effort that is being fostered by the UNESCO 2000+ program. It provides focus for the problems about which most agree and specific new directions and solutions that respond directly to the problems.

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Fostering Change in Science Education: Creation, Implementation, Evaluation and Research— The Israeli Experience

Uri Ganiel

Introduction

The issue of how to foster change in the science education scenery is complex. There are no clear truths and recipes, and as so often happens in the social sciences, to almost every convincing argument there exists a counter argument that sounds equally good. Thus, it is not helpful for someone who comes from the exact sciences to deal with this issue. Having been trained as a physicist, I tend to think like one. That may have some advantages, but it makes all the "ifs" and the "buts," with which social scientists are quite comfortable, somewhat difficult to digest. On the other hand, the questions and dilemmas are very real. So when one decides to look at science education development and reform, one must submit to thinking within a context that is, at least partially, a social science context, and that includes having to analyze situations with a somewhat "softer" approach.

What follows is not a research paper, relying on hard experimental data, heavy supporting statistics or any deep theoretical analysis. Rather, this is basically a position paper, reflecting some personal beliefs that slowly evolved from our experiences, working here in this country, as well as watching developments around the world. There may be those in the science education community who think they have some of the answers. So much the better. What I have to say simply reflects the opinions of one member of this community.

During the 1960s and 70s, many reforms took place in pre-university science education world wide. Many of these were influenced by the pioneering efforts of the so called "a-b projects" in the U.S., where "a-b" stands for the acronyms these projects were given at birth (e.g., PSSC, HPP, BSCS, SMSG, CBA, CHEMS, SCIS, ESS, etc., or the Nuffield projects in the UK). Twenty-five years later, we find ourselves in the midst of a new wave of science education reforms throughout the world. Furthermore, many of the less developed countries are becoming involved and awakening to the need for upgrading their science education efforts. We note, in passing, that one needs to be careful with the terms used. The "developing countries" tag is not suitable in the present context because it is not quite clear what the term means. Which countries are developed and which are under developed when it comes to science education?

That this is happening should come as no surprise: we are in the midst of a revolution of no lesser significance than the industrial revolution of the 19th century. The last quarter of the 20th century will probably enter history as the era of science, computing, communication and information technologies. Human knowledge and capabilities are becoming the most important assets in determining the economic, political and even physical well being of any country. Within the wide spectrum of human knowledge and skills, the importance of mathematics, the natural sciences, and related technologies is clearly increasing. Just compare the economic status of Japan to that of Saudi Arabia, and you have a direct realization of the relative importance of human knowledge and skills in science and technology versus the availability of natural resources. This is not the topic of the present paper, but it is tied closely to that with which we are dealing: the higher the level of scientific literacy and competence of the population of a country, the better off this population can expect to be in most respects. No wonder, then, that many countries are giving their science education scene a hard look and are trying to improve it.

Curriculum Reforms: A Critical Look at Past Experiences

Changes and innovations in the educational set up, in particular at a national level, are not a trivial exercise. It therefore makes very good sense to look at past experiences, to try to learn from successes and failures and to analyze what worked and what did not work, and in both cases, why. We have already mentioned the surge of activity of curriculum innovations in the sciences, which started in the 1960s, and continued well into the 1970s. As a historical side remark, it should be mentioned that this is usually related, in people's minds, to the launching of Sputnik: suddenly the Americans realized that the Soviet Union was ahead, and that led to an effort to upgrade science education in the U.S. and then throughout the Western world. Just to put the record straight: PSSC was initiated early in 1956, long before Sputnik was launched. The real influence that led to these efforts can be traced to the way science was done following world war II, to the methodology of teams linking together and working on large scale projects, rather than individuals working by themselves. This mode developed during the efforts of World War II and led to the establishment of national laboratories and large teams. It was natural for scientists, who became involved in curriculum innovation, to adopt a similar approach in that effort. However, not to belittle the effect that Sputnik did have, I hasten to add that it is of course true, that once Sputnik was launched, the Americans got nervous, and the National Science Foundation and other funds started pouring money into science education.

Let me mention some of these projects again: PSSC in Physics, Harvard Project Physics, which in some sense was an ideological reaction to PSSC, BSCS in biology, CBA and then ChemStudy in Chemistry (all in the U.S.[1]), the very important Nuffield projects in the UK, other projects in Europe, including some in Germany, Denmark, the Netherlands, and others. Most of these projects, as well as others aimed at younger age groups (SCIS, ESS), were good projects in terms of the learning materials that were created and published, and they were performed by excellent people. It is important to point out that in most cases, the initiatives did not come from the field. The originators of these large scale efforts were usually not teachers or people from the government educational establishment. It is important to note that these efforts were generally led by people who came from the academic environment: universities, research institutes, and the like. One exception that should be noted was the Nuffield projects in the UK, where the initiatives came from some outstanding teachers, and they were the ones who got the academic world interested. A single exception, however, only serves to prove the rule.

Let us remember how things were usually done. There would be a fairly large grant from some funding agency. Teams of experts—scientists, experienced teachers, perhaps some media experts, technical staff—were assembled. Materials were created: textbooks, teacher guides, films, equipment for practical work in the laboratory, and so forth. Teacher workshops were organized, and the materials tried in pilot schools. These first runs were generally quite successful, and also served as the first round for feedback. There is the well known Hawthorne effect: the enthusiasm and freshness of innovation, and the teachers participating in the first trial runs are keen, open to innovation and anxious to succeed. After perhaps another cycle of trial runs, feedback and corrections, the grant would run out. The materials would be published commercially, and the teams much reduced or even dismantled. The scientists would then return to their research laboratories, the feeling being something like: we have put the train on the right track, now let it roll. So now there are innovative materials available, and there are pockets here and there of teachers who are familiar with them. This is one mode of operation typical of the science curriculum reforms of the 60s and the 70s. For future reference, let us call it Mode 1.

The advantages of Mode 1 are obvious. There was input from the best subject-matter experts, as well as contributions of enthusiastic teachers who were willing to make the intellectual effort and put in the work. Looking at the harvest of learning materials that these years produced, the effect is quite remarkable. They were very exciting, innovative materials, much superior to what was previously available. This writer can personally testify to that in his own field of physics, but colleagues in other disciplines—chemistry and biology in particular—have similar praise.

What, Then, If Anything, Went Wrong?

One issue is implementation. The majority of teachers need to be trained and introduced to new materials and approaches. School administrations need to get used to a host of new needs and demands that modern science teaching presents. The availability of good learning materials does not ensure good teaching or successful learning. Related to this is the problem of continuity. Inherently, the educational system is conservative and slow to adapt to changes. Teachers tend to stick to their own habits and are not necessarily eager to make the effort that such changes demand. What is necessary, then, is an intensive effort of teacher training: pre-service for those in the pipeline and in-service for those already working in schools. Guidance in schools, and continuous encouragement, as well as help in the process of implementing the new materials and approaches, must be available in massive doses.

There are additional issues. Some scientists will perhaps dislike hearing about these issues, because scientists are at times somewhat arrogant and think they know all there is to know about education. However, many mistakes are made during the development phase. Scientists, who are subject matter experts, push for innovation, breadth and depth. These scientists are often not aware of the abilities and disabilities of their target population. When innovative learning materials are developed, they must be tried and their suitability assessed. Then they are usually corrected and changed, tried again, corrected again, and so on. In other words: cycles of development-implementation-assessment-feedback-correction and change-repeated implementation, are necessary. It almost never happens that the first trial of a new piece of curriculum is such a success that no revisions are necessary, even if the science included is all correct and exciting. Let us go a bit further and amplify this point. It often turns out, that in spite of all the learning materials developed—excellent as they might seem to be—the goals are not achieved, and students understand very little of the science they have supposedly been taught. In recent years it is becoming obvious to researchers that students' facility in memorizing facts and vocabulary, extends to memorizing algorithms and procedures. This phenomenon is not confined to the lower schools. Research shows that students at all age groups exercise some of the same rote talents in simulating understanding of science. It is becoming painfully clear that very often we cannot assume that students have understood even some of the fundamentals. The picture becomes even more gloomy when one looks at what some of the teachers themselves understand of the science they teach. So we find ourselves in a situation where very serious research into the teaching and learning of science is needed to identify foci of difficulty, understand the sources of these difficulties, and look for ways to overcome them. Again, the outcome of such research, if it is any good, will define new directions of development work, implementation, evaluation, and so on.

A short-range project is not geared to accomplish all this. Without continuity and persistence, the chances for success are very low indeed. Using a physics-based metaphor, I suggest that one can excite a system, but when left alone, it will invariably decay back to its lowest state.

The Discipline of Science Education: What Research?

The surge of activities at various academic centers, more or less along the lines of Mode 1, gave birth to a new field of activity that actually evolved into a scientific discipline: the discipline of Science Education. As late as 1950, for example, such a discipline did not exist. Today, many academic institutions have departments of science education, or centers for science education, or any other names that such centers of activity carry. In most cases, such centers are part of a school of education (or department, faculty or college, depending on the norm at that particular institution).

This immediately raises some problems. Unlike many other areas of human intellectual endeavor, science develops and changes very rapidly. Professors of Education, whose education in science is 20 or 40 years out of date, are not well equipped to train new science teachers, or to deal with some of the problems mentioned previously.

Furthermore, these academic structures with which we are dealing are often patterned along the usual schemes that govern university departments. Research for its own sake becomes the main activity. The sociology of academic structures, with graduate students, publications, promotion schemes, struggles for slots and tenure, and all the rest of what typifies our universities, all take over, in a sense. Within such centers, then, activities are often purely academic in character, but their impact on the educational system becomes minimal. We hasten to emphasize that this does not imply that educational research is superfluous. It has already been emphasized how necessary such research is: it is what Mode 1 so badly lacked. This does not refer to psychological research, which has had little impact on teaching in other disciplines, but research indigenous to specific subject matter areas, such as physics, or chemistry, or mathematics. We suggest that to help the difficult task of improving science education, such research needs to be mission oriented. Research that is not integrated into any development or implementation activity, or preferably both, can easily become sterile.

What is needed to foster change in science education is a combination of development, in which learning materials are created and teaching strategies are developed, and intensive implementation efforts. The implementation involves teacher courses, workshops, in-school guidance, and a whole range of related activities. The whole enterprise should be accompanied by on-going formative evaluation and by a spectrum of research activities that feed the development and implementation efforts and help in overcoming problems encountered in their course.

How, Where, and by Whom? Some Practicalities

The discussion so far dealt with the principles involved. Now it is important to look into some cardinal questions about how this very general model can be activated in practice.

Some of the issues that come to mind: Where will all this happen? Who will run these complex enterprises—government institutes, ministries of education, publishers and producers of books, software, equipment, etc.? It is not simple to prescribe a single recipe here, but we have learned a few lessons during the past 25 years.

It has already been noted that the innovations of the 1960s and 1970s usually originated from within the scientific-academic community. Our experience in this country shows that this is the preferred option, and I believe that this is true in general. After all, the frontiers of science move very rapidly; just note what the famous American physicist Michelson, who in 1894 had to say:

> *The more important fundamental laws and facts of physical science have all been discovered, and these are now so firmly established that the possibility of their ever being supplanted in consequence of new discoveries is exceedingly remote . . .*

This is the year 1894, and this is what Michelson, a world renowned scientist, had to say about his own discipline of physics. The time was just before the turn of the 20th century, which brought with it the Theory of Relativity, Quantum Theory and Quantum Mechanics, all revolutions in human thought, followed by all the enormous developments in science and technology which we saw during this century. Michelson himself won the 1907 Nobel Prize in physics for his important contributions and landmark experiments connected to the Theory of Special Relativity. If Michelson could fall into such a trap, how careful must we all be!

This feature of rapid, unpredictable change and development dictates that science education must be on the alert and be flexible enough to respond to the ever-changing needs. There is a constant struggle to define what belongs in the school curriculum, what can be taught, what is important, and even more difficult, what can be ignored. What will best serve to prepare an enlightened, scientifically literate, citizen? To define such priorities, a good understanding of science, its developments and current trends, is essential. The only place where the necessary understanding, expertise and sensitivities exist, where knowledge is constantly being updated, are the academic environments, whether they are universities or various research institutes in the sciences. This is not to say departments or colleges of education, but rather the science departments in such places. Indeed, the initiation and development phases, as they existed in the Mode 1 type operations during the 1960s and 1970s, were of such nature: they were led by top scientists. There may have been in the past, and there probably exist now, some local initiatives: an energetic teacher developing a module on this or that, or a team of teachers in a particular school working together on something interesting.

It is common for large publishers in some countries (the U.S. is one example) to commission writers to produce science texts for them. Often a large list of notables serves as an ornament on the title page of such books; thus, the consumers believe they are getting quality materials. Such commercial enterprises are, of course, driven by the prospect of making a profit. There is nothing wrong with this, in principle, except that commercial and educational considerations do not necessarily overlap. By and large, I am convinced that the teams in an academic, science-centered environment, will do a superior job because they will not be doing it for a profit, but rather regard it as an academic enterprise, worthy of their talent, dedication, and effort.

Next is the issue the implementation. Put simply: how do we get the materials into the schools, and how do we ensure they are being used properly? Implementation involves a close interaction with the school system, the administration, the inspectors, the testing authorities and many other bodies. In thinking about the way in which this necessary cooperation can best be achieved, we realize that school systems in different countries are organized very differently. Specifically, it must be asked how centralized the educational system is. Probably the instinctive reaction of most of us, regarding centralization, would be to prefer to have the system as decentralized as possible. The less interference from above, the better. Governments have a tendency to become overbearing and to choke creativity with bureaucracy. People function best when their originality is allowed to blossom, and we would expect this to be particularly true of our teachers. One could therefore argue for maximum decentralization. An example of this approach is the U.S., where practically no national standards are enforced. At most, there are some state requirements, but the responsibility usually rests with the local elected school boards. But if this decentralization is such a good idea, why is it that Americans are so deeply dissatisfied with the education their children receive? Let me quote from a well known report published in 1983:

> *... If an unfriendly foreign power had attempted to impose on America the mediocre educational performance that exists today, we might well have viewed it as an act of war. As it stands, we have allowed this to happen to ourselves.*
>
> (National Commission on Excellence in Education, 1983)

Another example is the British system, where teachers and schools were traditionally given a high degree of autonomy. A lot of dissatisfaction with the system has been expressed there as well in recent years. So democracy and "laissez faire" and all the rest of it is fine, but how do we guard against anarchy and mediocrity? The difficulties can be traced, at least partly, to the niveau of our teachers. If the teaching profession were to receive the best and most able, then perhaps it could all be left to them. I do not know of many countries where teachers are the sector commanding the highest salaries, or the prestige and respect of other professions. That being the case, teachers are not necessarily the cream of the crop. We say this with strong reservations, knowing that it does injustice to many dedicated, able and creative individuals. But in gross generality, it does represent a sad reality. It certainly is the case in Israel. Stated very simply, teachers need to be told which directions to take, what to teach, and how.

The concerns about inadequate educational standards led to the reexamination of goals in many countries, and frameworks are being set to establish a common base and to set standards in the learning of science. Examples that come to mind are Project 2061 in the U.S. (Project 2061, 1989), the National Curriculum in the UK(1988), the California Framework (1990) and more recently, a new project initiated by the National Research Council in the U.S., which established a National Committee on Science Education Standards and Assessment, to work through three groups: *Curriculum Standards*—to identify what students should know and be able to do; *Teaching Standards*—concerned with both classroom teaching strategies and teacher preparation, and *Assessment Standards*—to serve the instructional, programmatic and policy aspects of science education. Put differently, even the most decentralized systems are moving toward some degree of centralization to ensure an adequate level of scientific education. Other countries have always had national graduation requirements that are enforced through centralized examination systems. This is common in many of the West European countries (France, Belgium, Germany, Italy, and others), and it is also the situation in Israel.

From the viewpoint of implementation, a centralized system has clear advantages. Access to large portions of the system and reasonable levels of implementation can be reached if there is the support of the authorities. That requires close collaboration of the innovators and developers with the authorities in charge of the schools. That is sometimes easier stated than achieved. Once government bureaucrats, appointed inspectors and other officials have the authority, they want to be in control. Such is human nature. Now it becomes a question of chance, perhaps some diplomacy, or both: an enlightened inspector, who understands an innovative curriculum, agrees with its goals and approaches, and wants it implemented, will be a great asset to the whole process. In contrast, nothing can be more obstructive than an inspector or school principal who, for whatever reasons, does not want to see innovations and changes implemented. During years of educational reform in Israel, we have had both kinds. So from a discussion of academic principles we find ourselves coming to consider political issues. That, however, is what real life is like. We are dealing with complex systems, in which many parameters come into play.

The Israeli Experience

The experience of the Israeli Science Teaching Center exemplifies a number of the issues raised thus far. The Israeli Science Teaching Center was established in the mid-1960s as a cooperation between academic institutions (at first two, later two more joined in) and the Israeli Ministry of Education and Culture. The original initiatives came from academia. More specifically, as is so often the case, some concerned individuals, who saw it as their duty to influence science and mathematics education in this country, plunged in and started doing things.

Amos de-Shalit, who unfortunately died as a young man in 1969, Shimshon Amizur and Alexandra Polyakov-Maber, who are still with us, were some of the people involved. In the beginning, what basically

Figure 1. The Spiral

evolved, was a Mode 1 type of operation. The beginnings were somewhat naive, as in those days there were no well-defined procedures of curriculum development or much experience extant. Things were done intuitively, but they had the correct principles incorporated from the start. The teams assembled consisted of scientists as leaders and initiators, but included active teachers from the various disciplines as the main body of executors. One cannot overemphasize the importance of this combination. We have already stated our belief that scientists alone cannot do the job. Teachers, on the other hand, needed the drive and the environment, as well as the subject matter expertise which such a framework offered.

Budget support, as well as the cooperation of the people in charge—school principals, inspectors, and so on—were assured by the involvement of the Ministry of Education. So from the beginning we were fortunate to have established a structure that had most of the necessary ingredients built into it. Compared with most initiatives, there was one very important difference: the operation was not abandoned after one or two cycles of curriculum were produced. In fact, it was never stopped at all. Today, 25 years later, the Israeli Science Teaching Center is larger and more active than it was in its first years. It is very common for scientists and educators to complain about their governments on various issues, and they are often right. Therefore, credit must be given where credit is due. Within the context being discussed here, all the governments we have had in Israel from 1965 through today were very enlightened. Support for the operation of the Israeli Science Teaching Center was never stopped. Clearly the support is never enough, and much more is needed because there is so much that needs to be done. But then, as every project leader knows, budgets are never quite large enough.

The beginnings, then, were intuitive. There was a surge of production of new learning materials, teacher training activities, and other implementation efforts. However, as the first cycle of materials produced came into place and started being used, there came the phase of serious evaluation work, which in turn triggered intense research efforts, which in turn defined new directions of necessary development. This is a very general description. There are enormous variations, depending on the age groups toward which a particular effort is targeted, the preparedness of their teacher population, the subject matter area, and many more parameters. A basic general science course for the 10 year old presents different challenges and questions than an advanced unit on astrophysics for high school students. Still, some principles are common to all such projects.

The discussion may, perhaps, have created a conceptually erroneous picture. We used the words *creation-implementation-evaluation-research* in that order, and it may sound as if these activities occur in tandem, one after the other. That is probably how it happened during our first trials, back in the 1960s and 1970s. However, as our approach matured, these components became more and more mixed, and they occur in interlocking cycles, feeding each other continuously.

These generalities should be translated into specifics, describing what was actually done in a typical project. This cannot be done in proper detail within the frame of a general paper like the present one, so we shall only give some outlines for one or two projects that operate in our department at the Weizmann Institute of Science, to exemplify how things are done.

The High School Chemistry curriculum in this country has been one area of continuous activity. In the mid 1960s, the first efforts concentrated on translation and adaptation of the American CEMS program. The approach adopted was reflected in the name of the course *"Chemistry—An Experimental Science."* However, our educational system is very different from that of the U.S., and thus this course was unsuitable in many respects. This taught our chemists a valuable lesson: adaptation of a course from a different country, different culture, and different educational system is generally not a very useful practice. Certainly it makes good sense to learn from colleagues in other countries, and it would be foolish not to build on accumulated wisdom and expertise. But simple translation is not the way to go.

The next generation, then, was developed here from the beginning, building on the accumulated experience from the previous exercise. *Chemistry for High School* was the course for most high school chemistry students during the 1970s and early 1980s. Once the materials were available, the efforts shifted somewhat. The rate of development could be slowed, and more attention could be given to cognitive research. An additional factor that came into play was the change in the target population, from selective classes of science-oriented students to heterogeneous classes, including lower-ability students.

Diagnostic studies of students' learning difficulties in the various areas of the chemistry curriculum led to a complete re-conceptualization of the curriculum. (Ben Zvi, Eylon, & Silberstein, 1986), and this resulted in a new curriculum: *Chemistry—A Challenge.* This curriculum attempts to respond to students' learning difficulties in various domains. For example, it carefully responds to issues of memory load resulting from the need to integrate different levels of description in chemistry. The program is also very sensitive to the use of various representations and the meanings that students attach to them. So here was an R&D effort that combined development with on-going evaluation and research, not necessarily in that particular order. Evaluation studies show that successive refinements of the curriculum, on the basis of assessing conceptual knowledge, have culminated in a program that responds to many of the learning difficulties that have been identified previously in this domain (Eylon, 1993).

As another example of a similar chain of events, we describe the evolution of our *Electricity and Magnetism* (E&M) course, which forms a central chapter within the physics high school course in this country. Again, going back to the early 1960s, the first edition of the PSSC course was actually translated into Hebrew by a private publisher. However, it is a 1-year course, aimed at 17-year-old students, geared towards the American system. In our physics group, we adopted many of the approaches and ideas PSSC initiated. We also learned a lot from the Nuffield materials and looked at many other curricula.

Having absorbed all that foreign wisdom, we then carefully developed our own physics course for high school. It was planned for 3 or 4 years, starting at about age 14, as is common in many European educational systems. The 1970s were years of intensive development and implementation efforts in Israel, and physics teaching and learning in Israeli high schools certainly improved during those years. Again, changes in the target population, as described above, necessitated some serious consideration of learning difficulties, which became manifest as the curriculum was being used in schools. Cognitive studies aimed at identifying foci of difficulty in our ninth grade course were followed by the development of special remedial materials based on the diagnostic results of that study (Idar and Ganiel, 1985). Once our awareness to the problems of younger students became acute, we realized that similar issues concerning our older students, were also worth investigating.

One such study (Cohen, Eylon, & Ganiel, 1983) concentrated on student understanding of some central concepts in electricity. Specifically, how students perceive and use the concepts of current and potential difference. The outcomes were revealing because they substantiated some of our long-standing suspicions. Students often use certain concepts algorithmically without much understanding of the underlying physics. Still, they pass examinations successfully by developing formula manipulation techniques that carry them through most of the standard tests. A detailed follow up study (Eylon & Ganiel, 1990) enabled us to formulate clear assumptions about the sources of student difficulties. The outcomes of this research are now being applied in the development of a new E&M course. In this R&D effort, we are cooperating with a group at Carnegie-Mellon University (Bruce A. Sherwood and Ruth Chabay) who are developing a university course on the same topic in which they are adopting similar principles, as a result of our research findings.

Needless to say, these R&D activities reflect a cooperation of scientists, teachers and graduate students, whose research towards M.Sc. and Ph.D. degrees is concerned with topics that need investigation while the development effort continues.

Many other examples of similar activities could be given. The outstanding point is that the best place for this complex array of activities to take place is within an academic environment. However, as already stated, professors of science (physics, or chemistry, or biology or any other scientific discipline) will not accomplish it all by themselves.

Conclusion

Innovation is a slow process, and it requires time. To foster innovation, a systems approach is required—one in which longitudinal, progressive refinements of program development, school and classroom organization, teacher training, assessment and cognitive research are all considered and activated together.

Obviously this an expensive enterprise. Can every country afford it? My only answer to this is what a wise colleague told me once: we always calculate how much a Ph.D. in chemistry, or a medical doctor, an electrical engineer, or a lawyer cost to train. Has anybody ever calculated the cost to the system of an uneducated, unskilled, ignorant person? Or put differently: If you think education is expensive, try ignorance!

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A Look at the Educational System

Barry Fraser and Herbert Walberg

Two different models of educational productivity (i.e., models that incorporate a set of factors that powerfully and consistently have predicted student outcomes in past research) were tested empirically using quantitative syntheses of bodies of past research (Fraser, Walberg, Welch, & Hattie, 1987). Because financial and human resources are scarce both in developing and developed countries, it is important to draw on research to guide the wise investment of these resources.

For the purposes of this paper, a limited definition of school effectiveness is adopted, and attention is restricted to studies that have used one specific set of research methods. The measure of student effectiveness is student achievement, and this is defined predominantly in terms of cognitive outcomes only. The type of research considered here is restricted to quantitative, empirical studies of factors, associated with the school, that are empirically linked with student achievement. Clearly, these empirical studies of student achievement, although certainly important, cannot provide a complete picture of the schooling process and, therefore, other research methods (e.g., ethnographic techniques) and other criteria for school effectiveness (e.g., students' affective outcomes) are equally important and worthwhile.

Because most of past research on educational productivity has been conducted in developed English-speaking countries, caution is needed in generalizing findings in developing countries because of cultural and resource differences. However, some exemplary studies have been undertaken in developing countries (Walberg, 1991), and it is likely that some of the findings presented here would be applicable in developing countries.

Walberg's Model of Educational Productivity

Walberg (1981, 1983, 1986) claims that the following nine factors require optimization to increase affective, behavioral, and cognitive learning:

Student Aptitude Variables

1. Ability or prior achievement, as measured by the usual standardized tests
2. Development, as indexed by chronological age or stage of maturation
3. Motivation, or self-concept, as indicated by personality tests or the student's willingness to persevere intensively on learning tasks

Instructional Variables

4. Quantity of instruction (amount of time students engage in learning)
5. Quality of instruction, including psychological and curricular aspects

Educationally Stimulating Psychological Environment

6. Home environment
7. Classroom or school environment
8. Peer group environment outside the school
9. Mass media environment, especially amount of leisure-time television viewing

These nine factors are potent, consistent, and widely generalizable. Each aspect appears necessary for learning in school because, without at least a small amount of each, students can learn little. Large amounts of instruction and high degrees of ability, for example, could count for little if students are unmotivated or if instruction is unsuitable. Also, correlations among the productivity factors in the model are to be expected because "Mathew effects" (Walberg & Tsai, 1983) abound in education. For example, those advantaged in one factor, such as home environment, are likely to also be advantaged in other factors, such as ability and motivation, and will likely attend schools with better instruction and more positive classroom environments. The existence of relationships among variables also suggests that educators are unlikely to raise achievement substantially by the teachers' efforts alone; factors such as the academic stimulation at home, the out-of-school peer group, and the student's use of leisure time can influence learning directly or indirectly (e.g., through raising motivation).

Tests of Walberg's model of educational productivity have drawn on about two dozen past quantitative research syntheses or meta-analyses of over 2,500 individual empirical studies of the effect of particular factors on learning (e.g., Frederick & Walberg, 1980; Graue, Weinstein, & Walberg, 1983; Iverson & Walberg, 1982; Uguroglu & Walberg, 1979; Williams, Haertel, Haertel & Walberg, 1982).

The findings of these meta-analyses were surprisingly generalizable in that studies yielded similar results for national and international samples of students with different characteristics such as sex and age, in different subjects such as civics and science, and using different research methods such as surveys, case studies and experiments. That is, the more powerful factors appeared to benefit all students under all conditions, although of course some students benefited somewhat more than others under some conditions.

The average correlation with learning of the three student aptitudinal variables of ability, development, and motivation was relatively high. For example, IQ was found to be a strong correlate of general academic learning (r = 0.71) but only a moderately strong correlate of science learning (r = 0.48).

Table 1 shows the effects on student learning of 26 aspects and methods of instruction, which can be interpreted as quality of instruction variables in the productivity model. The results are provided in terms of the average effect sizes (i.e., differences between the means of experimental and control of groups divided by the standard deviation of the control group) and are recorded in order of decreasing effect size.

Of all the factors in Table 1, the psychological components of mastery learning ranked first and fourth in their affect on educational outcomes. Skinnerian reinforcement or reward for correct performance had the largest overall average effect (to 1.17 standard deviations). Instructional cues, engagement, and corrective feedback had effects equal to approximately one standard deviation. Separate syntheses of research on the use of mastery learning strategies in instruction specifically in science have shown an average effect size of 0.8. Syntheses of evaluations of post-Sputnik science and mathematics curricula reveal that they had moderate effects (0.3) on learning. Instructional time (or quantity of instruction in the productivity model), as shown in the last line of Table 1, had an overall correlation of about 0.4 with learning outcomes. Additions of time, with other factors held fixed, yield progressively smaller gains in learning.

Syntheses of the effects of environmental factors (including the environments proposed in the model of educational productivity—home, peer, class, and mass media) showed that these factors have strong influences on learning. The psychological morale or climate of the classroom group (e.g., cohesiveness, goal direction), strongly predicted end-of-course measures of affective, behavioral and cognitive learning (Fraser, 1986; Fraser & Walberg, 1991; & Haertel, Walberg, & Haertel, 1981). By comparison, the influence of the peer group outside of school is moderate and comparable to the influence of the student's socioeconomic status.

More than 12 hours per week of leisure-time television viewing, perhaps because it displaces more edu-

Table 1. Effects of Instructional Quality and Time on Learning

Method	Effect size
Instructional guality reinforcement	1.17
Acceleration	1.00
Reading training	0.97
Cues of feedback	0.97
Science mastery	0.81
Cooperative programs	0.76
Reading experiments	0.60
Personalised instruction	0.57
Adaptive instruction	0.45
Tutoring	0.40
Individualised science	0.35
Higher-order questions	0.34
Diagnostic prescription	0.33
Individualised instruction	0.32
Individualised mathematics	0.32
New science curricula	0.31
Teacher expectations	0.28
Computer-assisted instruction	0.24
Sequenced lessons	0.24
Advanced organisers	0.23
New mathematics curricula	0.18
Inquiry biology	0.16
Homogeneous groups	0.10
Programmed instruction	-0.03
Class size	-0.09
Mainstreaming	-0.12
Instruction time	0.38[a]

*Effect size is the difference between group means expressed in standard deviations.

[a] This effect size is the correlation between learning and instructional time.

cationally-constructive home activities, had a weak negative or deleterious influence on school learning. In addition to increasing supervised homework and reducing television viewing, school-parent programs aimed at improving academic conditions in the home have an outstanding record of success in promoting achievement. What might be called "the alterable curriculum of the home" (e.g., informed parent-child conversations about school and everyday events, encouragement and discussion of leisure reading, monitoring and joint critical analysis of television viewing and peer activities, and interest in the child's academic progress) is twice as predictive of academic learning as is family socioeconomic status. Collectively, the various meta-analyses (Walberg, 1986) suggest that the three groups of aptitudinal, instructional and environmental factors are powerful and consistent in influencing learning.

Despite the high status and cost of laboratory work in science teaching in both advanced and developing countries, research has not established the efficacy of laboratory teaching (Fraser, McRobbie, & Giddings, 1993). The research that has been conducted, mainly in advanced countries, has been sparse and inconclusive. Although some of these studies have involved laboratory classes that are poorly organized, it still is interesting to note that, despite its pride of place, laboratory work has not been indicated through research.

Hatties's Productivity Model Based on Student Learning Models

Hattie (see Fraser, Walberg, Welch, & Hattie, 1987) has reviewed and synthesized numerous models of student learning to produce a model of educational productivity (Bloom, 1976; Carroll, 1963; Glaser, 1976). Through a synthesis of these models of student learning, a number of critical elements of each was incorporated into a model of educational productivity containing the following seven main factors:

1. School factors, including aims and policy, physical attributes and environment
2. Social factors, including peers, mass media, socioeconomic status and home environment
3. Instructor factors, including background and style

4. Instructional factors, including quality of instruction, quantity of instruction and curriculum

5. Student factors, including affective background, cognitive background, physical attributes (e.g., gender), and disposition to learn

6. Method of instruction, including individualization, simulation/games, computer-assisted instruction, programmed instruction, tutoring, learning hierarchies, mastery learning, team teaching, amount of homework and instructional media

7. Learning strategy, including reinforcement, advance organizers, and remediation/feedback

A computer search of Psychological Abstracts, Dissertation Abstracts and ERIC revealed 134 meta-analyses that had related some facet of the model of school learning to student outcomes; most were related to achievement outcomes.

Table 2 presents a summary of the meta-analyses relating to achievement. (The number of correlations occasionally is less than the number of studies as only those relationships to achievement outcomes are presented.) Altogether, the 134 meta-analyses were based on 7,827 studies and 22,155 correlations and a sample of somewhere between 5 and 15 million people.

An attempt was made to synthesize this large number of meta-analyses. Table 2 shows that the average correlation with achievement for all factors is 0.20 (standard deviation = 0.15), the average weighted by the number of studies is 0.18, and the average weighted by the number of correlations is 0.19. Overall, 75% of the correlations were positive. Thus, with large samples, any facet that has a correlation with achievement of greater than 0.2 (or where the effect size is greater than 0.4 standard deviations) is well worth pursuing, and any correlation greater than 0.3 (0.62 standard deviation) should be of much interest. As Stinchombe (1972) has argued:

> *Comparing a real cause in the world with the strongest cause one can imagine, rather than with other causes actually operating, gives an artificially deflated estimate of the importance of the real cause(s). . . Thus it seems to me more reasonable to compare the effects of a particular systematic . . . cause to the total effects of all systematic causes we can find, excluding luck.*
> (p. 604)

It could be a mistake to assume that correlations of 0.2 or 0.3 are very small and are of little practical usefulness.

Because industrialized nations and developing countries share some characteristics in common, some of this chapter's findings for research in developed countries are likely to be generalizable to developing countries. However, because of important cultural differences, caution is needed before other findings from research in developed countries are applied to developing countries.

Conclusions and Implications

This paper's findings lead to implications for improving educational productivity and school effectiveness. Of the three aptitudinal variables of ability, development, and motivation in Walberg's model, the research suggested the importance of each in influencing learning. The research provided much evidence indicating the strong effect of quantity and quality of instruction on student learning. Increasing the amount of instruction by using the school day more effectively or by increasing homework is likely to lead to improvements in student outcomes. The studies reported also led to the identification of the following successful methods of instruction whose use is likely to lead to greater achievement: mastery learning (reinforcement and feedback), cooperative learning, personalized and adaptive instruction, advance organizers, national science curricula, high teacher expectations, longer wait-time, and good questioning techniques.

Table 2. Summary of 134 Meta-analyses Relating Factors to Achievement

Factor	Number of meta-analyses	Number of studies	Number of relationships	Average r
School	16	781	3313	0.12
Aims and Policy	6	307	542	0.12
Physical Attributes	5	372	1850	-0.02
Class environment	5	102	921	0.26
Social	4	153	1124	0.19
Peer	1	12	122	0.19
Mass media	1	23	274	-0.06
Home	2	118	728	0.31
Instructor	9	329	1097	0.21
Backgroud	1	65	22	0.29
Style	8	264	1075	0.20
Instruction	31	1854	5710	0.22
Quality	1	41	22	0.47
Quantity	4	110	80	0.38
Methods	26	1763	5668	0.17
Science	11	730	1562	0.18
Mathematics	6	416	1713	0.16
Reading	8	557	2333	0.24
Others	1	60	60	0.13
Pupil	25	1455	3776	0.24
Affective	8	355	1882	0.12
Cognitive	8	484	896	0.44
Physical	6	551	905	0.10
Disposition to learn	3	65	93	0.29
Methods of instruction	37	2541	6352	0.14
Individualisation	5	467	630	0.07
Simulation\games	2	151	111	0.17
Computer-assisted	11	557	566	0.15
Programmed instruction	4	285	220	0.09
Tutoring	2	218	125	0.25
Learning hierarchies	1	15	24	0.09
Mastery learning	3	106	104	0.25
Team teaching	1	41	41	0.03
Homework	2	44	110	0.21
Instructional media	6	657	4421	0.14
Learning strategies	12	714	783	0.28
Reinforcement	3	76	139	0.49
Advance organisers	5	430	387	0.18
Behavioural objectives	1	111	111	0.06
Remediation\feedback	3	97	146	0.30
Grand total or mean	134	7,827	22,155	0.20

Of the four environmental variables in Walberg's productivity model, this paper has provided considerable evidence supporting the effect of the home environment (especially intellectual stimulation and home interventions) and the class environment (especially cohesiveness, satisfaction and goal direction) in promoting learning, thus suggesting the important role to be played by teachers and parents in attempting to enhance student achievement through changing classroom and home environments. On the other hand, the paper provides limited evidence of the influence of peer environment or the media environment, although the small deleterious effect of excessive leisure-time television viewing was consistently demonstrated.

Not all of the factors in the productivity model are readily alterable by educators. For example, the length of the school day and the proportion of time devoted to different school subjects is partly a political decision outside the control of individual schools. Motivation is likely to be determined in part by parental influence and attitudes, and so too is the home environment (in terms of academic stimulation) and the amount and nature of television viewing. On the other hand, schools are likely to be able to take steps to improve quantity of instruction, quality of instruction, and the classroom environment (although the variables of ability, development and the peer environment are likely to prove more difficult to alter).

Because schooling occupies only about 13% of the waking hours of the first 18 years of life (which is smaller than the amount of time that some children spend watching television), school cannot be blamed fairly for all our educational problems. Educational experiences in the home, among peers, and in the community also make a contribution towards student learning. For example, studies show that families differ markedly in terms of how much time parents spend with their children to encourage and help them in relation to their schoolwork. These major differences in parental investment of time and concern could go a long way in accounting for children's varying capacities to profit from schooling and other educational experiences. Because children spend so much time at home with their parents, it is likely that altering home conditions and the partnership between home and school could have a favorable influence on student learning.

Another important finding from the synthesis of 134 meta-analyses (or 7,827 individual studies) is that the average effect size for all factors over all these studies was only approximately r = 0.2 or 0.4 standard deviations. This finding provides a timely reminder that we should not be too hasty in dismissing educational treatments just because their effects are relatively small. It could be unrealistic to expect massive effects in education, and factors with effect sizes greater or equal to this average figure (r = 0.2) could be well worth pursuing. Furthermore, the educational productivity research reported here indicates that we should not expect any single factor to have an enormous impact on student learning; rather, the key to improving student learning and enhancing school effectiveness lies in simultaneously optimizing several different factors, each of which bears a modest relationship to achievement.

Science educators have gone through many fads during the past half century. Ironically, innovations in science education have been based on eminent authority and popular opinion rather than research evidence on their effectiveness. It is by no means clear that today's approaches will work any better than those of the past, and it is still less clear that they will work efficiently in low-income countries. Still, research shows that a number of approaches from the past and present have reasonable histories of success in a variety of circumstances. They constitute no elegant framework but a menu of possibilities. Combined with the wisdom of experience, careful first-hand assessments of the particularities of culture and circumstance, effective means of organization and continuing evaluation, they offer one basis for improving science education in both advanced and developing countries.

In conclusion, it is important to remember Tobin's (1994) warning that teaching and learning science are not culture free. Before employing curricula or research findings from developed countries, careful consideration must be given to the nuances of the cultures of those countries.

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Fostering Change in Science Education: Does How We Teach Match How Students Learn?

Lillian McDermott

Introduction

A perception that there is a crisis in science education is common not only in many developing nations but also in some of the most highly industrialized countries. In the United States, findings from a series of national studies have been interpreted as evidence that a crisis exists. Appropriate or not, frequent use of this word in the media has generated interest in efforts to improve the teaching of science and mathematics. The environment has become much more supportive than it was 15 years ago when we began research on the learning and teaching of physics. Since then, the Physics Education Group, which is a part of the Physics Department at the University of Washington, has developed a coordinated program of research, curriculum development, and instruction.

The research conducted by our group has focused on student understanding of traditional topics from introductory physics. In the American university system, the introductory calculus-based physics course is required for science and engineering students (cf. Resnick, Halliday & Krane, 1992). This is also the first step (and sometimes the last) in the preparation of prospective teachers of physics. Results of systematic investigations indicate that the difference between what is taught and what is learned in a typical class is often greater than most instructors realize (McDermott, 1991). This discrepancy suggests the following: Is there a corresponding mismatch between how we teach and how students learn? In this paper, we consider this question entirely in the context of physics, but we expect that colleagues from other disciplines will have no difficulty in making appropriate analogies.

Traditional Approach to Instruction

Instruction in introductory physics has traditionally been based on the instructor's view of the subject and the instructor's perception of the student. Most teachers of physics are eager to transmit both their knowledge and enthusiasm. They hope that their students will acquire specific information and skills and also come to appreciate the beauty and power that the physicist finds in physics. Having obtained a particular insight after hours, days, months or years of intellectual effort, they want to share this knowledge. To save students from going through the same struggles, instructors often teach from the top down, from the general to the particular. Generalizations are often fully formulated when they are introduced. Students are not actively engaged in the process of abstraction and generalization. Very little inductive thinking is involved; the reasoning is almost entirely deductive. By presenting general principles and showing how to apply them in a few instances, instructors hope to teach students how to do the same in new situations.

In recalling how they were inspired by their own experience with introductory physics, many instructors tend to think of students as younger versions of themselves. In actual fact, such a description fits only a very small minority (Tobias, 1990). Typically, in the U.S. today, no more than one in every 30 university students taking introductory physics will major in the subject. The trouble with the traditional approach is that it ignores the possibility that the perception of students may be very different from that of the instructor. Perhaps most students are not ready or able to learn physics in the way that the subject is usually taught. Prospective teachers are in a particularly difficult position. They may be expected to teach a curriculum to which they will not be well matched as instructors, after having learned from a teacher to whom they were not well matched as university students (McDermott, 1990).

Some Generalizations about Learning and Teaching

The generalizations that appear below are based on results from research on the learning and teaching of physics. The evidence presented in support of the generalizations is taken from the cited articles on research by the Physics Education Group at the University of Washington. However, the same arguments could be based on findings by other investigators (Halloun & Hestenes, 1990; McDermott, 1984). Similar conclusions have also been reached by experienced instructors who have probed student understanding in less formal ways in the classroom (Arons, 1990).

A. Quantitative Problems

Facility in solving standard quantitative problems is not an adequate criterion for functional understanding. Questions that require qualitative reasoning and verbal explanation are essential.

The criterion most often used in physics instruction as a measure of mastery of the subject is performance on standard quantitative problems. As course grades attest, many students who complete a typical introductory course can solve such problems satisfactorily. However, they are often dependent on memorized formulas and do not develop a functional understanding of physics, that is, the ability to do the reasoning needed to apply appropriate concepts and physical principles in situations not previously encountered. We illustrate this first generalization with examples from dynamics and electricity.

Example from Dynamics: Impulse-Momentum and Work-Energy Theorems

In an investigation conducted several years ago, we examined whether students could apply the impulse-momentum and work-energy theorems to a simple motion that they could observe (Lawson & McDermott, 1987). In the demonstration shown in Figure 1, two dry-ice pucks that differ greatly in mass (one made of brass, the other of plastic) start from rest at line A and are subjected to the same constant force. They move without friction from line A to line B, where the force is removed. The force is applied by a steady stream of air from a reversed vacuum cleaner. Small strips of paper attached at the opening serve as spacers for maintaining a constant separation between the hose and pucks, thus ensuring that the force is constant. The pucks move in a direction perpendicular to the lines and do not rotate.

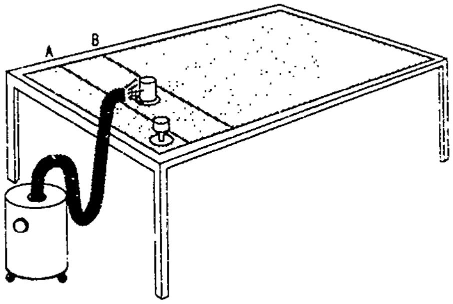


Figure 1. Apparatus Used for Impulse-Momentum and Work-Energy Comparison Tasks

LEGEND: The same force is applied to both pucks over the same distance. For the demonstration the impulse-momentum and work-energy theorems can be expressed as $F\Delta t=\Delta(mv)$ and $F\Delta s=\Delta(1/2\ mv^2)$, respectively.

Data were gathered through individual demonstration interviews. The 28 students who participated came from two classes: an honors section of calculus-based physics and a regular section of algebra-based physics. The investigator began each interview with a demonstration of the motion and then asked if, after crossing line B, the momenta and kinetic energies of the two pucks were the same or different.

1. Correct Response

No calculations are required. It is only necessary to understand the relationship between impulse and momentum and the relationship between work and kinetic energy. Since the same constant force is applied to each puck, the change in momentum is proportional to the time each takes to traverse the distance between the lines. Because of its greater mass, a smaller acceleration is imparted to the brass puck. During the longer time it spends between the lines, it receives a greater impulse. Hence, the brass puck experiences a greater change in momentum than the plastic puck. The total change in kinetic energy of each puck is equal to the work done on it. Because the same constant force is applied to each puck for the same distance, the change in kinetic energy is the same for both pucks.

For a response to be considered correct, both the right comparison and the proper reasoning were required. During the individual demonstration interviews, students who were unable to make a correct analysis were guided in making the necessary observations. If they still seemed at a loss after the demonstration was repeated several times, the investigator asked if the terms "impulse" and "work" would be useful.

2. Results

After observing the demonstration, only 25% of the honors students stated that the momentum of the brass puck would be greater than that of the plastic puck and gave a correct explanation. With the help provided by the investigator, the number rose to 65%. Performance on the kinetic energy task was somewhat better. Initially, 50% of the students said that the kinetic energies would be the same. With guidance, 85% eventually gave this response. Even with help, however, virtually no one in the algebra-based course was able to apply the concepts of impulse and work correctly in comparing the momenta or kinetic energies. When students in a regular section of calculus-based physics were later presented with the same comparison tasks in written form, they were similarly unsuccessful.

3. Examples of Conceptual and Reasoning Difficulties

The reasoning used by the students revealed a great deal about the nature of their understanding. The excerpts below illustrate some specific difficulties that we identified.

• Random Formula Search

The following dialogue between an investigator (I) and a student (S) took place late in an interview. To help the student, the investigator asks explicitly about the term "work."

> I: " . . . Do you remember what the term "work" means in physics?"
>
> S: ". . . Work was . . . the change in kinetic energy . . . or, . . . let me think . . . It might have been the force times. . . I'm not sure, I think I recall the formula: r, F, the cosine of the angle between the two. But we just did problems on that and I can't remember exactly."

The student remembers the statement that relates work to kinetic energy. His understanding of the concept of work, however, seems limited to a formula that he doesn't remember. He cannot connect the symbols with the features of the demonstration.

• Indiscriminate Use of Technical Terms

Students can often give formal definitions for concepts but may not be able to identify which is appropriate to apply in a particular physical situation. The comments below were made by students who were presented with the tasks in written form.

> S_1: "The momentum of the two pucks should be equal because the same energy was imparted to both . . . The kinetic energy should be equal because the same force acted with the same energy on both pucks."
>
> S_2: "[The momenta] are the same because the force applied upon them was the same and over the same distance."

The indiscriminate use of language by these students reflects the fragmentary nature of their understanding. Lack of consistency often makes it impossible to interpret unambiguously the meaning students ascribe to a particular technical term.

• *Inappropriate Compensation Arguments*

There seemed to be a general tendency to claim that the plastic puck had a greater kinetic energy than the brass puck. The following excerpt from an interview illustrates the reasoning that was often used.

> S: "I think the smaller puck would have a larger kinetic energy . . . because kinetic energy is $^1/_2mv^2$ and since the "v" is squared, the one with the larger velocity would probably have a larger kinetic energy."

The type of compensation argument that appears above is not valid in this situation. In claiming that speed is a more important variable than mass, because speed appears quadratically in the definition of kinetic energy, the student has missed the essential physics. The reasoning is based solely on the definition of kinetic energy and lacks any reference to the way in which the work done on the puck is related to the change in kinetic energy.

• *Incorrect Use of the Conservation Laws*

Another relatively common error was to claim that the final kinetic energy and momentum of the pucks were the same. The reasoning illustrated below was typical.

> S_1: "They have the same momentum because they were both moved by the same force F = dp/dt. They have the same kinetic energy because all the forces are conservative (no friction)."

> S_2: "The momentum of [pucks] A and B should be equal . . . It is like having an elastic collision because the force imparted on each puck is the same. . . . The kinetic energy should be equal as well, since it is like an elastic collision so energy should be conserved."

> S_3: "The momenta are equal . . . The same force is applied as in a collision . . . therefore they should have identical kinetic energy because there was no force outside acting on it."

All three students based their comments on an incorrect application of the principle of conservation of energy or momentum. Although the statements about the equality of the final kinetic energies are correct, the reasoning is not. The argument should be based on the fact that the same work is done on each puck by the external force.

Typically, students who referred to the conservation laws tended to interpret the term *conservation* as implying an *equality* of kinetic energy or momentum. Some of these students attempted to make an analogy to the situation in which the pucks undergo an elastic collision. They either neglected to consider the circumstances under which the conservation laws hold or failed to recognize the external forces acting on the pucks.

• *Incomplete Causal Reasoning*

Even when there was evidence of understanding of work and kinetic energy considered separately, it did not follow that a student understood the connection between the concepts. The following excerpt from an interview illustrates the type of guidance provided by the investigator to help students make a correct comparison.

> I: ". . . What ideas do you have about the term work?"

> S: "Well, the definition that they give you is that it is the amount of force applied times the distance."

> I: "Okay. Is that related at all to what we've seen here? How would you apply that to what we've seen here?"

S: "Well, you do a certain amount of work on it for the distance between the two green lines: you are applying a force for that distance, and after that point it's going at a constant velocity with no forces acting on it."

I: "Okay, so do we do the same amount of work on the two pucks or different?"

S: "We do the same amount."

I: "Does that help us decide about the kinetic energy or the momentum?"

S: "Well, work equals the change in kinetic energy, so you are going from zero kinetic energy to a certain amount afterwards . . . so work is done on each one . . . but the velocities and masses are different so they (the kinetic energies) are not necessarily the same."

Had the interview been terminated earlier, the impression would have been that this student's understanding was adequate. It was only by persevering that the investigator was able to determine that the student did not realize that the work-energy theorem expresses a special relationship that exists between the work done and the change in kinetic energy.

By and large, students did not recognize the cause-and-effect relationship inherent in the theorems. Some seemed to treat the symbol "=" as if it represented only a mathematical relationship in which the variables may take on any values, provided the equality is maintained (Arons, 1990). Such insights about how students think can seldom be obtained from written responses to the types of quantitative problems typically used for assessment.

Example From Electricity: Electric Circuits

We have been investigating student understanding of electric circuits over a period of several years (Shaffer & McDermott, 1992; McDermott & Shaffer, 1993). One task that has proved effective for eliciting common difficulties is based on the three circuits in Figure 2. All have identical bulbs and ideal batteries. Students are asked to rank the five bulbs according to relative brightness and to explain their reasoning.

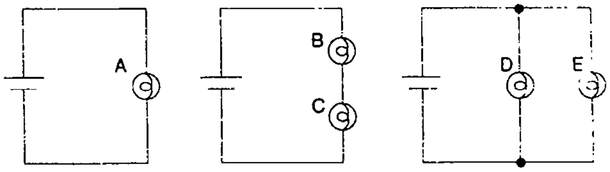


Figure 2.

LEGEND: Students are asked to rank by brightness the five identical bulbs and to explain their reasoning. They are told to assume that the batteries are ideal.

1. Correct Response

A correct comparison requires no calculations. A simple qualitative model, in which bulb brightness is related to current or potential difference, can be used to determine that Bulb A, Bulb D and Bulb E will be equally bright and brighter than the other two bulbs, which will be equal in brightness to each other (A = D = E > B = C).

The ranking given for the bulbs in Figure 2 depends on the use of ideal batteries. For real batteries, the order would be A > D = E > B = C. To determine whether a significant number of incorrect responses may have been because of a failure to notice that the batteries are ideal, we asked a similar question based on Figure 3. In this case, all the bulbs would be dimmer with a real battery but the relative ranking would be the same. If the use of ideal batteries in Figure 2 had confused students, a higher percentage of correct responses might have been expected for Figure 3. However, the percentage was the same in both cases.

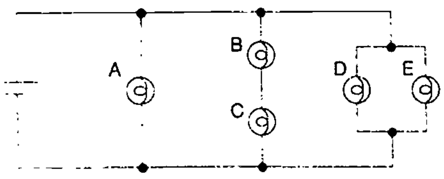


Figure 3.

LEGEND: Students are asked to rank by brightness the five identical bulbs and to explain their reasoning. Unlike the situation in Figure 2, the relative ranking does not depend on whether or not the battery is ideal.

2. *Results*

The task of ranking the bulbs in Figure 2 or Figure 3 has been administered to more than 500 university students. Almost every possible bulb order has appeared. Whether before or after instruction, only about 15% of the students in a typical calculus-based physics course give the correct ranking. We have obtained the same results from high school physics teachers and from university faculty who teach other sciences and mathematics. Many people who are unable to rank the bulbs properly can use Ohm's law and Kirchhoff's rules to solve more complicated problems. A careful analysis of errors has led to the identification of specific difficulties. Some of these have been noted by other investigators (Fredette Lochhead, 1980; Fredette & Clement, 1981; Cohen, Eylon & Ganiel, 1983; Delacote, Tiberghien & Schwartz, 1983; Duit, Jung & Rhöneck, 1984; Dupin & Johsua, 1987; Pfundt & Duit, 1991). Evidently, success on standard problems is not a reliable indicator of functional understanding.

B. Coherent Conceptual Framework

A coherent conceptual framework is not typically an outcome of traditional instruction. Students need to participate in the process of constructing qualitative models that can help them understand relationships and differences among concepts.

Perhaps the most serious difficulty that we have identified is the failure to integrate related concepts into a coherent framework (diSessa, 1988). Rote use of formulas is common. To solve standard circuit problems, skill in mathematical manipulation may suffice. To be able to apply a concept in a variety of contexts, however, students must not only be able to define that concept but also relate it to others. They also need to differentiate that concept from related concepts.

The question on ranking the bulbs was first administered several years ago on an examination in a standard calculus-based course. Lacking a conceptual model on which to base predictions, most students relied on intuition or formulas. About 40% used algebra to find the equivalent resistance of the series and parallel circuits. They then substituted their answers (2R or R/2) into the formula for the power dissipated in a resistor and associated the result with the brightness of each of the bulbs in the corresponding series or parallel network. Their ranking depended on which form of the power formula they used (I^2R or V^2/R). For example, if they chose $P = V^2/R$, the bulb order obtained was $D = E > A > B = C$. Such errors revealed a failure to separate two related concepts: the resistance of an element and the equivalent resistance of a network containing that element.

Constructing a Qualitative Conceptual Model

A general instructional strategy that we have found useful for helping students relate electrical concepts and distinguish one from another is to engage them actively in the intellectual process of constructing a qualitative conceptual model for an electric circuit (Arons, 1990; Schaffer & McDermott, 1992). Development of the model is based on observations of the behavior of batteries and bulbs, preferably through experiments that the students themselves perform.

The students begin the model-building process with two assumptions that appear plausible from their initial observations: (a) a flow (electric current) exists in a complete circuit and (b) bulb brightness indicates the amount of flow. From these assumptions and from observations of the relative brightness of identical bulbs in series and parallel circuits, the students draw inferences about the behavior of bulbs in various configurations. They predict the effect of specified changes on bulb brightness and check their predictions. Using both inductive and deductive reasoning, they formulate the concept of resistance and recognize the critical role of the equivalent resistance in determining the current in a circuit.

The model that the students have developed is sufficient to predict bulb brightness in the relatively complicated circuit shown in Figure 4. They can readily determine that the current through Bulb E is more than half of the current through the battery. Because Bulb A and Bulb B each receive half of the current through the battery, they are equally bright, but not as bright as Bulb E. Bulb C and Bulb D each have the same current, but because it is less than half of the current through the battery, they will be dimmer than the others (E > A = B > C = D). Only after students have attained a qualitative understanding of current is the ammeter introduced.

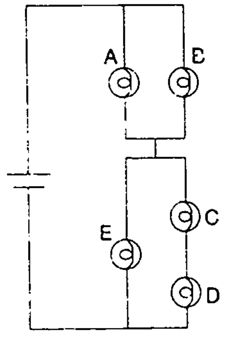


Figure 4.

LEGEND: Students are asked to rank the bulbs in the circuit according to brightness.

As the students analyze circuits of increasing complexity, they realize that the model that they have developed thus far is inadequate for predicting the brightness of all the bulbs in some circuits. They recognize that when the switch in the circuit shown in Figure 5 is opened and Bulb C is removed, the equivalent resistance of the circuit increases. Therefore, the current through Bulb A and Bulb D decreases and both become dimmer. However, the students cannot predict from their model what happens to the current through Bulb B.

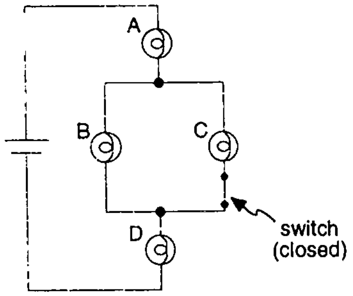


Figure 5.

LEGEND: Students are asked to predict: (1) the relative brightness of the identical bulbs while the switch is closed, and (2) how opening the switch will affect the brightness of each bulb.

With the aid of a voltmeter, students formulate the concept of potential difference. They recognize that a voltmeter placed across the terminals of an element does not measure current but another quantity that is identified as the potential difference. Additional experiments help sharpen the distinction between current and potential difference. The students observe that the potential difference across an element increases or decreases as its resistance increases or decreases with respect to the other resistances in series with it.

Other experiments lead the students to associate the brightness of a bulb with the potential difference across its terminals (i.e., the brighter the bulb, the greater the potential difference). With the extended model, they can now predict the change in brightness of Bulb B when the switch in Figure 5 is opened. Because the problem-solving, examination results indicate that becomes brighter. Using similar reasoning, they can also predict bulb brightness in more complicated circuits, such as the one in Fig. 6 (A > D = E > B = C).

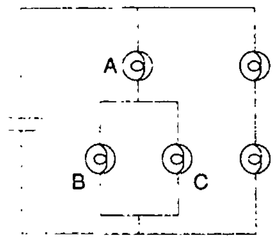


Figure 6.

LEGEND: Students are asked to rank the bulbs in the circuit according to brightness.

When students work with circuits with more than one type of bulb, they find that neither current nor potential difference alone is sufficient for predicting bulb brightness. The concept of electrical power is introduced. A single bulb, two bulbs in parallel, and two bulbs in series are connected in separate circuits to a battery and left for an extended period. The students note that the battery with the parallel connections runs down first, followed by the one in the single-bulb circuit, and finally the one in the series circuit. They realize that a battery has a finite lifetime and associate the shortest lifetime with the circuit in which the current is initially the greatest. Thus, the way is paved for identifying electrical energy as the quantity that is dissipated. The students can now reconcile their intuitive belief that something is "used up" in a circuit with their formal knowledge that current is conserved.

Quantitative Problem-solving

Experience has shown that emphasis on concept development and model-building does not detract from performance on quantitative problems. Many students need explicit instruction on problem-solving procedures to develop the requisite skills. However, once equations are introduced, students often avoid thinking of the physics involved. Postponing the use of algebraic formalism until after a qualitative understanding has been developed has proved to be an effective approach. Although less time is available for practice in numerical problem-solving, examination results indicate that students who have learned in this way often do better than others on quantitative problems and much better on qualitative questions.

C. Addressing Conceptual Difficulties

Certain conceptual difficulties are not overcome by traditional instruction. Persistent conceptual difficulties must be explicitly addressed by repeated challenges in more than one context.

Some student difficulties disappear during the normal course of instruction. Others seem to be highly resistant to change. If sufficiently serious, they may preclude meaningful learning, even though performance on quantitative problems may be unaffected.

Identification of Two Persistent Conceptual Difficulties

In the process of constructing a conceptual model, students often correct their own several misconceptions about electric circuits. However, we have found that certain common difficulties tend to persist unless explicitly addressed. Two that research has shown to be especially persistent are the belief that current is "used up" in a circuit and the belief that a battery is a constant current source. In courses taught in the standard manner, these misconceptions occurred with about the same frequency before and after instruction. Both are illustrated above in the context of Figure 2.

- *Belief That Current is "Used Up" in a Circuit*

The belief that current is "used up" is widespread and appears to be intuitive. It is not necessarily a sharply differentiated concept of current that students have in mind. The language many use, however, strongly suggests that they think of current as constantly being produced by the battery and being "used up" by the elements in a circuit. In predicting bulb brightness, many students claimed that one bulb in the series circuit would be brighter than the other. They usually said that "Bulb B is brighter than Bulb C because Bulb B 'uses up' the current first and Bulb C gets the 'leftover current.' "

- *Belief That the Battery is a Constant Current Source*

Perhaps even more pervasive and persistent is the belief that the current through a battery is always the same. Even good students often do not realize that the current in a circuit depends on the resistance as well as on the battery. The following explanation by a student reflects a conviction that the current in all three circuits in Figure 2 is the same.

> *A, B and C [are] all equal [in brightness] and brighter than D and E, which are equal to each other. The same current goes through A, but in the third circuit the current is divided between D and E.*

Instructional Strategy for Addressing Persistent Difficulties

Deep-seated difficulties cannot be overcome by warning students about misconceptions. Active learning is essential for a significant conceptual change to occur. An instructional strategy that we have found effective for obtaining the necessary intellectual commitment from students is to generate a conceptual conflict and require that the students resolve the conflict. A useful first step is to *elicit* a suspected difficulty by contriving a situation in which students are likely to make a related error. Once the difficulty has been exposed and recognized, the instructor must insist that students *confront* and *resolve* the issue. This sequence of steps does not define a single strategy but a continuum. Below a variant is used to address the misconception that the battery is a constant current source. Students are asked to compare the current through identical batteries in two circuits: one has a single bulb; the other contains two bulbs in parallel. This task almost always evokes the claim that the current is the same. After this idea has been expressed, the students are asked to note the relative brightness of the bulbs and to consider the implications. The following statement was made by a high school teacher during a workshop when she observed that the bulbs were equally bright and recognized the discrepancy between what she thought would happen and what did happen:

> *That would mean that the amount of current from the battery is different in different cases and that doesn't make any sense!*

This comment illustrates the kind of reaction that the teaching sequence is meant to generate. In confronting and trying to resolve the conceptual conflict, the teacher was forced to conclude that the current through a battery is not the same in all circuits.

A single encounter is rarely sufficient to overcome a serious difficulty. Students do not make the same mistakes under all circumstances; the context may be critical. Unless challenged with a variety of situations capable of evoking a given difficulty, students may simply memorize the answer for a particular case. To be able to integrate counter-intuitive ideas into a coherent framework, they need time to apply the same concepts and reasoning in different contexts, to reflect upon these experiences and to generalize from them.

D. Cultivating Scientific Reasoning Skills

Growth in reasoning ability does not usually result from traditional instruction. Scientific reasoning skills must be expressly cultivated.

An important factor in the difficulties that students have with certain concepts is an inability to do the multi-step qualitative reasoning involved in applying the concept. It is often impossible to separate difficulties with concepts from difficulties with reasoning. An error may be a symptom of an underlying conceptual or reasoning difficulty, or of both.

A failure to think holistically in dealing with compound systems is one kind of reasoning difficulty that may be hard to disentangle from conceptual confusion. For interacting systems, such as elements in an electric circuit, it is impossible to predict the behavior of one without taking into account the effect of the others. Below are two examples of a common tendency to use local sequential reasoning when a holistic approach is needed.

• *Belief That Direction of Current and Order of Elements Matter*

In predicting bulb brightness, students often considered only the order of a bulb in an array. Many claimed that the first bulb in a series network was the brightest. This error is consistent with the misconception that current is "used up" and also with improper use of local sequential reasoning. Instead of considering the circuit as a whole, many students focused on one bulb at a time. The conservation of current was an abstraction for which they might be able to write an equation but could not apply to a qualitative problem.

• *Failure to Distinguish Between Branches Connected in Parallel Across a Battery and Connected in Parallel Elsewhere*

Predicting the effects of a change in a circuit requires a more sophisticated level of holistic reasoning. In one task, students were shown a circuit diagram in which a network containing two branches in parallel was connected in series with other bulbs. (See Figure 5.) The students were asked to predict how opening the switch would affect the brightness of Bulb B. As discussed earlier, qualitative reasoning is sufficient to determine that Bulb B increases in brightness. However, many students predicted that the brightness would not change. Often the explanation given was that the bulb was part of a parallel combination. In treating the parallel branches as independent, the students were not recognizing the difference between parallel branches connected across a battery and parallel branches connected elsewhere. Instead of using qualitative reasoning to check the consistency of their predictions, the students relied on a rule that they had incorrectly memorized. Traditional instruction does not challenge but tends to reinforce a perception of physics as a collection of facts and formulas (Hammer, in press). Students often do not recognize the critical role of reasoning in physics, nor do they understand what constitutes an explanation. They need practice in solving qualitative problems and in explaining their reasoning (Arons, 1990). However, they are unlikely to persevere at developing facility in scientific reasoning unless the course structure, including the examinations, emphasizes the importance of this ability.

E. Relating Concepts, Formal Representations and the Real World

Connections among concepts, formal representations, and the real world are often lacking after traditional instruction. Students need explicit practice in interpreting physics formalism and relating it to the real world.

Students are often unable to relate the concepts and formal representations of physics to one another and to the real world. An inability to interpret equations, diagrams and graphs underlies many conceptual and reasoning difficulties.

Difficulty With Algebraic Representations: Three Examples

In all our investigations, students have had difficulty in applying algebraic formalism to real situations. Below are examples from dynamics, electricity and optics.

- *Failure to Relate the Impulse-Momentum and Work-Energy Theorems to a Real Motion*

The demonstration for the impulse-momentum and work-energy comparison tasks created a simple physical environment in which the theorems could be applied. If students did not note that the displacement and the applied force were the same for both pucks, the investigator would draw attention to those features of the demonstration. The differences in mass, velocity, and time-in-transit between the parallel lines were great and should have been obvious to any observer who recognized that these differences were significant. However, few students could interpret the motion in terms of the relevant dynamical concepts.

- *Failure to Recognize That the Same Algebraic Symbol is Used to Represent the Resistance of an Element and the Equivalent Resistance of a Network*

Interpretation of algebraic formalism was also a source of difficulty on the electric circuits tasks. As mentioned earlier, many students confused the resistance of an element with the equivalent resistance of a network or circuit. In their calculations to compare bulb brightness, students often treated the equivalent resistance as a property of an individual bulb rather than as a useful abstraction for finding the total current or potential difference in a branch, network, or circuit. They often did not realize that the power formula refers to the resistance of an individual element. An additional complicating factor was the use of the same (or almost the same) symbol for resistance and equivalent resistance. To a physicist, each algebraic symbol in an equation represents a well-defined entity. Students, however, may not recognize differences in interpretation that may be associated with the same symbol.

- *Failure to Recognize the Unique Relationship Between Object and Image Distances Implied by the Thin Lens Formula*

Our investigation of student understanding of geometrical optics provided another example of the difficulty students often have in relating an algebraic expression to a physical system (Goldberg & McDermott, 1987). Students who had studied the relevant material participated in interviews in which they were shown a demonstration that consisted of an object, a thin converging lens, and an inverted real image on a screen (see Figure 7). The students were asked what changes would occur if the optical system were altered in certain specified ways.

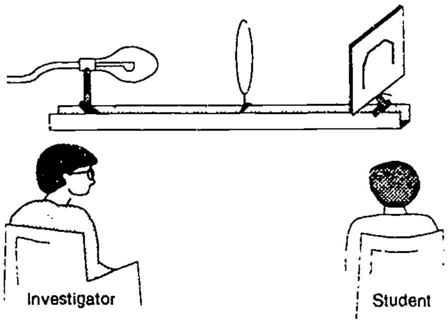


Figure 7.

LEGEND: Demonstration for interviews on converging lens tasks. The investigator asks the student what changes would occur if the system were to be altered in certain specified ways.

When asked to predict whether moving the screen toward the lens would change anything on the screen, only 40% of the students recognized that the image would become blurred and disappear. About 45% said that the image would remain clear but its size would change. Students who could use the thin lens formula to locate an image did not recognize the implication that the position of the object uniquely determines the position of the image.

Difficulty With Diagrammatic Representations: Example From Optics

In addition to difficulty in relating algebraic formalism to the real world, students often cannot interpret the diagrammatic representations used in physics. During interviews on the converging lens tasks, students were encouraged to draw ray diagrams. Many who produced correct diagrams could not relate the information represented to the task at hand.

In one of the tasks, the investigator holds a piece of opaque cardboard above the lens and asks the student to predict the effect of covering half of the lens. Only about 35% of the students realized that the image would remain intact. The most common immediate response, given by about 55% of the students, was that half of the image would disappear. Some of the ray diagrams drawn by the students reinforced this mistaken intuition.

- *Failure to Recognize That the Special Rays Used in a Ray Diagram are Not Necessary for Forming an Image but are Merely Convenient for Locating its Position*

In the diagram in Figure 8, the student located the image by drawing two rays from the top of the object. One, parallel to the principal axis, is refracted through the focal point; the other through the center of the lens is undeviated. From this essentially correct diagram, the student decided that both rays would be blocked and concluded that the bottom half of the image would be missing. This student was typical of many who did not seem to understand the role of the ray diagram as an algorithm for locating the position of an image. Although most of the students who participated in the interviews could solve standard problems, they often were unable to apply the formalism to the simple demonstration in front of them. Furthermore, we found that several factors made no difference in performance: completion of a high school physics course, enrollment in algebra-based or calculus-based physics, participation in the associated laboratory course, or the identity of the instructor.

Difficulty With Graphical Representations: Examples From Kinematics

In an investigation conducted several years ago, we probed student understanding of the kinematical concepts (Trowbridge & McDermott, 1980, 1981). We have also tried to identify specific difficulties with the graphical representation of motion (McDermott, 1991; McDermott, Rosenquist & van Zee, 1987). Below are two examples from this ongoing study.

- *Failure to Sketch Correct Graphs for a Real Motion*

Students are shown the motion depicted in Figure 9 and given the diagram along with a description similar to the following: The ball moves with steady speed

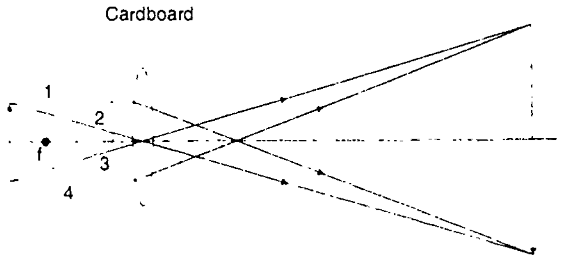


Figure 8.

LEGEND: Ray diagram drawn by a student to justify the prediction that half the image would disappear if half the lens were covered

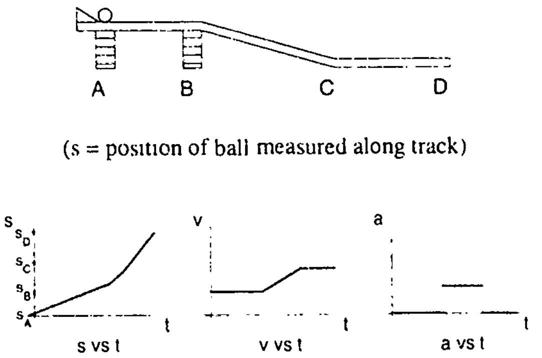


Figure 9.

LEGEND: Track arrangement for which students must produce position versus time, velocity versus time, and acceleration versus time graphs

The correct response is illustrated. (The time interval over which the acceleration changes is too small to be visible on the time scale represented.)

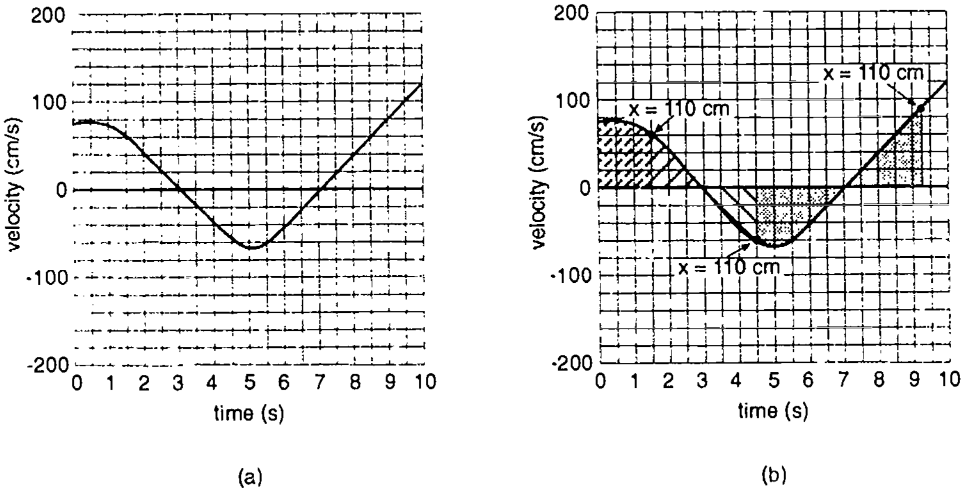
on the level segment of track, speeds up as it moves down the incline and continues at a higher constant speed on the last segment. The students are told that the position, s, is measured along the track and are asked to represent the motion in graphs of position, velocity, and acceleration versus time.

The task has been presented to several hundred students who have studied kinematics. Few students in a standard calculus-based course produce graphs similar to those in Figure 9. The most prevalent error is a failure to indicate that the three segments of the motion occur in successively shorter time intervals. More serious is a tendency to emulate the appearance of the track in the shape of the graphs. For example, on the s vs t graph, about half of the students use a straight line to represent motion along the incline. Almost as many students draw parallel lines for the first and third segments, for which the tracks are parallel in space.

- *Failure to Visualize the Real Motion Represented by a Graph*

We have examined student understanding of the reverse process: visualization of a real motion from its graphical representation. Students are given the velocity vs. time graph in Figure 10, told that the graph depicts the motion of an object located at x = 0 when t = 0, and asked to determine when the object would be at x = 110 cm.

We have found that most students do not obtain a qualitative overview of the motion from the graph. They fail to recognize that the alternating positive and negative areas above and below the v = 0 axis represent alternating positive and negative displacements. It is difficult for students to envision a quantity associated with square units as representing one with linear units. Without an image of an oscillating motion, students may not realize that they need to find more than one instant when the object is located at x = 110 cm.



(a)

(b)

Figure 10.

LEGEND: (a) Students were given the velocity vs time graph above and told that the object began at x=0 cm at t=0 s. They were asked to find when the object would pass x=110 cm.

(b) Analysis of the motion into a series of displacements. The particle passes x=110 cm three times.

Only after they have visualized the motion are students ready to attempt a quantitative solution. A quick inspection of the graph and a rough count of squares reveals that the object passes x = 110 cm for the first time at t = 1.5 s. At t = 3.0 s, it reaches its maximum displacement and reverses direction. It passes x = 110 cm for the second time at t = 4.5 s and continues in a negative direction until it reaches x = 0 at t = 7.0 s. Reversing direction again, it moves in a positive direction until it passes x = 110 cm for the third time at t = 9.3 s.

The ability to relate actual motions and their graphical representations does not develop spontaneously with the acquisition of simple graphing skills, such as plotting points, reading coordinates and finding slopes (Rosenquist & McDermott, 1987; Thoronton & Sokoloff, 1990; Arons, 1990; McDermott, 1991). Students need practice in translating both ways: from motion to graphs and from graphs to motion.

F. Teaching by Telling

Teaching by telling is an ineffective mode of instruction for most students. Students must be intellectually active to develop a functional understanding.

All the examples of student difficulties discussed above share a common feature: the subject matter involved is not difficult. Many instructors expect university students who have studied the relevant material to be able to answer the types of questions that have been illustrated. Yet, in each instance, we found that a large percentage of students could not do the basic reasoning necessary. On certain types of tasks, the outcome did not vary much from one traditionally taught class to another, nor did it matter when in the course the problems were posed. Enrollment in the associated laboratory course also did not appear to affect the quality of student performance. Moreover, there was no correlation between the success of students and the proficiency of the course instructor as a lecturer (Goldberg & McDermott, 1980; Halloun & Hestenes, 1985; Shaffer & McDermott, 1992; Hestenes, Wells & Swackhamer, 1992; Mazur, 1992). The difficulties that students have in physics are not usually because of the failure of the instructor to present the material correctly and clearly. No matter how lucid the lecture, nor how accomplished the lecturer, meaningful learning will not take place unless students are intellectually active. Those who learn successfully from lectures, textbooks, and problem-solving do so because they constantly question their own comprehension, confront their difficulties and persist in trying to resolve them. Most students taking introductory physics do not bring this degree of intellectual independence to their study of the subject.

The common tendency to teach physics by lecturing from the top down runs counter to the way most people learn best. In beginning a new topic, students need to become familiar with the phenomena to be studied, preferably through observation and open-ended investigation. Simple demonstrations can also serve as an introduction, provided that students are intellectually active observers. Instead of introducing new concepts or principles by definitions and assertions, the instructor should set up situations that suggest the need for a new concept or the utility of a new principle. Generalization and abstraction should follow, not precede, specific instances in which a concept or principle may apply. Rather than giving direct answers when students ask questions, the instructor should respond with questions that guide students through the reasoning necessary to arrive at their own answers.

The generalization that teaching by telling is frequently ineffective has special implications for the education of precollege teachers. Below are two more generalizations about teaching and learning that should be borne in mind for instruction for all students, but especially for prospective teachers.

1. Real world experience is needed by most students as a basis for constructing physical concepts and interpreting physics formalism. Instruction should commence from direct experience with common materials and simple phenomena.
   Teachers should be prepared to teach in a man-

ner that is appropriate for their students. Science instruction for young people is known to be more effective when concrete experience establishes the basis for the construction of scientific concepts. If we want teachers to have the capacity to teach "hands-on" science, the teachers need to be given the opportunity to work through a substantial amount of content in a way that reflects this spirit. In addition to learning how to teach their own students in an effective manner, prospective teachers benefit directly from such instruction. We have found (as have others) that concept formation at the university level is also enhanced by "hands-on" experience guided by appropriate questions.

2. Most people teach as they have been taught (both what and how). Teachers should learn the physics that they should teach in the way that they should teach: as a process of inquiry, not as an inert body of information.

Whether intended or not, teaching methods are learned by example. Teachers who have learned a given topic by listening to lectures and reading a textbook often attempt to teach that topic in the same way. It is difficult for most people to separate content from the manner in which it was presented. Thus, it is especially critical for prospective teachers to study physics as a process of inquiry, not as a compendium of facts to be memorized. Of course, it would also be desirable for all students to gain a perspective of physics as a process of raising questions and searching for answers.

Although the traditional lecture and laboratory format has disadvantages, it may be the only mode possible when the number of students is large. Such instruction, however, need not be a passive learning experience. There are several techniques that instructors of large classes can use to promote active participation by students in the learning process (Heller & Hollabaugh, 1992;Van Heuvelen, 1991; Hellen, Keith & Anderson, 1992; Shaffer & McDermott, 1992).

Conclusion: Improving the Match Between Teaching and Learning

The evidence in support of the generalizations that have been presented comes from research conducted over many years. We have used this resource as a guide in developing instructional materials. Our experience indicates that success in incorporating a particular topic into a course often depends as much on how the material is taught as on what is taught. Research on learning and teaching can increase the likelihood that the instructional materials developed will be well matched to the students for whom they are intended.

The process of curriculum development by our group has three parts: (1) conducting systematic investigations of student understanding; (2) applying the results in the development of instructional strategies to address specific difficulties; and (3) designing, testing, modifying and revising instructional materials in a continuous cycle on the basis of classroom experience with the target population (McDermott, 1995). We consider research, curriculum development and instruction as components of an interactive, iterative process.

Perhaps the most significant contribution that research physics education can make to the improvement of instruction is to underscore the importance of focusing greater attention on the student. Meaningful learning, which connotes the ability to interpret and use knowledge in situations different from those in which it was initially acquired, requires that students be intellectually engaged. Development of a functional understanding cannot take place unless students themselves go through the reasoning involved in the development and application of concepts. Furthermore, to be able to transfer a reasoning skill learned in one context to another, students need multiple opportunities to use that same skill in different contexts. The entire process requires time. Inevitably, this constraint places a limit on the breadth of material that can be covered and the pace at which instruction can progress.

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Can We Prepare Teachers to Teach the Way Students Learn?

Richard Gunstone

Introduction

The most obvious feature of research on science learning in the last decade has been the strong interest in learning as personal construction, usually described as constructivism. A constructivist focus is at the heart of Lillian McDermott's paper. This focus on learning recognizes that it learners construct their own understanding. Much of the interest in the focus arises from one of the consequences of personal construction—alternative student conceptions.

This paper considers constructivist science learning in the context of science teacher education (pre- and in-service). The implications of constructivism for teacher education come from two intertwined perspectives: what is implied for teacher education per se, and what is implied about learning and teaching of science. This paper addresses classroom learning issues as well as teacher education, begining with some relevant issues arising from constructivist research in science education, then turning to the necessary links between constructivism and metacognition, and finally considering how the constructivism-metacognition perspective leads to approaches to teacher education.

Constructivist Learning and Discovery Learning

The discovery learning movement of the 1960s, in its most extreme forms, argued that the role of the teacher should change to concentrate on providing the environment and facilities necessary for students to discover for themselves. As a consequence the movement was also often described as student-centered. The classroom implications of constructivism are also student-centered. This has led some critics of constructivism to argue that it is consistent with any student construction being acceptable, that constructivism means "anything goes" in terms of student learning, and that therefore it is discovery learning re-visited. This is demonstrably erroneous on a number of grounds.

In summary, constructivism asserts that individuals construct their own understandings of experiences and that these individual understandings are strongly influenced by what the individual already knows and believes. This influence of existing ideas (knowledge *and* beliefs) is strong because the creation of meaning comes from linking the new with the existing. (Many much more substantial descriptions of constructivist science learning exist, e.g., several chapters in Fensham, 1988; White, 1988). The teaching implications of this are quite the opposite of "anything goes." Much more stringent demands are placed on the teacher, because the strong focus of constructivism on the learner and learning provides approaches to teaching that are not otherwise evident. That is, teaching from a constructivist perspective is student-centered *and* strongly teacher controlled.

Teacher controlled means teacher direction of learning; it does not mean didactic teaching. Therefore, there are much greater demands on teachers. As an example, consider the issue of linking via a context where a teacher wants to use a demonstration to teach (or, better, have students learn) a particular concept. A number of factors influence the nature of the links students make and, therefore, the understanding they construct for the concept. These include existing student ideas, which of these ideas the student selects for linking, and on what the student focuses during the demonstration. Rather than just showing the demonstration and assuming it will be the defacto teacher, the teacher has a plethora of possible teaching strategies to use to focus on existing ideas, linking, and the salient features of the demonstration, for example, predict-observe-explain, interpretive discussion, concept maps, and creative writing. (These and many other teaching strategies drawing from constructivist learning are described in, e.g., Baird & Northfield, 1992; Grant et al., 1990; White & Gunstone, 1992.) The focus on learning provides new, demanding, and highly effective roles for the teacher. This is a far cry from the extreme form of discovery learning described above. It can be crudely characterized, and contrasted with, discovery learning, as spending less time interacting with apparatus and more time interacting with ideas.

Rethinking "Conceptual Change"

This, the second of the issues arising from constructivist research in science education, has its origins in the nature of the constructed meanings students bring to science classes. As has been widely reported, these meanings are often at odds with the tenets of science. A few examples of commonly found student "alternative conceptions" are that a force is required to maintain motion, human beings are not animals, and that the space between gas molecules is occupied by a continuous form of the gas. Among the large number of reviews of alternative conceptions are Driver et al. (1985), McDermott (1984), Osborne and Freyberg (1985).

The variety and extent of personal constructions at odds with science concepts that are held by students (including university students) has led to the frequent discussion in the literature of "conceptual change." This term is intended to imply a teaching/learning focus toward having students somehow stop using a conception such as, for example, a force is needed to maintain motion, and accept instead a Newtonian perspective on force and motion. The use of the term "conceptual change" in the past has been used frequently in the sense of conceptual "replacement," that is, to mean abandoning one belief and accepting and using the alternative being advanced by the teacher. This is a somewhat simplistic and unreasonable view. Consider, by way of illustration of the important point here, a student holding the rather Aristotelian view of force-needed-to-maintain-motion described above. The origins of this view are very likely the obvious; it is a conception that is consistent with all commonplace, out-of-school experiences. To consider that somehow we should have the student "unlearn" this conception is unreasonable. Both the student and physicists will have experiences for which the Aristotelian view will have utilitarian value. What we, as teachers, can more reasonably seek is to have the student understand the Newtonian perspective, understand the value and use of this physics perspective, and be able to determine the contexts in which it is appropriate to use the Newtonian perspective. In other words, we should not be seeking a direct replacement of the Aristotelian conception by the Newtonian conception. We should pedagogically seek to have the addition of the Newtonian perspective and the restructuring of the Aristotelian, in the sense of the conception being understood in the Newtonian framework,with the student able to make informed decisions about which conception is of more value in a given context. In general then, conceptual change is better seen as conceptual addition and restructuring.

This view of conceptual change may also have important links with two other schools of thought on learning for understanding, but to date, insufficient analysis of this has been undertaken. These schools are Marton's phenomenological group at the University of Gothenburg with a focus on links between the multiple conceptions held by an individual (e.g., Renström et al., 1990), and the situated cognition/cognitive apprenticeship movement emerging in U.S.A. (e.g., Brown et al., 1989). This latter school has potential links with the notion of selected appropriate contexts for particular conceptions advanced above.

A more substantial discussion of this view of conceptual change as addition and restructuring is in Fensham and Gunstone (1993).

Attempts to teach for conceptual change, both in the sense of conceptual change described here and in the sense of earlier notions of conceptual replacement, have revealed two more issues of fundamental importance to a constructivist perspective. One is metacognition, which is considered in a later section. The other is the importance of affect in cognitive learning.

That the cognitive learning affect, in various manifestations such as motivation and attitude to science, has an impact on learning is clearly not a novel thought. However our attention has been re-focused on this issue by the reactions of some students in classrooms in which teachers have adopted a constructivist perspective in their teaching and assessment. Some students embrace the greater cognitive demands wholeheartedly, while a small number in most classrooms are resentful of these greater demands. This latter group rarely shows any cognitive benefit. Our understandings of the relationships between affect and cognitive learning, and of ways of helping students with negative affect towards constructivist approaches, are still poor. The only clear statement that can be made is that the Posner et al. (1982) construct of fruitfulness of new ideas being accepted by students is most important, and that, to many students, assessment is a significant aspect of fruitfulness.

Beyond this we, as yet, know little, although an attempt to explore the relationship between cognition and affect has given rise to conjecture with potential (Baird et al., 1990). In simple terms, we know much about making learners more able to learn with understanding but little about making them willing and able.

The issue of affect is sometimes even more powerful in a teacher education context. My experiences with seeking conceptual change in science conceptions with teacher education students who are holders of science degrees (e.g., Gunstone, 1990, with concepts in D.C. electricity) suggest that affective issues make conceptual change either easier or harder. With some student teachers it is easier than with school students because of their high motivation arising from the student teachers' recognition that they will subsequently have to help others learn the same concepts with which they are grappling. With other student teachers affect makes the achievement of conceptual change harder. This has three sources: alternative conceptions can be held very strongly, particularly by student teachers who see their science degrees as a certification of the appropriateness of their specific conceptual understanding; sometimes content such as DC electricity can be seen, in general terms, as beneath their serious consideration as learners and therefore it not being appropriate to invest effort in; previous learning experiences can have resulted in student teachers forming the belief that they cannot understand the concept (this is more common with physics concepts).

Personal Constructing of Teaching and Learning—The Central Role of Metacognition

In the preceding brief description of constructivism and conceptual change I have referred to student alternative conceptions in the context of science-related phenomena. These content-related alternative conceptions are central to an understanding of the nature of learning outcomes in our science classrooms. So also are the ideas and beliefs held by students about learning, teaching, and the nature of appropriate roles for learners and teachers in classrooms. These ideas and beliefs about learning/teaching/roles are of the same general origin and status as science-related ideas and beliefs. That is, they are personal constructions about learning/teaching/roles that arise from previous experiences and that have a fundamentally determining effect on learning. This effect is seen in the ways in which students link (or do not link) the new with what is already known and believed, on the ways students approach tasks given by the teacher, on the ways students accept (or reject) the validity of the pedagogies used by the teacher, and so forth. I illustrate this with two classes of examples, one class in which the nature of these student conceptions of learning/teaching/roles assists their learning and another where the conceptions inhibit or even prevent learning.

First, the negative examples. There are many of these, and they are often all too familiar to science teachers. Tasker (1981) first revealed some of these ideas and beliefs more than a decade ago, although we were slow to see the importance of his work. He showed that students did not attempt to link what was learned in one lesson with what was learned in another (revealing a view of learning at odds with what teachers want), and students did not see any value in knowing the purposes for doing particular laboratory experiments. Indeed, the students Tasker interviewed simply did not know the purposes of the experiments they undertook. De Jong and Gunstone (1988) found a number of Grade 11 physics students who believed that the ability to understand physics was solely dependent on possessing a good memory and high intelligence. This group of students also believed that they possessed neither of these. Hence their views of learning, in this physics context, led them to "know" that they could not learn this subject. Anecdotal examples of student ideas and beliefs about learning/teaching/roles that have negative effects on students' science learning are legion, e.g. "you [the teacher] are getting us to have a discussion because you can't be bothered teaching," and "all this thinking is getting in the way of our work."

Examples of positive effect on learning of student views are, sadly, much less common. The examples are from the latest report of the Project for Enhancing Effective Learning, or PEEL (Baird & Northfield, 1992). The examples have not arisen accidentally. PEEL focuses on having students understand their own learning so as to be able to control that learning. In science classes in particular PEEL teachers have worked from explicit constructivist perspectives.

> *I had to think a lot about whether, when the force was downwards, was the speed increasing or decreasing and vice versa. I ended up getting myself a little confused but I think I've worked it out now. I have to redo the work I did in class tonight because my prior views were not right. Because they were wrong this means I learned something.*
>
> (p.85) (A student writing about a science lesson involving the dynamics of a mass when oscillating vertically on a spring)

> *Ward's view was correct . . . I had to think a lot longer and a lot harder in this lesson because I was confused and I had to try to understand why my view was wrong.*
>
> (p.86) (Another student writing about a science lesson in which the culmination of an on-going debate about forces on a book on a table occurred.)

> *If we can't talk how can we learn? All he does is to give us notes and expects us to understand it.*
>
> (A group of students talking about a new teacher who used very traditional methods.)

Students' ideas and beliefs about learning, teaching, and appropriate roles for learners and teachers can be described as students' metacognitive ideas and beliefs. More specifically, I use the term metacognition to refer to a person's *knowledge* about learning (the nature of learning, their own learning characteristics, effective learning strategies); their *awareness* of the nature and purpose of current learning and their progress towards learning goals; and their *control* over their own approaches, progress, and outcomes. This description of metacognition implies that an educational focus on metacognition should be toward making learners more metacognitively aware.

There are strong metacognitive undercurrents in the early sections of this paper. In contrasting constructivism with discovery learning I referred to the central issue of linking and the consequent implications for the teacher. I also referred to learners and the need for them to be aware of existing ideas, make appropriate selections from these ideas for linking with new concepts, and be able to focus on salient aspects of experiences. This could have been phrased as "the learner undertaking appropriately informed metacognitive behavior." Metacognition is even more central in the discussion of conceptual change. There I referred to learners making informed decisions about which conception is most appropriate for a given context.

Metacognition, in this sense of knowledge, awareness and control, is a central issue in teacher education. In both pre- and in-service contexts it is common for student teachers/teachers to hold ideas and beliefs about learning/teaching/roles that prevent them from understanding the pedagogical messages of constructivism. I return to this in the final, section of the paper, which considers aspects of the nature of appropriate teacher education. It is central to my teacher education arguments that constructivist views of learning lead logically to the importance of metacognition. If we embrace the idea of learning as personal construction for science-related phenomena and concepts, we also embrace the nature and importance of personally constructed ideas and beliefs about learning, teaching and roles.

Constructivism—Metacognition and Teacher Education

This paper's title is a rhetorical question: Can we prepare teachers to teach in the way that students learn? Below I support the simple answer "yes" to this question by first considering pre-service teacher education, then, briefly, in-service teacher education, and finally by summarizing some common features shared by the pre- and in-service arguments. In the previous sections of this paper I have broadly sketched my views of "how students learn" and how therefore "teachers should teach." I concentrate in this section on the messages these views have for student education. That is, I consider aspects only of teacher education, although it is appropriate for these aspects to be pervasive in teacher education programs.

Pre-service Teacher Education

My focus is on the pre-service teacher education program for intending high school science teachers at Monash University, as arguments and data have previously been presented to show that this program has some success in preparing teachers to teach the way students learn (e.g., Gunstone & Northfield, 1992; Gunstone et al., 1993). At the heart of the constructivist-metacognitive messages for teacher education is the need for student teachers to recognize their existing ideas and beliefs (in science content and in learning/teaching/roles), to have an informed basis for personally evaluating the appropriateness of these ideas and beliefs, and so then to be able to decide whether or not to embrace new conceptions and consequently reconstruct old. There is substantial evidence of beginning student teachers having conceptions in science and teaching/learning which are quite inconsistent with constructivism-metacognition (e.g., Gunstone & Northfield, 1992; Gunstone et al., 1993, and references given in these papers).

Put another way, for teachers to teach in the way students learn requires that the teachers understand the science they are to teach, understand how students learn, and have a wide repertoire of pedagogical strategies from which they can select on the basis of judgment informed by their content understanding, pedagogical content understanding (Shulman, 1987), and understanding of student learning. This includes student teachers being more metacognitively informed and, hence, being explicitly aware of their own conceptual changes. From this position, and through practice, a number of statements about the nature of appropriate teacher education have been made previously. They are reproduced here:

1. Learners have a dual agenda in teacher education programs—learning the content being taught, and learning about pedagogy by example. Put another way, all teachers in teacher education programs are models. This modeling must be positive, and student teachers should be metacognitively informed in their learning from this modeling. This requires, *inter alia*, teachers discussing their pedagogies with student teachers and linking these with their pedagogical purposes, and, whenever appropriate, teachers using the pedagogies argued to be important for student teachers to embrace.

2. Student teachers need ideas (from broad philosophies to specific new teaching/learning strategies) about teaching/learning/roles to have an informed basis for the evaluation and possible reconstruction of existing ideas and beliefs.

These new ideas must be advanced in ways that show that the teachers value the ideas.

3. Conditions that encourage intellectual risk-taking by student teachers must be provided. Trust and support are needed when student teachers are trying to acknowledge and restructure existing views, and trying to understand and evaluate new views. This risk-taking is needed both during the university-based component of the program and during periods of teaching practice. One dimension of the origins of the risk-taking is that often experience precedes understanding when learning to teach.

4. A genuine understanding of the content the student teacher will teach is a necessary component of a student teacher's ability to conceptualize and implement alternative pedagogies. Thus, an understanding is needed by teacher educators of the conceptual areas of the content student teachers will teach for which student teachers hold alternative conceptions, and of the detail of these alternative conceptions. This allows the teacher to use contexts that involve real conceptual learning for the student teachers as vehicles for the exploration of pedagogies.

5. Discipline content, as discussed in (4), is a significant context for change of ideas and beliefs about teaching/learning/roles. That is, some content is more appropriate for effecting conceptual change about pedagogies.

6. The teacher (of pupils or student teachers) is central to conceptual change. Put another way, a necessary consequence of our embracing of constructivist perspectives on learning is that we must accept that our ideas cannot be handed directly to others; people must construct their own understandings of these ideas, whether they are our student teachers or other teacher educators.

7. Many of the above issues require, as a minimum condition, a genuinely collegial approach. This is not only collegiality between teachers, but between teachers and student teachers, and the student teachers themselves. In addition, the collegiality provides safeguards against the perception that seeing learning as the learner's responsibility is to believe that all learning is relativistic and that any outcomes are acceptable.

From both of these collegial issues, the positive importance and safeguard against perceived relativism, it is also clear that a single teacher in a teacher education program will find it difficult to adopt our philosophies. Alone, with other teachers embracing different philosophies, that teacher runs the risk of being dismissed by student teachers (Gunstone & Northfield, 1992).

In-Service Education

Below are three in-service contexts in which teachers have come to teach in the way students learn. The three differ in terms of the "starting point" of the teachers concerned. In the first, all have been willing volunteers motivated by an informed acceptance of constructivism; in the second, all have been volunteers motivated by less informed concerns about the quality of learning of their students; and in the third, participants initially had little or no such concerns.

Context 1—The Monash Children's Science Group

This is a network of teachers, drawn from a variety of schools, that began in 1985. A detailed description of the group and its origins is contained in Gunstone and Northfield (1988). The essential concern of the group is to understand the science classroom implications of constructivism—teaching, assessment, curriculum—and to find ways to influence other teachers. The group and its agenda are in the hands of the school teachers. Participating university staff respond but do not initiate. Outcomes from the group include a range of alternative approaches to teaching and assessing a variety of science concepts (with some of these being written for the use of others) and the provision by its members of in-service programs for others (with materials for use in in-service currently in preparation). Its most obviously important characteristics are teachers owning the group, the genuine collaboration among all members, and the time dimension inherent to such a long on-going activity.

Context 2—PEEL (the Project for Enhancing Effective Learning)

This involves groups of teachers within one school, and a number of schools, and extends across the school curriculum. Its prime motivation has been to generate more informed metacognitive behavior. To pursue this goal, teachers have explored a wide variety of alternative teaching strategies derived from considerations of how students learn. The project and its consequences are the subject of two books (Baird & Mitchell, 1986; Baird & Northfield, 1992). The quotations from students in an earlier section of this paper are one indication of the project's impact. Although university staff have been involved, the teachers have directed the detailed approaches. As in Context 1, university staff have responded, not initiated. Again, as for Context 1, the project has been a highly collegial exercise with much of its progress coming from teachers in a school discussing with colleagues teaching and learning and the outcomes of alternative pedagogies. The two books referred to above are rich with insights about classrooms and change.

Context 3—PASMEP (Philippines-Australia Science and Mathematics Education Project)

In 1990, 34 selected Filipino physics teachers undertook a 10-month in-service program at Monash University. This program is described in Fensham and Gunstone (1993). In essence it aimed to enhance the understanding of participants of physics, of learning, of consequent teaching, and of in-service education. The participants became providers of whole-country physics teacher in-service programs in the Philippines after they completed this program. Obviously, a 10-month full-time in-service program is unusual. However, it did illustrate many important points. Our approach was very much in line with the seven points listed for pre-service above. Of particular relevance to the thrust of this paper is the time required for conceptual change in thinking about learning and teaching. This took a number of months and was achieved only after much anguish. Utterly crucial to the change was teaching the participants physics in ways absolutely consistent with the approaches we later argued the participants should use to teach physics. The early part of the program focused almost exclusively on their learning of physics and parallel reflections on our teaching. This was a difficult time for them as they struggled with our refusal to be didactic (and, at this stage, their quite widespread feeling that we were therefore inadequate teachers). Individual turning points came largely with the realization of the development of their own physics understanding as being a function of our pedagogies. This, deliberately, gave them a significant insight into a major dimension of any new teaching strategy—the learner's perspective and the demands made on the learner by the strategy. This is an undeniably important component of any teacher's understanding. These experiences also helped develop the genuine collegiality necessary to any translation into the Filipino context. Most participants came first to value for themselves the constructivist-metacognitive learning/teacher approaches and perspectives we were using. Then the participants came to own the approaches and perspectives, and thus became able to modify them for appropriate use at home. This they had to do, as we could not seriously understand teaching classes of 60 without equipment. More importantly, they had to accept that translation and modification was their task, that we could help with what they initiated but could not initiate ourselves. The collegiality in the group was central.

Some Common Features of These Teacher Education Examples

In outline, the significant common features, which I argue to be appropriate for any teacher education program seeking to teach in ways that student learn, are as follows:

- An explicit understanding by participants and their teachers of the nature of relevant ideas and beliefs they bring to the program
- Time, both to come to recognize existing ideas and belief and to evaluate these
- Knowledge of alternative perspectives on teaching and learning, with this knowledge being introduced in ways consistent with the new perspectives
- Time to consider and explore and reflect on these alternatives and their implications for classrooms ("... practice precedes understanding; most of the change process occurs after teachers try new approaches, not before." Baird & Northfield, 1992, p.193)
- An understanding of science and learning such that the consideration, exploration, and reflection is informed

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Assessment and Feedback in Science Education

Paul Black

Assessment, Testing and Examinations

The ideal this paper attempts to illuminate is illustrated by the following quotation, taken from a report to the U.K. government in 1988 by a group established to advise on national policy for assessment and testing:

> *Promoting children's learning is a principal aim of schools. Assessment lies at the heart of this process. It can provide a framework in which educational objectives may be set, and pupils progress charted and expressed. It can yield a basis for planning the next educational steps in response to children's needs. By facilitating dialogue between teachers, it can enhance professional skills and help the school as a whole to strengthen learning across the curriculum and throughout its age range.*
>
> (D.E.S., 1988)

This can be compared with the next quotation, which is from an account of the operation of the examination system in a developing country, written by a visitor who spent several months there studying the system:

> *The effect of the examination on the primary schools is by common consent disastrous. In the words of a primary head teacher who had recently returned from teaching in another country, "It hinders true development and deprives the children of both understanding and enjoyment." Or, as a secondary head put it, "Five years of cramming stifles the eagerness to find out . . . when boys come here they are no longer interested in work." In order to cover the curriculum teachers press ahead whether or not the children have acquired a skill or understood a concept. "We have to drive on even if the children haven't grasped what is being taught" lamented another primary head. The effects on the secondary schools are no less deleterious.*
>
> (Dockrell, 1991)

It must be immediately stated that the ideal set forth in the first quotation was accepted in principle in the U.K., but in practice, assessment and testing policy has developed in the direction indicated by the second quotation. The two extracts are not meant to set up a contrast between developing and so-called developed countries. They serve rather to highlight a tension between two functions of assessment and testing, the internal-formative and the external-summative. The resolution of this tension has profound effects on the quality of teaching and learning in classrooms throughout the world. This takes for granted that the effect of external examinations on learning is all powerful and, as presented by Dockrell above, can be injurious.

This paper first concentrates on the summative assessment in public certificate examinations to show examples of improvement. Then some examples of test items are presented to illustrate some of the problems involved in making valid and reliable assessments, which limit what any external summative examinations can do. This leads to addressing, more directly, some issues about learning that ought to be influencing assessment strategy. Such considerations have implications for formative assessment, which will be discussed in the next section. Finally, two types of conclusions are presented. The first emphasizes that we need new initiatives, both in research and development and in the influencing of public and political opinion. The second is to consider what this thinking might have to contribute to policy in developing countries.

Better Summative Assessment

External certificate tests have to work under tight constraints, and their harsh reality leads inevitably to limitations on teaching that are so familiar in public certificate examinations in most countries of the world. There are several points to be argued here. Two examples of public examinations that show what can be achieved are discussed here. The first is the examination in physics in the U.K. set up for the Nuffield Advanced Physics course. This is an examination taken after 2 years of specialist study by 18-year-old pupils, most of whom will proceed to tertiary education, entrance to which will be decided on the results of Advanced Level examinations, usually in three subjects (Dobson, 1985; Black, 1993b).

The examination is in six parts. The weightings of these are shown in Table 1.

Table 1. Nuffield Advanced Physics—Paper Weightings

Examination Part	1	2	3	4	5	6
Marks	60	60	60	45	30	30
% Weight	21	21	21	16	10.5	10.5

The first four of the six components are timed tests, externally set and marked. Paper 1 comprises 40 multiple choice questions to be attempted in 1.5 hours. In Paper 2, pupils have 1.5 hours in which to do seven or eight short questions. These are problem-solving types of question. They are "structured" to lead the candidate through a problem, often getting more difficult towards the end. They can be searching tests of understanding, analysis, and the ability to make calculations with accuracy.

In paper 3, the questions are usually strongly related to applications of physics in technology or everyday life, but research physics may also appear. Recent topics have included: how buildings are protected against earthquakes, using microwaves in radar and in cooking, drag coefficients in car design, accelerating particles in the CERN system, optical fibre transmission, why a gust of air can knock a person down, light bulbs, batteries, and how helicopters work. The paper, which takes 2.25 hours, has questions in three main sections. In the first , the "comprehension paper," candidates read about a new topic, with questions that require them to understand and apply their knowledge and skills in physics to, say, check the meaning or accuracy of the statements made. The second section is a "data analysis" question that tests candidates' ability to select and use the appropriate data from an unstructured data set. The data may be numerical, graphical or diagrammatic—preferably, all three. In the third section, candidates choose three from a set of five short paragraphs that outline an effect, a device, or a phenomenon; candidates must give a short analysis or set of comments relating these to the underlying physics. Any sensible answer based on the physics of the situation will be rewarded—some paragraphs are very open ended, others focus quite closely on a simple effect.

In Paper 4, "Practical Problems," pupils have 1.5 hours in which to attempt eight short "questions with apparatus." The aim is not to test the ability to design an experiment, or to take very precise and accurate readings. Sometimes the observations to be made are very simple, for example, tearing a sheet of paper in two different directions. Others require a set of readings from electric meters, stop watches or cathode ray oscilloscopes. But all will require the candidates to think about the significance of the observations, in the context of a problem, and where they can see, handle, and change the physical effects involved.

The other two components are based on assessments by teachers made during coursework in their classes. Both papers 5 and 6 require students to think, plan, test, check, reflect, and review. They choose their own resources and areas of interest. They can make mistakes, change their minds, and try again. This takes time, and cannot be done with a timed test in an ex-

Table 2. The Six Category Scheme of A.P.U. Science

1. Use of graphical and symbolic representations	Reading from graphs, tables, charts; representing as graphs, tables, charts
2. Use of apparatus and measuring instruments	Using instruments, estimating, following instructions
3. Observation	Making and interpreting
4. Interpretation and application	Interpreting presented information; applying science concepts from biology, chemistry, physics
5. Planning investigations	planning parts of investigations; planning entire investigations
6. Performing investigations	Performing entire investigations

amination hall. The aim is to encourage original thinking, and the ability to make and carry out plans. Practical skills are important in Paper 5, which is entitled "Practical Investigation." Candidates spend about 2 weeks of school physics time in performing an extended investigation into a topic of their own choice. They write a "diary style" account of their work and conclusions. For paper 6,"Research and Analysis," candidates spend about 2 weeks in reading and collecting information about a problematic topic or issue of their own choice.

For both of these papers, the pupils work is graded by their teacher using criteria supplied by the Board. Each school has to send five graded samples to the Board so that standards of grading can be checked. If discrepancies are found, further samples may be called for and grades may be adjusted.

This collection of instruments was planned with three principles in mind. The first was to reflect and so reinforce the aims of the course, which stressed making students active and thoughtful learners. The second was to employ a variety of methods so that the particular difficulty that a few students are always bound to have with any one method could be compensated by evidence of strength in another type of work. The third was to involve teachers in sharing responsibility for the judgment of their pupils through pupils' classroom work. A fuller account of this examination, and of systems at this level in 10 other countries, can be found in a UNESCO publication (Black, 1993b).

Tamir and Frankl (1991) published an account of a public certificate examination in Israel that was also designed to break with tradition in an attempt to produce a test system that would genuinely reflect and encourage a new approach to teaching and learning. Such examples deserve wide publicity, for many who feel constrained by present systems might be helped by encouragement and examples to be more ambitious to innovate and escape some of the constraints.

Examples of Assessment Items and Lessons They Teach Us

However hard we try to improve external examinations, and a great deal can be achieved in this direction, we must recognize that these examinations will always have severe limitations. This view is illustrated and supported by examples drawn from the national surveys of pupils performance conducted in the U.K. by the National Assessment of Performance

Unit (A.P.U.; see Russell et al., 1988; Schofield et al., 1988; Archenhold et al., 1988; Johnson, 1988; Black, 1990). The science monitoring was based on constructing assessments and reporting the results in the six categories shown in Table 2. The quality of the work depended on the appropriateness of this scheme. Seen in general terms, there was nothing unique or surprising about it. Those interested in the process approach had produced similar schemes over the years. However, this version has particular properties. The first was that its detailed specifications were refined during several years of work, during which each aspect had to be clearly expressed through assessment items and their mark schemes. Furthermore, those items and their mark schemes had to be tried with pupils whose responses were analyzed to determine whether they actually yielded evidence concerning the particular aspects of performance for which the questions had been designed. The second property followed from the first—each component of the scheme had been operationalized in terms of questions that evoked responses from pupils relevant to the aim expressed by that component.

This last feature was not a trivial one. For some of the aims reflected in the above scheme, an attempt was made in the early stages of the project, to collect from schools the assessment items they were using in their teaching. This was done to give the teams a start with questions based on good practice. It was found in several areas that although many schools said that they valued and paid attention to the aim (say) of Observation, they could not produce any assessment items that expressed and helped to reinforce this teaching aim. When the teams came to invent the items themselves, it soon became clear that questions were peculiarly difficult to set and mark. Thus, it also became clear why suitable items did not exist in schools. Therefore, for this aim, as for some others, the A.P.U. work was to give the aim an effective operational basis for the first time.

This feature raises a larger issue about the scheme. By focusing attention on areas of innovation and by subsequently giving them expression through published examples, the teams helped to develop and define these new areas. Thus the monitoring became prescriptive, and it could be said that A.P.U. science has been as much a curriculum development project as an assessment project.

Several of the significant lessons follow. The first, shown in Table 3, is one of a group of questions which required pupils to see and to express the pattern in tabulated data.

Table 3. Country Energy—A Question About Interpreting Presented Information

Country	% of population working in agriculture	Amount of energy used per person (units of energy per year)
Ceylon	50	0.8
Cuba	42	5.1
France	26	19.5
Italy	31	8.4
USA	12	66.0
W. Germany	23	26.8

LEGEND: Describe what the table shows about the way the percentage of people working in agriculture relates to the amount of energy used per person in a country.

Records are kept of the total amount of energy a country uses each year (from oil, coal, etc.). From this the average amount used by each person in that country can be worked out. This table shows the percentage of the population working in agriculture and the amount of energy used per person each year for six different countries.

The success rate of pupils on such questions showed wide variations among the questions. This particular question is more difficult than many similar ones, and comparisons indicate that it would be easier if the data had been presented in numerical order, and that the inverse relationship that the data displays is more difficult for pupils to describe than a direct relationship. Similar questions have been set displaying three columns of numerical data with a systematic relationship between only two of them—this variation can lower the success rate even further. If such questions are meant to help determine whether or not a student can see patterns in observations, which of the above possibilities best meets the criterion? This illustrates a general problem in criterion referenced assessment—the problem of ambiguity of interpretation of criteria—that faces those who have to construct and grade assessment instruments. However, it is clear that such statements cannot be made unambiguous without making them either unintelligible, or perhaps elaborate to the point that they could only be met by one particular question, which every pupil would then learn by heart.

The detailed and extensive evidence of A.P.U. Science both illustrates this problem and provides many of the data and examples required to tackle it. The answers given by pupils are relevant here. When the question above was set to 15 year olds, 49% were able to explain the correct relationship, although only 14% were able to do this in precise terms, that is, using explicit reference to "*percentage* of people" and to "energy *per person* ." However, this question was set in an open-ended form and any "result" is dependent on the grading criteria, which have to be fashioned to give valid categories for the range of ways in which pupils might respond. Analysis of responses from several hundred pupils on the above question showed that the following (real) examples were typical of the main types of response:

1. The less the percentage of people working in agriculture, the more energy will be used.
2. Ceylon uses the most amount of energy working in agriculture.
3. Because the people working in agriculture use more fuel than the average person.
4. The countries where a lot of people work in agriculture can make their own energy. In industrialized places they would have energy running into their homes off a main energy giver.

The first of these is a good answer—perfect except for the omission of "per person" after "energy." The second is a common response to questions of this type. The pupil selects an extreme value and states it. It is not possible to say whether such a pupil has misunderstood the demand, or is unable to meet it (although has a glimmering of the relationship through looking at extreme cases), or can perceive it but is unable to express it. The third and fourth answers represent another very common type of response: the pupil attempts an explanation, because the demand of the question is not understood, or because the pupil's experience has always been that science questions demand explanations, or because the pupil has to think in terms of her or his model of the particular context and cannot abstract the "pattern" aspect from this context. The third response proposes an explanation that does not fit the data, but the fourth is a valid and ingenious attempt; it is ironic that this able pupil must be recorded as failed in company with the third. The general problem that undermines the validity of external tests more seriously than many recognize is that the student is trying to respond to somebody else's question, when she or he may not understand the purpose, the context, or even the language of this unknown questioner.

The example illustrates another value of the survey results of this type: they enable one to anticipate the range of responses and to shorten the process of producing comprehensive grading schemes; they can indicate fully the potential of the question to evoke pupil response; and, finally, they expose some of the difficulties with which pupils need help. In addition, the ways in which the success and character of responses change, as the nature of the questions about a particular skill or topic is altered, can give useful empirical evidence. Such evidence can help to identify those features that characterize progression in the particular aspect of pupil performance which the questions reflect. The development of formative assessment, and

Table 4. Comparison of Results: Manner of Measurement for Sweets and Chemical

Measurement Stage-level	Description	% pupils Sweets	% pupils Chemical
1.	Timed until all dissolved; used clock accurately	26	54
2.	Timed accurately but failed to use an accurate end point of measurement	24	23
3.	Clock not used accurately ; end point judgement inaccurate	24	9
4	Qualitative judgement of end point	24	14
	No apparent judgement	2	-
	Number of pupils	257	248

of its related criterion statements, will require that criteria and practice are refined by empirical evidence in this way. Thus, sets of such results are a mine of information for both summative and formative assessment of the relevant criteria.

The next example covers a set of considerations arising from questions about measurement. Practical tests of specific measurement skills are increasingly common in both curriculum and assessment materials. A.P.U. Science developed many such items for its Category Two and has extensive results for them. However, pupils' ability to undertake measurement was also assessed in the context of Category Six, where students were required to devise and perform investigations in which there was usually ample opportunity to use measurement skills. It was found that many pupils who were able to use measuring instruments and procedures when required directly in the artificial and isolated contexts of a Category Two skill test did not deploy this ability in Category Six. Typically, a pupil asked to undertake an investigation and, provided with a equipment that included measuring instruments, would use a qualitative comparison even although she or he might have shown , in a different context, the ability to use the same instruments. This leads us to formulate a more comprehensive view of the ability to use measurement, which may be expressed under three main headings as follows:

1. *When to measure:* Pupils will only choose to deploy measurement methods to tackle their own problems if they have the idea that quantification is a powerful tool and that the scientific method is often powerful because it transforms problems into a quantifiable form.
2. *What to measure:* This requires a clear concept of the variable involved: "speed" or "rate of flow" often require a coordinated pair of measurements, which pupils will only perform correctly in their own investigations if they understand these concepts.
3. *How to measure:* This includes the ability to read accurately off a scale and to set up or adjust instruments. (Strang 1990)

Hitherto, a great deal of training and assessment has been devoted to only the third of these three, but although this one is a necessary condition for the first, it is not, on its own, of any great value. The A.P.U.

Table 5. "Paper Towel"—Comparison of Pupil Performance in Planning or Performing Investigations

Overall performance level	Description	% pupils (age 13 only) Prose (n= 501)	Pictorial (n = 398)	Practical (n = 824)
1.	An accurate quantitative measurement method	12	24	43
2.	A rather less accurate method but still capable of discriminating between the towels	3	8	5
3.	Either 1 or 2 but with no restriction on size of towel used	13	14	19
4.	Here, only a final measurement was made in those approaches where this is not sufficient	1	3	10
5.	Qualitative measurements only or no measurement either taken in the practical or mentioned in the written versions	71	51	23

(Data for age 15 pupils follow a similar pattern)

Science evidence suggests that unless more emphasis is given to the first and second aspects, students may be learning a skill that is useless because they have no experience in deciding when to apply it. The scheme of the three elements set out above is an example of "procedural knowledge," which we are now able to describe in several important areas and which is to be distinguished from "process skill." Such "procedural knowledge" must involve more than the sum of the relevant "process skills," for it must include the ability to deploy the skills in an effective articulation. Thus, the relationship is rather like that between strategies and tactics.

The third example is again from Category Six (Schofield et al., 1988). A pair of questions from this category were designed to be identical with respect to the structure of the tasks and the demands that they entailed. Both were about the factors that might influence rate of dissolving, but whereas the first (Sweets) was set as an everyday problem, expressed in everyday language and provided with kitchen equipment, the second (Chemical) was set as a science problem with scientific terms and laboratory equipment. Each was set to a different sample of about 250 pupils, the two samples being matched on those criteria that were known to affect performance. The performances of the two groups were then compared on a number of criteria. Table 4 shows the results for "Manner of Measurement," one of the several sets of criteria used. The pattern shown is typical of several results for this category of question: the average performances were better for the version set in a science context than for the everyday context (see also Song, J. and Black, P.J. 1991, 1992).

This is but one of many examples that show that the way in which the demand of a question is presented can affect response. Whereas this example was concerned with the effect of context, other features, such as the language used, whether the information is presented with pictures or with prose, or the layout of the question all affect success rates. Table 5 is another example of such effects. Another example of such effects shows the results for a Category Six question (Gott and Murphy 1987), which was presented to matched samples of pupils in three ways. In the first two, the pupils were asked to give their plan for the investigation, but in the first the equipment was listed in prose only, whereas in the second a picture was provided. In the third way, the actual equipment was given and pupils performed the experiment. Plans and performance were assessed by the same criteria. The results showed clear—and very large—differences among all three.

It follows that if we were to rely on paper and pencil methods to give evidence of pupils' abilities to perform investigations we would be seriously misled (see also Swatton, 1992). The differences between the first two types of presentation also illustrate another effect of the mode of presentation.

This same example also illustrates another feature of the investigation questions that were used. In the practical version, pupils were asked to find out which of three types of kitchen paper towel " . . . would hold the most water." They were provided with water, trays, funnels, beakers, measuring cylinders, and clocks. The responses were varied. Some made small cups by folding pieces of the paper into cones and observed the amount of water these would "hold." Others soaked pieces of the towels in water, squeezed them out, and hung them out, as if on a washing line, to dry, using the clock to measure how long they took to do so. Others followed the procedure intended by soaking pieces and then squeezing them out over a funnel so that the water could be collected in a measuring cylinder. Such variety of interpretation was very common. It illustrated that the conceptualization of the problem, the ideas that pupils formed about how the presented situation or phenomenon might work, and students' interpretations of the demand of the questioner had a strong influence on the outcome. It is not possible to consider such work as a test only of pupil's process skills—their conceptualization determines and makes sense of their process activities. This particular example also illustrates further the problems of measurements: the chief obstacle to making effective measurements in this task was pupils' ability to operationalize the dependent variable, not their ability to read scales on measuring instruments.

Other differences between pupils' responses to different ways of assessing the same ability showed that there are many pupils who appear to satisfy a given performance criterion on one item but not on another. Unfortunately, the observed variations in successful response rates among questions cannot all be explained. A special study undertaken by the A.P.U. Science teams attempted to explore the problems of assessing a profile of performance for individual pupils. In composing assessments for this study, an attempt was made to compose a set of four questions on "Planning of Investigations" that were on different topics, but that were as closely matched as possible in relation to all of the features that we knew to have irrelevant effects on performance. Here again the percentage of pupils in (say) the top level of performance were 57%, 57%, 55% and 34% on the four—a difference that could not be predicted or explained (see also Donnelly, 1987).

The final example concerns Category Three, which was designed to assess Observation. The process of refining our definitions of various aspects of Observation in the light of the problems of setting questions and of the nature of pupils' responses was more difficult and unrewarding in this category than in any other. At the heart of the problem is the conceptual basis on which observers select and see significance in the welter of sense data with which they are constantly assailed. The position is summarized at the end of the chapter on observation in the Review Report for the age 15 monitoring:

> *Thus while making and interpreting observations is included for testing in the A.P.U. science framework of scientific activity categories, it may well be that the appropriate place for its specific inclusion in taught science is a practical test closely related to the pupils' conceptual knowledge base.*
> (Archenhold et al., 1988)

One implication of this view is that the assessment of the ability to observe by isolated short exercises, devoid of any wider context to give them purpose, is invalid.

From all the A.P.U. Science evidence, of which the above examples represent a small fraction, I wish to draw several general lessons as follows :

1. A wide range of methods must be used. The narrow range used in such exercises as the I.E.A. and the U.S.A. National Assessment is unacceptable because it gives an unreliable picture of pupils' capabilities and because it fails to illuminate lessons about learning and about its assessment ,which are of central importance.

2. Short tests of pupils' performance, limited to only one or two questions for any one criterion, cannot give a reliable result, even for the average of a large group, let alone for one individual child. For example, the A.P.U. Science monitoring at Age 13 in 1984 used 35 packages including 465 different questions to obtain reliable results. To take all of the practical and written tests in this set would have involved a pupil in about 35 hours of work (Johnson 1988).

3. A teacher who can record a pupil's performance over time and in several contexts, and who can discuss idiosyncratic answers to understand the thinking that might lie behind them, can build up a record of far better reliability than any external test can achieve. However, to do this, teachers need help from substantial programs aimed to support teacher assessment with resources of questions, procedures and in-service training.

4. The lessons reviewed here should be of serious concern in any system where external tests are used to determine important decisions about a pupil's future. It is significant that in most public examination systems, including those in the U.K., not only have these problems not been solved, they have not even been clearly identified. The reason lies in the scale of resources that have been devoted to appraising such examinations. There have been very few systematic attempts to compare them with assessments that explore performance over a much wider range—types of question and assessment times—than public external examinations can allow. The expertise and intelligence built up in the A.P.U. Science research far exceeds that of those engaged in public examinations in science.

Formative and Summative Assessment

Assessment of pupils' learning is an essential feature of good learning and teaching. However, it seems that in general teachers know too little about their pupils' progress with the material they are supposed to learn. Evidence of this was found by the U.K advisory group mentioned above and was also found in a development work on graded assessment schemes discussed in a later section. Others have found similar evidence.

There have been attempts, within the newly developing national assessment system in the U.K., to lay much greater stress on the need for teachers to produce and report their own assessments of their pupils, to compare and perhaps combine with results of external national tests. This development has uncovered much confusion, among both primary and secondary teachers (Harlen & Qualter, 1991). Some, for example, have stopped teaching at set times to set pupils timed written tests under formal examination conditions. Others have interrupted their teaching to test children and have complained that such work was taking time away from teaching. Earlier research into teacher assessment has illustrated other facets of difficulty. A sample of 106 schools surveyed in England (Hodson, 1986; Hodson & Reid, 1988) ranked assessment results as number 20 in a list of 20 possible influences on their curriculum decisions. They also seemed to regard assessment failures as due to children's weaknesses and not as evidence of problems with their teaching, and they used multiple choice and short answer written tests as their only sources of evidence. A different study of two Australian teachers (Lorsbach et al., 1992) showed the link between their views on learning and the assessment strategies that they used. This work also exposed problems arising because pupils did not construe the meaning of an assessment task in the way that their teachers had intended—the students were often responding to a perception of demand that the teacher did not understand and had not intended to make.

Thus, the ideal behind the requirement, set out in the opening statement of this paper, seems to be unfamiliar and difficult to establish in schools. Two principles must be grasped here.

The first challenges the idea that the need to assess interferes with and so harms normal teaching and learning. How can either teacher or pupil proceed without checking that the learning is effective and understanding that immediate feedback is essential to correct misconceptions and omissions that can render a pupil incapable of proceeding in the later stages of the subject ? To teach without assessment feedback is to travel blind.

The second principle follows from the first. Assessment is not an extra to be attached to a piece of teaching like a barnacle to a ship's hull. It ought to be built in to the design of the teaching from the start. If such design has clear aims, then pupils learning work will naturally need to show how those aims are being grasped by students. The pupils' learning work thereby provides the formative assessment that is needed—there is no question of assessment being an "extra" (see A.S.E., 1990 for an excellent example of this approach).

One of the reasons why this model of assessment is not easily grasped, quite apart from the practical problems of putting it into action, is that the model of assessment and testing that many teachers have is that established by their experience of external examinations. Such examinations are bound to have a strong influence on everyday teaching, and this influence is often far from benign. However, just as the need for good formative assessment is undeniable, so too is the need for fair methods to provide certification for students when they leave school and to provide the public with information about the performance of schools as a whole. The problem that is often overlooked is that such information can only be fair to individuals, and useful to the public, if it is both valid and reliable.

It is difficult for external examinations to satisfy these conditions. This is because such examinations have to be short in time and are set in artificial and stressful circumstances. It has been established, for example, that written tests of this type cannot tell us about the abilities of students to use equipment or to carry out experimental investigations (Al Busaidi et al., 1992; Brown & Njabili, 1989; Brown et al., 1992; Lock, 1989, 1990). Other limitations of such tests have already been discussed. These limitations arise both in terms of validity, because of the artificial and restricted means available, and in terms of reliability, because such tests have to be so brief.

If performed with care, the information that teachers can assemble as part of formative assessment can escape many of these limitations. If a collection of such information could be used for the summative purposes of certification and reporting, then many difficulties might be overcome. The external examinations could be replaced by information of better quality, the collection of which would be a helpful part of learning, in place of the harmful backwash effects of terminal external tests. The status of teachers' own judgments would be raised, and the profession would be responsible toward its students.

However, there are many problems that stand in the way of such a target. Some would argue that a system designed to give information for one purpose—the formative—cannot be used for the different purposes of summative assessment (Harlen et al., 1992). At this point the argument has to be refined. Formative assessment has to be internal to the school. Summative assessment can be either internal or external or a combination of the two. If summative assessment is external, the invalidity and the undesirable backwash effects of such assessments will damage learning and inhibit efforts to improve formative assessment. If summative assessment is to be partly or wholly internal, the relationship between teachers' formative assessment and their collection and use of evidence for summative purposes will have to be developed with some care.

A more evident problem is that every teacher may have different standards, expectations, and interpretations of curriculum aims from all other teachers, so that the public cannot trust their judgments, even if strict honesty could be assumed. Means to ensure that teachers' judgments are honest and are calibrated to a common scale would therefore have to be rigorous and would be expensive. There would also be the expense of the extensive in-service training that teachers would need to develop the skills of formative assessment.

Better Learning Needs Better Assessment

The arguments to be presented here draw upon recent publications in the United States, where the practice of assessment is undergoing a rapid change. The use of short external standardized tests, almost always multiple choice tests, has been widespread for several decades, and the technical expertise in developing these has reached a far higher level than anywhere else in the world. However, many of the states are now abandoning them because it is evident that they have done almost nothing to improve education. Since 1989, 16 states have begun to develop and implement alternative forms of assessment in science, 20 in mathematics, and a review in spring of 1992 said that further new initiatives are developing rapidly (Blank & Dalkilic, 1992). The new interest is in tests of performance, which are closer to good classroom practice, which take longer to use, and in which teachers can be fully involved.

The nature of the concerns that underlie the changes can be illustrated by quoting from the most recent authoritative book on the subject, entitled *Changing Assessments: Alternative Views of Aptitude Achievement and Instruction* (Gifford & O'Connor, 1992). This is a collection of studies by 12 leading authorities in the U.S., produced under the aegis of their National Commission on Testing and Public Policy and published earlier this year.

Here, first of all, are three quotations from a closing summary by Professor Lorrie Shepard :

> *The most important contribution . . . is the insight that all learning involves thinking. It is incorrect to believe, according to old learning theory, that the basics can be taught by rote followed by thinking and reasoning. As documented by the Resnicks, even comprehension of simple texts requires a process of inferring and thinking about what the text means. Children who are drilled in number facts, algorithms, decoding skills or vocabulary lists without developing a basic conceptual model or seeing the meaning of what they are doing have a very difficult time retaining information (because all the bits are disconnected) and are unable to apply what they have memorized (because it makes no sense). . . . "[M]easurement-driven instruction" will lead reform in the wrong direction if tests embody incomplete or low-level learning goals. . . . Various efforts to reform assessment use terms such as "authentic" "direct" and "performance" assessment to convey the idea that assessments must capture real learning activities if they are to avoid distorting instruction.*
>
> (Shepard, 1992)

The article by Resnick and Resnick, to which Shepard refers, develops a critique of the multiple choice or very short answer tests which were until recently almost the only form of testing in U.S. schools:

> *Children who practice reading mainly in the form*

> *in which it appears in the tests—and there is good evidence that this is what happens in many classrooms—would have little exposure to the demands and reasoning possibilities of the thinking curriculum. Students who practiced mathematics in the form found in the standardized tests would never be exposed to the kind of mathematical thinking sought by all who are concerned with reforming mathematical education.*
>
> (Resnick & Resnick, 1992)

The article goes on to emphasize the inevitable effects on teaching of any tests designed for accountability purposes, and concludes :

> *Assessments must be so designed that when you do the natural thing—that is, prepare the students to perform well—they will exercise the kinds of abilities and develop the kinds of skills that are the real goals of educational reform.*
>
> (Resnick & Resnick, 1992)

The article then describes assessments that would have a positive effect on teaching. Of the three examples given, one is the teacher assessed project in a U.K public certificate examination in Engineering Science, and a second was a test of higher order thinking skills devised by NAEP (the U.S. National Assessment of Educational Progress), which drew heavily on A.P.U. science items discussed earlier in this paper. The authors conclude that :

> *If widely adopted as part of the public accountability assessment system, performance assessments (including portfolio assessments) could not only remove current pressures for teaching isolated collections of facts and skills but also provide a positive stimulus for introducing more extended thinking and reasoning activities in the curriculum.*
>
> (Resnick & Resnick, 1992)

Finally, another quotation from Shepard that could have been written as a commentary on the current position in many countries, and in particular the U.K., follows:

> *If they are unaware of new research findings about how children learn, policy makers are apt to rely on their own implicit theories which were most probably were shaped by the theories that were current when they themselves attended school. . . . Some things that psychologists can prove today even contradict the popular wisdom of several decades ago. Therefore, if policy makers proceed to implement outmoded theories or tests based on old theories, they might actually subvert their intended goal—of providing a rigorous and high quality education for all students.*
>
> (Shepard, 1992)

Developing Formative Assessment in Practice

The arguments and examples given so far can be used to build a strong case for new initiatives in assessment work. The first evident need is to develop and disseminate examples of good assessment practices that can be used as part of teaching that is consistent with the ideals of the thinking curriculum. Examples of efforts in this direction are to be found in the work in several states in the U.S. to develop authentic assessment practices, in the work of the A.P.U. and in several projects in the U.K. aimed at developing the use of open-ended experimental investigations in science classrooms (Fairbrother et al., 1992; Jones et al., 1992; Simon et al., 1992).

A further need is to explore systems in which regular assessment under the choice and control of teachers as the formative servant of learning can be used also for external certification and reporting. In the State of Queensland in Australia, teacher assessment is the only source used for certification—there are no external examinations (Butler & Bartlett, 1989). In the State of Victoria, assessment of loosely prescribed coursework forms the major component of certification results (McRae, 1992). In the U.K., teacher assessed coursework is a requirement in science, but only accounts for 20% of certification marks. Other national schemes are increasingly incorporating some element of teacher assessment (e.g., King & Braithwaite, 1991). In Sweden, external tests are used to calibrate the mean and distribution of performance scores of a school, but within this calibration it is up to the school to decide the results for individual pupils using their own internal evidence (Black, 1993b; Marklund, 1991).

In one U.K. project, the Graded Assessments in Science Project (GASP), students accumulate certificates throughout the 5 years of compulsory secondary schooling (Iredale 1990; Swain 1988, 1989, 1991). Each certificate represents success in a specified combination of easy, medium and hard assessments, which can be achieved within a very flexible set of requirements. Thus, content can be assessed by drawing on a large bank of items that cover many different curricular approaches, process skills can be assessed in a variety of contexts, and skill in explorations can likewise be covered in class work using the teachers' own selection from a range of task proposals. The requirements ensure a balance across the content, process, and exploration dimensions. The use of external banks of items and the need to work to external criteria and produce samples of pupils work to justify judgments help to ensure equality and fairness between schools and with the normal terminal external examination routes. It has been found that the routine of accumulating certificates strongly motivates pupils. The aim in the assessment designs at lower levels has been to achieve scores of 75% as a condition for a pass, and many experienced teachers have found it very hard work to adjust teaching and testing habits to achieve such a high rate of success. However, although this system was accepted some years ago for certification without any terminal examination at the school leaving age, this acceptance has recently been rescinded and an element of external terminal examination is now to be required, for reasons which have nothing to do with any evidence about the operation of this particular scheme.

The GASP scheme provides an "off-the-shelf" assessment scheme and many teachers would not like to accept its constraints. What is needed more generally are research and development programs to strengthen the practice and reputation of teachers' formative assessment so that it can play its full part both inside and outside the classroom. Such programs need not be ambitious attempts to change a whole system. They might well be modest work with and between teachers to improve their day-to-day practice.

I and my colleagues in King's College are working in this way with a group of teachers from local schools (Fairbrother et al., 1993). An assessment sheet of a type given to every pupil in a junior secondary class sets out the aims of the particular piece of work. The same aims are also set out in the formal language of the national curriculum. Pupil-friendly versions are given. The "comment-boxes" are for pupils to complete, expressing their opinions about success or difficulty with the aims. When this was first tried, only the most able pupils wrote anything at all in these boxes. The rows of five small squares in the top left hand corner of each comment-box were then introduced. Each pupil was required to color these— all five to express full confidence, one or none to express complete uncertainty or incomprehension. This new demand seemed to catalyze the production of far more comments by the less able pupils. The scheme was used for every topic, but it took a year of persistent work before all pupils came to be fluent in expressing their own assessment of their work.

Essential elements of programs to develop formative assessment should be:

1. Assessment should be built into the design of the curriculum (A.S.E. 1990); this design should stress assessment of skills and knowledge in the context of tasks for which the student can understand and share the purposes; these tasks and the purposes they serve should be contributors to the thinking curriculum, that is, should involve students both in deciding what to do, in thinking about how and why they are doing it, and in reflecting upon the successes and limitations of their work (Tobin et al., 1988).

2. It follows that pupils should understand and play a part in their own assessment, on a regular basis, as part of the development of their learning (Tamir, 1984; Lock & Wheatley 1990; Wheldall et al., 1992).

3. The recording and reporting of assessment results that teachers have to do should be limited, focusing on the specific aims of each particular learning exercise and only producing information of which they or others will make some direct use.

4. Teachers should be helped to take advantage of the many different sources of assessment information that are available in the classroom; formative assessment must not be based only on written exercises (Lidstone, 1991).

5. Criteria expressing curriculum aims must strike a balance between such vagueness that they cannot be interpreted, and such precision that they prescribe the teaching and are too numerous to handle (Simpson, 1990; Ratcliffe, 1992).

6. For reporting, teachers have to summarize or aggregate the detailed data that they need in formative use; clear rules for such aggregation need to be agreed.

7. Means by which teachers can exchange work and share experiences and standards with colleagues have a vital role to play both in ensuring uniformity of standards and fair practices, and in the mutual professional development of teachers.

Politics and Publicity

This is a formidable list, yet for much of it one can say that if we cannot meet the requirements, this lack shows up an enduring weakness of present practices. However, there are also other exigencies. In the last year in the U.K., assessment practices have, by the criteria and assumptions reflected in this paper, made significant negative progress (Black, 1993a). Similar phenomena are reported in Australian states (Braithwaite, 1992). The causes are the same. Superficially, politically conservative governments have reacted against what they see as woolly fashions in education and have moved to restore traditional practices. More fundamentally, they have been motivated to make such changes, and have been able to make them with public acquiescence, if not support, because of a widespread lack of public understanding in matters of assessment and testing.

Public external examinations are given a status and a public confidence that they do not deserve because they are seen to be "fair," and their serious deficiencies are not understood. The judgments of teachers are seen, on the other hand, to be untrustworthy. Because great damage to education can follow from actions fed by these assumptions, we all have a serious duty to try to challenge them, insofar as they are not justified, and to change the situation insofar as they are. That is to say, that better use of assessment to serve better learning now calls for a long process of public and political education about assessment matters.

Developing Countries

The following draws on the above to list briefly four lines of action:

1. Start modest work with the best teachers to improve formative assessment, and look to producing samples of their work, illustrated by their pupils' work, to inform and encourage more of their colleagues. The collection of good sample questions form other countries might be of value.

2. Try to make a modest change to the public examination to incorporate a small contribution of teacher assessment in the final result; this will raise many problems about reliability and trustworthiness, but a start should be made to

tackle these as a contribution to future development of teacher assessment.

3. Review external public certificate examinations and try to improve them by using a greater variety of methods and by trying to make their demands and pressures more valid, so that their influence in teaching is a positive one.

4. Try to improve information and understanding about the examinations and assessment system so that parents, the public and particularly politicians are better informed in future.

Different agencies can contribute to these changes. Some can only be achieved from inside a country. For others, the prestige given—often unwisely—to the judgment of outsiders may be a useful catalyst to produce change through the decisions of politicians.

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Student Assessment in Developing Countries

Pinchas Tamir

Introduction

The interrelationships and interactions among testing, learning and curriculum are complex. Although, in theory, the curriculum should determine the nature of testing, in practice the testing requirements often determine what teachers teach and what students learn.

As observed by Klinckman (1970), tests are "one of the most effective ways through which students come to understand what is expected of them and are motivated to move in the expected directions" (p. 433). Linn (1987) has observed that teachers teach to the test and students study to the test, hence, "innovations in the curriculum fail to persist unless they are reflected in similar innovations in testing" (p. 203).

One characteristic that strikes visitors to the United States is the existence of a huge testing enterprise that operates independently, with relatively little reference to the school curriculum. Most standardized tests have attempted to concentrate on skills and abilities that are not associated with particular instructional programs. No wonder that studies that rely on these kinds of tests reveal little impact of schooling compared with that of the home and general aptitude (Coleman et al., 1966). Having recognized the powerful impact of testing, the need to design a variety of tests has been gaining more and more attention among science educators in various countries (Black et al., 1987; Linn, 1987).

At the same time there has been increasing recognition of the importance of matching instruction to the prior knowledge of students and the understanding that learners respond to formal instruction in terms of their preexisting intuitive preconceptions. Thus, there is a growing need to provide teachers with tools that will help them in the diagnosis of their students' "entry position" regarding the learning of particular skills and concepts. Finally, there is growing disappointment about currently used standardized tests, either as measures of accountability or as indicators of progress in science education (Shavelson et al., 1990).

We review several recent trends and show, with concrete examples, how assessment can be used to enhance progress, facilitate innovations, and improve the effectiveness of schools, all of which are especially important for developing countries with limited resources. It is important to first define what students can learn in formal and informal science learning situations. Champagne and Hornig (1987) offer a useful outline that is presented in abbreviated form in Table 1.

Traditionally, testing has focused predominantly on the knowledge products with some attention given to finding out how well students act upon or apply information. The most commonly used tests have been paper-and-pencil multiple-choice items. Standardized tests, as well as many teacher-made tests, are norm referenced. This means that standards of achievement are not determined by the extent to which students have achieved mastery of the intended goals, but rather how well they achieve in comparison to their classmates, or, in the case of standardized tests, in relation to the national mean.

Criterion-Referenced Versus Norm-Referenced Testing

A criterion-referenced test is one that is deliberately constructed to yield measurements that are directly interpretable in terms of specified performance standards. Criterion-referenced tests are not designed to facilitate individual difference comparisons such as

Table 1. What Students Can Learn in Formal and Informal Science Learning Situations

About	
Knowledge Products of Scientific Inquiry	Facts, Concepts, Principles, Theory
Nature of the Scientific Enterprise	World view, Methods, Habits of thought, Approaches to problems
Values and Attitudes of:	Society, community, one's cultural group, one's family
Applications and Risks of Science and Technology	Social context, personal context
Science Careers	What scientists are, What they do, How they get educated, Interest in science, Capacity to do science
How To	
Act upon or apply information	Evaluate, Manipulate, Solve problems
Learn	Strategies to seek and acquire new kr vledge and skills
Produce Knowledge	Question, Test, Evaluate

the relative standing of an examinee in a norm group or population, nor are they designed to facilitate interpretations about an examinee's relative standing with respect to a hypothetical variable, such as reading ability. Rather they are specially constructed to support generalizations about an individual's performance relative to a specified domain of tasks. In the instructional context such a domain of tasks may be termed a "domain of instructionally relevant tasks" (Glaser & Nitko, 1971, p. 653)

As observed by Anderson (1981),

> *until recently most achievement tests have been based on a norm referenced perspective: that is, a pupil's achievement is rated high or low on the basis of how his or her performance compares to that of other pupils.*

However, since the introduction of the notion of mastery learning (Bloom, 1970), more and more educators have come to believe that criterion-referenced tests are most appropriate for most purposes of assessment in schools. As observed in Bloom (1970),

> *There is nothing sacred about the normal curve. It is the distribution most appropriate to chance and random activity. Education is a purposeful activity and we seek to have students learn what we have to teach. If we are effective in our instruction, the distribution of achievement should be very different from the normal curve.*

As long as we continue to use norm-referenced grading, the message to many students is that even if they invest more time and effort in their studies, they will not be rewarded, because their place in class has been already determined by their scholastic aptitude. This message is further supported by teacher expectations for normal distribution of grades and, as shown by several studies (e.g., Rosenthal & Jacobson, 1968), what a teacher expects of a student is closely related to the achievement of that student. It is interesting to note, however, that predictions of teachers regarding the level of achievement of their students on criterion-referenced tasks in a national survey were not accurate and revealed a wide range and lack of consistency (Black, Harlen, & Orgee, 1987).

The implications of the findings reported above regarding the undesirable effects of norm-referenced testing on student learning are obvious and should be considered along with those related to test format.

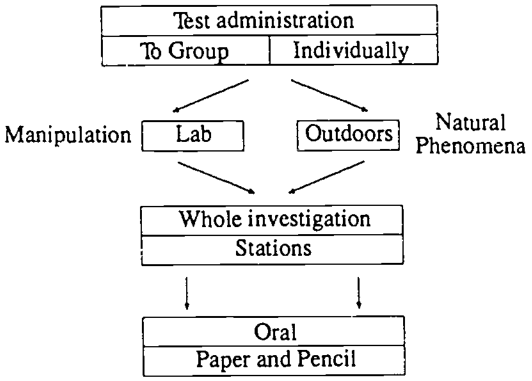
Authentic Valid Tests

In recent years one may observe an increased interest in tests that reflect what students are actually studying in school. Educators in the U.S. are discovering what their colleagues in many countries have known for years. namely, that as a rule testing should be an integral component of the school curriculum. Nowadays the value of varied and rich learning environments and the use of diversified instructional approaches is widely recognized. Because assessment should reflect learning, the use of a broad range of assessment tools is strongly recommended. A list of different types of tests is presented in Table 2.

The richness of assessment tools that are available is striking. Hopefully many of them will be used advantageously by many teachers.

Studying for the Test

There is another reason for using a variety of tests: It appears that many students study differently for different tests (Wandersee, 1988). Tamir and Wandersee (in press) found, for example, that typical students participating in their study considered multiple-choice tests to be easier because they provide identifiable answers and because recognition of the correct answer is much easier than producing it. Consequently, less time is devoted to studying; students concentrate on becoming familiar with facts, terms, or the gist of the material. On the other hand, because essays require students to formulate answers in their own words, students need to be able to retrieve rather than recognize important concepts. Hence, learning becomes much more serious and thorough: you have to know more details, understand the concepts well, and memorize supporting evidence. Although studying for multiple-choice items usually involves just reading through the material, several study strategies were associated with essay tests, such as: taking one idea at a time and mentally tracing its structure, arranging and organizing key information, jotting down phrases to sum up, writing a story containing the concepts, highlighting major topics, explaining things, and establishing cause-and-effect relationships. These appear to be operational characteristics of meaningful learning, expressed in the students' own words. It is interesting to note, however, that there is a minority of students who study harder and more meaningfully for multiple-choice tests. About half of the students either study in the



References: Tamir, 1974; Tamir et al., 1982

More Test Types

Long-term transfer
Cloze
Modified cloze
Game-like
Computer based
Cooperative
Open book
Take home

References: Ausubel, 1968; Friedler et al., 1992.

Figure 1.

Table 2. Types of Test Formation and Strategies

Self Assessment

Aspirations
Further Learning
Intentions
Career Choices

Affective References
Attitudes
Preferences
Interests
Curiosity

Cognitive
Knowledge Inventories
Opportunity to Learn
Inventories (OTL)
Microcomputers
Confidence Level

Using More Effective Multiple-Choice Items

Increasing the use of best answers, decreasing the use of correct answers
Ascertaining proper balance among low and high cognitive demands
Using items in which guessing is a useful problem-solving task
Constructing items with options collected from student answers to open questions
Requiring justifications to about 10% of the multiple-choice items
Allowing for explanation why a particular item has no unequivocal best answer
Avoiding tricky or "wise" items, such as double negatives, or more than one required answer
Designing tests in which multiple-choice items might account for 25%-35% of the total score

Understanding of Concept Relationships

Associations: e.g., "Write down the first 3 things that come to your mind in relation to transportation."
Concept maps: Analysis of prepared maps
Concept maps: Design on the basis of assumed concept affinity
Proposition Generating Tasks
Causal Reasoning test

Problem Solving

A situation taken from the history of science
Interpretation of a graph. Interpretation of data presented in a table
Interpretation of data presented in drawings
Interpretation of experimental results presented by drawings
Interpretation of data presented in a pedigree diagram
A test based on an analysis of a research report
A test based on an inquiry-oriented single topic film
A critical thinking test

Practical Tests: Laboratory and Outdoors

same way for both types of test, or, even though they study in different ways, give us no reason to consider one way superior to the other.

Communicating Test Results Meaningfully

Even though the use of a variety of items and test formats is important, without proper analysis of the outcomes and meaningful communication of these outcomes to teachers and students, the potential will not be realized. The nature of the problem with which we are dealing and its inherent complexity may be illustrated by the following citation:

> *The test user must recognize that measurement in education is extremely imprecise in comparison with the more common types of physical measurement. . . .He needs to know what kinds of uses of tests are appropriate for his purpose, what kinds are inappropriate and how to get maximum information from these measurements. To do this he needs to understand the meaning of the score itself and what it represents. . . . Clearly, meaning is essential, for without meaning the score itself is useless.*
>
> (Angoff, 1971, p. 508)

Traditionally, marks or scores have been used to communicate the level of achievement. Often only the total test scores are reported. This may be sufficient for assigning grades, but much of the diagnostic potential of the test is not realized. Anderson has observed that:

> *Reporting on an objective by objective basis helps to clarify the specific difficulties students are encountering. Teachers often find that test results are readily explained to parents on this basis. . . This sort of specific information is more helpful than broad generalities, e.g., your child is not doing as well in math as other fourth graders.*
>
> (1981, p. 145)

Different and, to a large extent, idiosyncratic reporting procedures have evolved in each country, some of which procedures are deeply rooted in local traditions. In several countries an attempt has been made to avoid the use of marks altogether and, instead, using descriptive narratives. Other devices, such as profiles or grade related criteria (Long, 1985), have also been tried. Our general impression, however, is that while the above mentioned procedures, and perhaps some others, may be incorporated into various systems, grades and marks will continue to play a major role in communicating information regarding student achievement.

External Examinations as a Means of Upgrading Learning

We have seen how learning may be influenced by assessment, especially emphasizing the interactions between learning and assessment. It appears that these interactions may operate quite intensely in developing countries where many students are culturally disadvantaged. In many of these countries external examinations, known as matriculation examinations, play significant roles in determining the opportunities of students for further learning and upward mobility.

The Israeli biology matriculation examination that has accompanied curriculum innovations for 25 years provides a unique example of how matriculation examinations may be used to upgrade learning. The use of external matriculation examinations has continually been one of the most debated and highly controversial issues. Most countries have been using matriculation examinations in spite of severe criticisms pointing at a number of negative effects these examinations have had on education, as well as on the society at large. Some countries, such as in several states in Australia and several provinces in Canada, have abolished external matriculation examinations altogether. Other countries, such as most states in the United States, have never had external matriculation examinations and have relied on general scholastic aptitude tests as a means for selecting and admitting high school pupils to institutions of higher education. Some of these states have recently been considering the institution of state-designed external examinations as a means of upgrading learning and educational achievement. Other countries, such as the province of Alberta in Canada, had abolished external matriculation examinations several years ago, but re-instituted them recently for the purpose of maintaining educational standards that appear to be declining without such examinations.

In Israel, curriculum reform in the sciences has been accompanied by substantial adaptations and modifications in the matriculation examinations. These adaptations and modifications resulted, in the case of biology, in the design of a highly innovative format that aims at maximizing the benefits and minimizing the potential drawbacks of external examinations. Before describing the format, let us briefly consider some of the major potential benefits and drawbacks of external matriculation examinations in general, as far as they relate to the curriculum, the pupils, the teachers and the society (see Table 3).

The Israeli Matriculation System

Until the mid-1970s, the matriculation examinations in Israel offered little flexibility. Pupils had to choose their special fields of study at the end of year 10, and each special field consisted of a predetermined package of subjects. For each subject only one examination was offered. In the mid-1970s, a much more flexible system was established. Each subject is now offered on two levels, designed by credit points ranging from 2 to 5 points. To be eligible for a matriculation certificate, a pupil has to accumulate at least 22 points. About one half of the number of points is covered by compulsory subjects (Hebrew, English, Maths, Bible), and the rest are electives. Accordingly, any pupil can build his own program, either taking fewer subjects at 4 or 5 points, or more subjects at 2 or 3 points. The system's flexibility is even greater, as it offers two additional options. Thus, any school can design a course on any topic of interest (e.g., anthropology, economics, etc.). Once the course has been approved by the Ministry of Education, the school designs an adequate matriculation examination and submits it for approval. A pupil may accumulate up to 4 (out of total 22) points by offering such school-based examinations. Another important option is open to pupils who achieve well (above B) in a particular subject. Such pupils may substitute the examination in that subject with an individual research project, usually under the supervision of a university professor. These pupils are evaluated through the report they submit as well as by an oral examination.

The major purpose of this section is to show that a centralistic educational system can be very flexible indeed. Moreover, it should be noted that only half of the final marks in any subject is determined by the examination mark, while the other half is contributed by the subject teachers based on their own criteria.

The Biology Matriculation Examination

The biology matriculation examination has been designed to match the objectives of the inquiry-oriented curriculum introduced into Israeli schools in the mid-1960s. It has evolved along with the implementation and continuous revisions of this curriculum and has made a substantial contribution to the institutionalization of the inquiry orientation in classrooms. Table 4 presents a description of the components of the examination and their relative weights at the present (year 1992).

In the laboratory test, pupils are presented with a novel problem (sometimes a novel situation that requires problem identification) and are required to formulate a relevant hypothesis; design an experiment to test the hypothesis; actually perform the experiment and collect the data; process the data and communicate the findings in an adequate manner (e.g., tables, graphs, drawings);draw conclusions; suggest explanations; and apply the knowledge gained to answer new questions. The examination is carried out as a group test. Normally, one examiner monitors up to 15 examinees. This examiner determines the mark for manipulation, which accounts for 10% of the total mark. The rest is

Table 3. Potential Benefits and Drawbacks of Matriculation Examinations

Potential Benefits	**Potential Drawbacks**
Curriculum	*Curriculum*
1. Ascertaining coverage of the intended curriculum	1. Discouraging school-based curriculum development
2. Maintaining standards of literacy in different subjects	2. Forcing specific and rigid subject-matter content
3. Communicating desired emphases of different educational aims	3. Decreasing in-depth learning in favor of superficial covering of material
4. Defining the knowledge and skills which may be expected from matriculants	4. Lowering the chances of unexamined objectives (*e.g.*, attitudes) to gain adequate place in the operational curriculum
	5. Serving as a means of curriculum evaluation
	6. Some tests are used as useful curriculum materials
Pupils	*Pupils*
1. Motivation and facilitating learning efforts	1. Forcing pupils to study topics of no interest to them
2. Ascertaining equality of requirements at the present and equality of opportunities for the future	2. Creating anxiety and competitiveness
3. Communicating specific and well-defined objectives	3. Raising the tendency to cheat
4. Ascertaining that certain instructional standards are maintained	4. Facilitating rote learning
5. Awarding a certificate necessary for progress in future life	
6. Preparing for further studies and future careers	
Teachers	*Teachers*
1. Communicating desired norms and providing specific guidelines for teaching	1. Preventing teachers from following their own interests
2. Helping in motivating pupils to study	2. Creating anxiety and competitiveness among teachers
3. Establishing collaboration with pupils to reach a common goal	3. Discouraging creative teaching
4. Providing a potential framework for rewards for teaching efforts	4. Tempting teachers to cheat in order to support their pupils and their reputation
5. Motivating teachers to participate in in-service education activities	
6. Providing essential feedback	
7. Providing opportunities to serve as external examiners	
Society	*Society*
1. Enhancing equality of educational opportunities	1. Costing a great deal of money
2. Providing a means for control and accountability regarding instruction and the achievement of educational aims	2. Differentiating between citizens who have and those who have not acquired a matriculation certificate

Table 3. Potential Benefits and Drawbacks of Matriculation Examinations (cont.)

3.	Helping to guide further study and career counselling	3.	Creating situations which may cause cheating and dishonesty
4.	Motivating teachers to keep up-to-date and participate in in-service training	4.	Enhancing private tutoring which is easily available only to the rich and exerts severe financial pressure on the poor
5.	Encouraging schools to create conditions that facilitate their pupils' success in the matriculation examinations		

determined by the written answers and assessed together with the paper-and-pencil tests. For more details, see Tamir (1974), Tamir, Nussinovitz, & Friedler (1982). The oral examination is based on an ecological project that pupils perform from the middle of year 11 to the middle of year 12. The project provides opportunities to observe and study organisms in their environments. Because pupils are free to choose their own topics, the oral test is tailor-made to each examinee.

Identification of non-familiar organisms with the aid of a dichotomous key is a basic skill that should be mastered by any pupil who chooses to specialize in biology. As seen in Table 4, the paper-and-pencil test consists of four parts. The multiple-choice section covers a broad range of topics and tests for functional knowledge, with emphasis on comprehension, application and analysis. Justification of the choices made on three multiple-choice items tests for in-depth understanding, with special emphasis on misconceptions.

In the third section, there are six questions, each representing one of the following areas: energy relations, nervous and hormonal regulation, genetics, ecology and evolution, reproduction and growth, and microbiology. Four questions present phenomena in the form of tables or graphs, and the pupils are asked to describe the phenomena and to offer explanations. Two are essay questions that require application of knowledge and evaluation in relation to important issues, often controversial, such as chemical pest control. This section offers a choice of three out of six questions, thereby allowing teachers and pupils to concentrate in depth on three of the six areas. The unseen passage tests the ability to understand and criticize research and, as well, requires the pupil to propose a next task to continue the research. For more details, see Jungwirth and Dreyfus (1972) and Tamir (1985).

Congruence with Goals

How well does the matriculation examination reflect the goals of biology teaching? Table 5 presents our analysis of the knowledge and skills assessed by the various components of the matriculation examination in terms of Champagne and Hornig's (1987) categories, (presented in Table 1).

An examination of Table 5 shows very clearly that each component plays a different role and caters for different dimensions of knowledge and skills. This is in addition to the diversity of topics covered by each component. For example, all the components involve knowledge of the products of scientific inquiry, namely, facts, concepts, principles, and theories. However, the particular facts and concepts involved in plant identification may be very different from those applied in the analysis of unseen research.

The crucial implication of our analysis is that when students and teachers devote their efforts to preparing for the biology matriculation examination, they learn the kinds of knowledge and skills that are congruent with most of the major goals of science education. In

Table 4. Description of the Israeli Biology Matriculation Examination

Mode	Test	No. of points	Time in minutes
Practical	40		
(a) inquiry-oriented laboratory test		20	150
(b) oral examination on ecological project		15	20
(c) identification of unknown plant using a key		5	45
Paper and pencil	60		
(a) multiple choice (30 items)		30	60
(b) justification of multiple choice (3 items)		6	15
(c) problem situations and essays (3 out of 6 questions)		42	60
(d) unseen research paper (6 questions)		22	50
Total	100	100	400

Table 5. Champagne & Hornig (1987): Categories and Their Representation in the Biology Matriculation Examination

Category	Practical			Paper and Pencil				
	A	B	C	One	Two	Three	Four	
	Plant identification	Oral (Project)	investigation	Multiple choice	Justifications	Unseen research	Essay	Data based
ABOUT								
Knowledge products	+	+	+	++	++	+	++	++
Nature of scientific enterprise	+	+	+	-	-	-	-	+
Values and attitudes	-	+	-	+	+	-	+	-
Applications and risks	+	+	-	-	-	+	+	-
Science careers	-	+	+	-	-	+	-	-
Interest, capacity to do science	-	+	+	-	-	+	-	-
HOW TO								
Evaluate, manipulate, solve problems	+	++	+	+	++	++	+	+
Acquire new knowledge or skills	+	++	++	-	-	++	-	-
Produce knowledge	-	++	++	-	-	++	-	-

- Hardly any + Present ++ Specially emphasized this way the benefits derived from the external matriculation examination outweigh by far the constraints imposed by such examination on the curriculum.

Additional benefits are gained by the participation of some teachers in the design of the tests and especially by the participation of many teachers in the actual evaluation process. Special inservice meetings are conducted every year in which the results of the matriculation examinations are presented and their implications are discussed. In this way external examinations become a constructive contribution to the upgrading of teaching and learning.

Impact of the Biology Matriculation Examination

The reader can appreciate that this kind of examination is not widely used, if at all, anywhere else in the world. Our experience has shown that, by and large, we succeeded in diminishing the potential drawbacks and optimizing the potential benefits of a matriculation examination, as stated in the first part of this article.

Curriculum

As far as potential drawbacks are concerned, although the examination is based on the prescribed syllabus, it allows a great deal of freedom. For example, research papers for classroom analysis and problems for laboratory investigations are chosen by the teachers. The teachers have to design or choose tests and resources for those three topics that they choose to study in depth.

As to potential benefits, all of them have actually been achieved. The practical tests, which were designed anew every year, have been published as integral components in currently used textbooks. All test results, which are carefully analyzed and used for assessment, serve also as an important tool of curriculum evaluation.

Pupils

Anxiety and competitiveness are somewhat reduced by spreading the different parts of the examination along several occasions, and by allowing for some individual choices according to individual interests. Rote learning is, by and large, ruled out by the nature of the tasks (e.g., novel problems, unseen passage). Pupils are encouraged to learn by themselves, to inquire, to observe nature outdoors, and are rewarded for these efforts in the examination. Cheating is reduced by the nature of the tasks, especially those of the practical. To accommodate low ability students, a different biology matriculation examination (known as "3 points") is offered. In 1992, 8,000 students sat for the high level "5 points," and 3,000 sat for the low level "3 points" matriculation examination. For more details, see Tamir and Frankl (1992).

Teachers

Despite a prescribed syllabus, teachers are free to choose their inquiry-oriented laboratory investigations, the research papers for analysis, three out of six areas for in-depth study, the way they supervise ecology projects, and the textbooks they use. Although opportunities and temptations for cheating exist, a close monitoring of the results and strong teacher support diminish the probability of their occurrence.

The variety of learning environments (class, laboratory, outdoors) and learning tasks, promotes and rewards creative teaching. Teachers receive detailed feedback on their pupils' performance. In-service sessions devoted to the matriculation examination have been very attractive. Many teachers tell us that they learn a lot while serving as external examiners in various parts of the examinations, especially in the practical sections, when they meet face to face with pupils of their colleagues in other schools.

Society

It is true that the examinations cost money. However, considering the positive impact they have had on upgrading learning and on raising the status and prestige of biology as a school subject, as well as on the implementation of the necessary conditions(e.g., well-equipped laboratories, availability of lab technicians, facilitating outdoor nature studies, and environmental education), cost effectiveness appears to be rather high.

Conclusion

To be sure, one cannot eliminate all the potential drawbacks of external matriculation examinations. However, we have shown how such examinations, when treated as an integral part of the curriculum, can be of great benefit to pupils, teachers, schools, and society at large. The Israeli experience shows that the beneficial effects of the biology matriculation examination are especially distinctive in culturally disadvantaged communities where resources are scarce, but everything that has to do with the matriculation examination has high priority. Developing countries need not, and should not, repeat the mistakes of their developed counterparts. They should study the history of successful projects and critically adapt suitable practices. Wise investment in assessment is bound to yield substantial gains.

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Science Education Research: From Theory to Practice

Richard Kempa

Introduction

As the title of this paper suggests, I propose to take a look at the issue of how research in science education can influence and affect the practice of science education. The fact that I raise this issue reflects my conviction that currently the link between science education research and the practice of science education is far from strong. My basic thesis is that, so far, the effect of the former upon the latter has remained rather weak. Obviously, this situation is far from satisfactory and therefore we need to ask ourselves how it might be improved, that is, what can and should, be done to bring about a closer link between the two.

It is expedient to take a brief look at the relatively young history of science education research to identify whether it gives rise to particular lessons to learn with respect to future science education research. For this reason, this paper focuses on the following three particular aspects:

1. Where we have come from in science education research?

2. What we have achieved in this research?

3. Which direction(s) should we take in future science education research ?

From Where Have We Come?

It is generally acknowledged that science education as a recognized academic discipline, and with it science education research, grew out of the science curriculum development movement in the 1960s. This movement had its origins in the U.S. and the U.K., with such curriculum projects as BSCS (Biological Science Curriculum Study), CBA (Chemical Bond Approach project), ChemStudy (The Chemical Education Material Study project), PSSC (Physical Science Study Committee project), and the Nuffield Science projects (so called because they were financed by the Nuffield Foundation in Britain). However, this movement also extended to many other countries including, for example, Sri Lanka, Thailand, India, Israel, France, Germany, to mention but a few.

Research undertaken during those early days of science education focused predominantly on scientific aspects of science education, that is, on the science dimension of science education. For example, it concerned itself with the re-examination of the key concepts and issues that should feature in science teaching programs and with ways and means of teaching these concepts and issues. As was aptly expressed by Millen (1965) in relation to chemistry:

> *This particular conception of science education research, viz . that it should continually re-examine and appraise the content of science education to ensure its up-to-dateness, as well as its appropriateness for the learner, is of course still valid, given that scientific knowledge continues to expand. Those who engage in curriculum development work in science, e.g., the Salters' science group at the University of York in England, still pursue this particular line of science education research.*
>
> (p. 45)

The expectations associated with the curriculum reform movement in science education in the 1960s were that:

1. The new curricula would enhance students' interest in, and commitment to, science and that this, in turn, would increase the number of students wanting to pursue the study of the sciences at university level; and

2. The new curricula would result in a higher quality of learning and, hence, improved student achievement.

It did not take long for us to realize that neither of these expectations was fulfilled in reality. This nonfulfillment of our expectations gave rise to a new orientation in science education research: it shifted its attention from science-related to *educational* issues and, not surprisingly, focused initially on two major areas:

1. The identification of factors influencing and affecting students' choice of academic subjects, especially their choice (or non-choice) of science or individual science subjects.

2. The exploration of students' learning difficulties in science and its constituent branches, especially those arising from misconceptions and "alternative" frameworks of thinking.

The first of these research lines was relatively short-lived. Despite many research efforts in this area, it soon became clear that the influences on students' subject choice were far too numerous and complex to be explored in a comprehensive way and to lead to reliable conclusions. Nowadays, we are not surprised by this, having recognized that students are subject to a whole host of influences that include psychological, sociological, economic, and curricular variables.

The second of the foregoing areas has proved to be a most fertile domain of research. Studies of students' learning difficulties have become the most common type of research in science education, as is readily seen from a survey of the literature. To illustrate this, let me refer to a recent bibliography on *Students' Alternative Frameworks and Science Education* compiled by Pfundt and Duit (1991). In the foreword to this bibliography, which represents the third, updated edition of a bibliography first published in 1985, the following observation is made:

> *Research on "students' alternative frameworks" is still flourishing. The first edition of the bibliography (1985) contained some 700 references, the second (1988) edition some 1400, and the present (third) edition arrived at more than 2000.*

The figures given by Pfundt and Duit apply to the science area as a whole and cover all aspects of research into "alternative frameworks" and conceptions (including misconceptions) in relation to all age levels, including teachers. Therefore, it is not easy to make good estimates of the number of studies that has been directly concerned with students' learning in individual science subjects. For example, studies into students' conceptions of the particulate nature of matter often have relevance to both physics education and chemical education. Nevertheless, there is a distinct preponderance of studies concerned with physics topics, compared with studies concerning students' conceptions and misconceptions in either biology or chemistry. In fact, the number of studies concerning chemical topics is relatively small: my estimate is that this number is less than 200, and the figure for biology-related studies is similar.

It is perhaps of interest to look briefly at the main topics that have been the subject of investigations of students' conceptions/misconceptions. These are listed in Table 1. It has to be said that the conceptions/misconceptions area is, of course, not the only one that has attracted the attention of science education researchers. Other investigations that may be located within the 'education dimension' of science education research have focused on such issues as students' problem-solving behavior in science, classroom interactions, and the effect of students' psychological characteristics on science learning and achievement. However, in comparison with the number of studies

Table 1. Main Topics Featured in Research Into Students' Conceptions and Misconceptions

Conceptions of the nature of electricity, its flow in circuits and factors affecting the latter

The nature of, and relationship between, heat and temperature

Interpretation of phenomena of motion, especially in relation to the role of force and energy in bringing about and sustaining motion

Optical phenomena, including the nature of light, vision and colour

Particulate nature of matter/states of matter (structure of gases, liquids and solids)

Matter and transformations, with reference to such concepts as oxidation, burning, conservation of matter, dissolving, acid/base reactions

Structure of, and bonding in, molecules

Chemical equilibrium and composition of equilibrium systems

Interpretation of biological phenomena, e.g., plant and animal nutrition, inheritance and genetics, and general human body functions

Use and interpretation of symbols and language in science

Use and interpretations of models and analogies

into students' conceptions/ misconceptions, the investigations into the foregoing issues have been little more than "minority" pursuits.

At this stage, it is necessary for me to comment that I have deliberately not included, in my considerations here, researches concerned with, for example, the historical, philosophical, and sociological aspects of science and science education. Neither have I included here the many research studies into the assessment of achievement in science, both on the theoretical and on the practical side. My reason for these apparent "omissions" is not that I regard these research areas as unimportant —I certainly do not—but that I want to focus specifically on those research areas that relate directly to the learning and teaching of science.

What Have We Achieved?

My particular concern with research into aspects of the learning and teaching of science stems from the realization that it is this kind of research that offers most potential for an improvement in the quality of science education in schools, colleges, and universities. Indeed, I want to suggest that, in my view, the main rationale and justification for the pursuit of research in science education lies ultimately in its application in curriculum development and the design of instruction.

Given this proposition, it is logical to ask what *impact* science education has had on the practice of science education. To what extent, if at all, have the findings of science education research been taken into consideration by curriculum developers? To what extent have they influenced the teaching of science in the classroom and laboratory?

Trying to answer these questions from the basis of my own experience and perspective, I have to say that I see little evidence that our research has, so far, had a significant and wide-spread impact on the practice of science education. In curriculum development work, for example, the preoccupation still appears to be with the content of courses, that is, with the subject-matter. Ideas about how to respond to students' learning difficulties, to their misconceptions, to their problem-solving characteristics, and so on (all areas that have been extensively explored in research), have, by and large, not as yet found their way into curriculum materials and textbooks. Thus, we may argue that, so far at least, science education research and the practice of science education have coexisted as parallel pursuits, without meeting and interacting with each other.

There exist, of course, exceptions to this. For example, the "Children's Learning in Science" (CLIS) project in England has deliberately addressed itself to the task of exploring novel teaching approaches for overcoming learning difficulties that stem from misconceptions and alternative frameworks held by pupils (Needham & Hill 1987). Also, in Israel a number of researchers have made successful attempts to integrate findings from science education research into curriculum materials. Generally speaking, though, such attempts to translate research findings into strategies for teaching are still relatively rare.

The question that we need to ask is this: "Why is it that the impact of science education research on the practice of science education has, so far been, rather low?" It may be that the answer to this question enables us to remedy the existing, unsatisfactory situation.

I want to put forward two main reasons for the lack of interaction between research and practice.

1. Researchers themselves have concentrated largely on the *generation* of research findings, but have given low priority to their application (or applicability).

2. In the choice of research issues, insufficient attention has tended to be given to the notion of "practice-relatedness," with the consequence that the issues tackled by researchers are not always regarded by practitioners as important and relevant to their work.

In relation to the first of these points, evidence is readily available from the research literature itself, in two ways. First, when we compare the number of publications in which the focus has been solely on knowledge generation, with the number of reports dealing with applications, the latter is very much in the minority. (For example, in Pfundt and Duit's analysis, of some 180 studies into misconceptions and alternative frameworks in chemistry, only about 20 publications may be classed as "teaching studies." Thus, in the majority of studies the concern was with the identification and description of students' notions.)

The other type of evidence stems from a review of the research publications themselves, particularly the "implications" section that forms the customary concluding part. Here, authors frequently assert that the findings reported in their paper have definite implications for the work of teachers. But these implications are usually not well articulated, let alone "operationalized," that is, translated into guidelines for teaching.

The second point also merits brief comment. Here, my contention is based on the perceptions of science education research as they are held by classroom practitioners. The viewpoint frequently expressed by the latter, is that in the formulation of research questions the reality of the classroom and, hence, the priorities of teachers are not always adequately taken into account. One cannot be but sympathetic to this point of view if one considers the multitude of studies in which intrinsically complex learning/teaching situations are reduced, rather simplistically, to relationships between a few variables.

It is tempting to illustrate the foregoing assertions by appropriate examples from the literature. However, to do so would entail the criticism of individual researchers, something that might not be viewed as constructive. Therefore, I want to leave it to the readers to convince themselves of the correctness of my statements.

Directions for Future Research

The important matter is that we should ask ourselves what we can and ought to do to bridge, or at least reduce, the gulf between science education research and the practice of science education. I want to propose and discuss three lines of action that we should embark upon to bring research and practice closer together:

1. Evaluation of past research for the purposes of identifying clear "lessons to be learned" from them for (a) classroom practice and (b) curriculum development.

2. Establish a partnership in the conduct of science education research, involving both traditional researchers and practitioners.

3. Set an "agenda for research," with particular emphasis on the identification of research areas that are both "important" and potentially "beneficial" for the practice of science education.

Evaluation of Past Research

The evaluation of past research in science education should not be viewed simply as a matter of collecting and collating research findings and turning these into general guidelines for practitioners. The task goes beyond this: it must also address itself to the issue of how "generalizable" the results derived from our researches really are.

The issue of generalizability is (or, at least, should be) of central concern not only to those who conduct research in science (and other branches of) education, but also to those whose interest is the application of research findings in the context of, for example, curriculum development and the design of instruction. This follows from the fact that empirical studies of learning and teaching are inevitably conducted in instructional settings that have their own characteristics, characteristics that are not necessarily reproduced elsewhere. Without a reasonable guarantee that research findings derived from one context are, in fact, transferable to another context, the scope for making research "applicable" would considerably diminish.

The need for looking closely at the generalizability issue is amply demonstrated by the fact that research findings derived from different studies are often non-concordant and may even be contradictory. A simple example will illustrate this.

Table 2. Summary Analysis of Research Findings About the Relative Effectiveness of Discovery Learning and Expository Teaching

Criterion Used	Result	
	Discovery superior to expository	Expository superior to discovery
Retention of Information		
early (after 1 week)	4 (1)	8 (2)
delayed (after 3 months)	5 (1)	5 (2)
Discovery Skills		
early (after 1 week)	10 (6)	3 (-)
delayed (after 3 months)	7 (4)	4 (1)

Consider Table 2, which produced a summary of research into the relative effectiveness of discovery learning and expository teaching (cf. Hermann, 1969). For the purpose of compiling this summary, two measures of effectiveness were used:

1. The acquisition and retention of information/knowledge by learners; and

2. The acquisition of "discovery skills"by the learners, that is, their ability to derive knowledge and information through a process of (usually guided) discovery learning.

Hermann's analysis was, admittedly, rather unsophisticated in that it merely involved what may be called a "head-counting" procedure and did not seek to compare the magnitudes of the effects reported. In each cell, the first figure represents the total number of studies for which the particular result was obtained. The figure in parentheses indicates how many of the studies yielded statistically significant results. I do not propose to discuss here the figures in Table 2 in any detail as this would require additional information to be presented. However, it is evident from Table 2 that the issue of whether discovery learning, as an instructional strategy, is superior to expository teaching methods is large unresolved, at least in the sense that it cannot be answered in a generally valid way. It must also be evident, of course, that the issue could not be resolved simply by carrying out additional investigations.

In recent years, a number of attempts has been made to evaluate research findings obtained for various areas of science education. In the main, these evaluations have involved a technique called "meta-analysis" (Glass et al., 1981). In essence, this involves the estimation of the average "effect-size" that a particular instructional intervention has on, for example, students' knowledge or skills acquisition. An interesting example of a very extensive meta-analysis of the effect of different instructional strategies on pupil learning and achievement has been provided by Fraser et al. (1987) and makes worthwhile reading.

It follows from the foregoing that the evaluation of past research is a more complex task than would appear at first sight. Nevertheless, it is a task upon which we ought to embark to identify from past science education research the lessons to be learned for the practice of science education.

The translation of research findings derived from research into appropriate strategies and practices in the classroom and teaching laboratory remains a major challenge that, I am certain, we cannot solve unless we collaborate closely with the practitioners of science education and develop full partnerships with them. The notion of "the teacher as researcher" springs to mind.

There are several reasons why I attach much importance to the development of partnership in science education research. The first is that, in the application of research findings, the particular characteristics in which the application is to occur need to be considered. The practitioner is likely to be far better informed about these characteristics than an outsider.

The second reason is that the implementation of teaching and learning strategies suggested by research findings can hardly ever be effected without adjustments to suit particular circumstances. Again, it is inconceivable that adjustments can be made, and evaluated, without the practitioner's contribution.

There is a third reason, in my view, although it may appear somewhat "selfish": it is that, through collaboration with practitioners, the researchers can gain ready access to the classroom and teaching laboratory in which they want to conduct their studies.

Setting an Agenda for Research

If we are to bring research and practice closer together, we need to take greater care in the choice of research topics than we have done so far. It seems to me essential, when formulating research plans, to consider such as "practice-relatedness" and "potential applicability" of research findings in our work with students.

There can be no doubt that a fair proportion of research studies in science education h failed, and is still failing, to meet the criteria of "practice-relatedness" and "applicability." To alter this situation, it is appropriate that we begin to identify and tackle research questions that arise from, and relate to, the practice of science education. In other words: We ought to make an agenda for research in science education.

It would be presumptuous of me to specify here what such an agenda should contain. The agenda has to be the result of purposeful deliberations and reflections by researchers and practitioners alike, not least because it could (and should) serve as a reference for the choice of future research topics. (I venture to suggest, in passing, that the availability of this "reference" might also lead to an improved coordination of research activities undertaken by different individuals and groups.) However, let me suggest a few areas that would feature prominently in my "agenda for research," these are listed in Table 3. Please note that each area shown in the table has a distinct "applied" component that relates to the practice of science education.

I have to stress that the areas listed reflect largely my own interests and the concerns of the practitioners with whom I have close professional contact. For different situations, the list of research priorities may well be different.

Table 3. Some Broad Areas for Inclusion in an "Agenda for Research in Science Education"

Identification and description of the causes of learning difficulties in science, coupled with the development and evaluation of instructional strategies for their remediation.

Critical examination of instructional strategies used in science education, with particular reference to the management of students' learning.

Study of students' learning styles and traits, and the design of instructional approaches to match them.

In-depth investigations of teacher behaviour and student response in 'natural' instructional settings, for the purpose of deriving rules and guidelines about what constitutes 'effective teaching'.

Let me, at this juncture, give a brief description of one research line that we have created in a deliberate attempt to bridge the traditional gulf between research and practice.

Example: The Study of Group Work in Science

Group work involving between two and four students is one of the most common instructional settings in science education. It features regularly in laboratory work, but is equally popular for the pursuit of problem-solving and similar tasks. In British schools, as much as 60% of a lesson can be spent on group work, which suggests that we have a strong faith in its effectiveness. Yet, we have to ask: what is our evidence that group work is as effective as we generally believe it to be? The review of the literature offers little help: group work, it appears, has not been a subject of much interest to researchers.

Against this background, we have attempted to shed some light on what actually goes on within groups of students faced with scientific problem-solving tasks. (The tasks chosen by us involved the planning of scientific investigations.)

Among the particular questions chosen on the basis of our investigation, were the following:

1. What are the (verbal) interactions among students engaged in group work in science and which students do they involve?
2. How does students' achievement from group work relate to their involvement in and contributions to, the transactions within a group?

For the analysis of verbal interactions among students, a discourse classification system was used that sought to distinguish between different functions of discourse. As is seen, the total discourse divides into two broad categories, task-related and task-unrelated talk. (The latter can be quite varied in nature, ranging from reports on social activities to joke-telling.)

Task-related utterances divide further into two subcategories referred to here as interpersonal talk and cognitive information, respectively. The former arises in connection with the "negotiations" within a group engaged in the problem-solving task, without addressing the task solution itself. A variety of different types of utterance can be detected within this subcategory.

Utterances that relate directly to the problem-solution are grouped together under the heading "cognitive information." Here, an important distinction can be made according to the depth or "level" of the utterance. At the descriptive level, utterances do little more than repeat or paraphrase information provided as part of the task or, in the case of practical work, report observations or data. Information exchange at this level is probably essential to the generation of a solution to the problem.

Utterances at the "explainer" and "insight" levels are different in this respect. They address the problem and its solution, either by reference to problem-solving situations previous encountered (using the information from them as explanations in the present situation) or by suggesting novel interpretations ("insight" level).

To what extent do these various utterances actually feature in group work? We may draw attention to the following:

1. The extent to which our students engaged in task-unrelated talk was low *on average*, although was as high as 70% in a few cases. The group to which the latter applied were clearly not attending to the task set.
2. In the task-related discourse, the proportion of interpersonal talk was generally higher than that in which cognitive information was exchanged. On average, the ratio between interpersonal talk and cognitive information was 2:1, but could be as high as 3:1.
3. On the whole, working relationships within groups appeared to be "free of tensions," judged by the low proportion of discourse in the "issuing instructions" and "expressing disapproval" categories.
4. As regards the cognitive information exchanged among students engaged in group work, this was generally held at the lowest (intellectual) level, the "describer level." Relatively little information appeared to be exchanged that relates directly to the solution of the problem(s) posed.

The observation under number 4 is clearly disappointing and becomes even more so in view of the fact that in about one-third of the groups investigated by us *no* exchanges at the explainer or insight level took place. A further interesting finding emerged when we looked at the direction of the verbal interactions among students engaged in group work. This was that much of the talk within working groups appears to take the form of "dialogues."

It is obvious that, while two students are engaged in a dialogue, the remaining group member assumes a passive role in the group activity, at least in the sense that he/she is then not contributing to it. This does, of course, not necessarily mean that a "silent" group member derives no benefit from the discourse conducted between other students. Provided that the "non-participant" actually listens in on the dialogue and, on other occasions, becomes a "participant" in the discourse, educational benefit for that student from involvement in group work should ensue.

However, we were able to observe numerous instances where individual students made little or no contribution to the group discussion. In fact, in nearly half of the groups studied, "unbalanced participation" was evident, in which at least one individual was a "marginal" contributor. Table 4 gives a summary of these findings; it also suggests that "imbalance" in participation in group work increases with increasing group size.

I have confined myself here to presenting just a few results that have emerged from our study of students' group work, merely to illustrate that even the most common instructional strategy offers scope for investigation and, thereafter, improvement. What our findings suggest is that learning in group settings is not as effective as is usually believed. One particular reason for this, in our judgment, is an inadequate realization on the part of the teachers that students are unlikely to work efficiently in collaborative settings unless they possess adequate "management skills." Among these are:

1. The ability to analyse a task and break it down into component tasks;
2. The ability to negotiate the distribution of "labor" among group members;

Table 4. Analysis of Task-Related Information Exchange Within Groups in Terms of "Balance"

	Number of Groups
All groups (N = 24)	
"Balanced" participation	13
"Unbalanced" participation	11
"Unbalanced" participation	
confined to 1 pupil	7
involving more than 1 pupil	4
Three-pupil groups (N = 13)	
"Balanced" participation	9
"Unbalanced" participation	4
confined to 1 pupil	3
involving more than 1 pupil	1
Four-pupil groups (N = 11)	
"Balanced"participation	4
"Unbalanced" participation	7
confined to 1 pupil	4
involving more than 1 pupil	3

3. The ability to carry out discussions with a clear focus on the task and its solution; and
4. The ability to evaluate one's own contribution and those of others in a positive and constructive way.

If we agree that these and related skills are important prerequisites for effective group work, then we ought to help our students to develop them. It is at this point where research and practice meet, for the purpose of improving students' learning.

Conclusion

In this paper, I have deliberately taken a critical look at science education research. I have done so not to dismiss it as an enterprise that is only of limited value to the practitioner of science education, but rather to point to ways and means in which it can become a major influence on classroom practice. There are several conditions that, in my view, need to be fulfilled for this to happen, the most important being that in the choice of research topics, far greater attention has to be given than has been the case hitherto, to practice-relatedness and applicability, and closer cooperation needs to be achieved between researchers and practitioners, preferably in the form of a genuine partnership between the two.

The first of these points calls for an "agenda for science education research" to be created that takes account of the concerns and priorities of those teaching science "at the chalk-face." The generation of such an agenda is itself an important research task: only if this task is properly addressed, can we expect to move towards a less fragmented and more purpose-directed research effort than we have been able to produce in recent decades. This, in my view, is the precondition for bringing about a closer link between science education research and the practice of science education and to ensure that future research is not seen as a predominantly theoretical enterprise, but as something of sound practical value.

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Chapter 2

The Learner

Introduction to Strand A: A Focus on the Learner

Rosalind Driver

What are Learners' Needs, Perceptions and Motivations for Learning Science?

In this strand, the symposium contributors and papers focused mainly on learners in formal educational programs in schools or in college courses.

How was the learner characterized? There was a general commitment accepting that learners have their own personal knowledge and motivations, as well as recognizing that learning requires the active engagement of the learner in the knowledge construction process.

Some important differential features about the learner were discussed. In her paper "The Learning Profile of Somalian Students," Bandiera draws attention to features of the everyday culture of students that may form particular knowledge representation and that may differ from the scientific culture into which they are being socialized. For example, in everyday life in Somalia, measurement is typically inexact, (milk is measured in "large" or "small" bottles; length is a variable measure of "arm's length").

The contrast between everyday culture and science culture is not limited to the developing world; it is a feature of all societies and raises an important issue for science education, namely, identifying the features of people's everyday culture that frame their "common-sense, at-hand, taken-for-granted" knowledge about the world and considering what is involved when learners move from this to the culture of science. Kempa's paper matching teaching strategies and learning styles' presented evidence for a number of different motivations for learning among secondary school students, each of which would lead to different instructional strategies. This was a healthy reminder that the search for the "best" instructional strategy may be misguided and that different strategies may be needed for different learners.

Understanding and Promoting the Learning Process

The studies of the learning process focused mainly on learning as conceptual change, with a small number addressing issues of metacognition. Little emphasis was given to learning practical problem solving, reasoning, and decision making about scientific issues.

Understanding Conceptual Change

In studying conceptual change, most studies focused on change in the content of students' conceptual schemes, though some attention was also given to changes in students focus of reasoning, for example, their casual reasoning. The picture of conceptual change in science that emerged was that of the evolution of knowledge representation with age and experience. Learners constructed intermediate representations (or as Schoenfeld called them, transitional conceptions) of phenomena that could be more helpfully seen as stepping stones to greater conceptual power, rather than misconceptions to be eradicated. For example, Nussbaum's paper "Gaining Insight From Historical Sources to Invoke Desired Conceptual Change: The Case of Matter, Vacuum and Particles" reminded us of what can be learned from the history of science about complex changes in ways of thinking and how this slow and messy change is reflected in classroom learning.

Promoting Conceptual Change

A range of strategies were reported for promoting conceptual change, including the use of analogies, conflict strategies, and bridging. The methods used by most researchers to study conceptual change involved detailed studies of the learning of a small number of students during a prescribed unit or topic of work. The researcher typically acted as a participant observer, collecting detailed accounts of the students' learning activities using transcriptions of audio or video recordings. This way of working was recognized in some studies not only as a way of studying conceptual change, but also as a means of professional development for the teachers participating.

There were a number of recurring features in the findings that were reported of such studies:

1. Providing opportunities to students for reasoning and reflection on activities is important.

2. "Critical junctures" or "crises" in students' reasoning were identified, in which students recognize that their current schemes fail or are in conflict with events and that they need to restructure their knowledge schemes. Zietsman's paper "Beyond Rules: Models for Conceptual Understanding" gave a graphic account of the knowledge construction paths of college students in South Africa in the domain of reasoning about levers. She argued that students' basic physical intuitions (which, following Clifford Geertz, she hypothesized, would be universal) can be triggered in critical cases to promote more developed reasoning encompassing a wider range of phenomena in question. Her study, undertaken with students in a college preparatory physics course, showed marked improvement in the reasoning of students and in their physics grades as a result of their involvement in such in-depth reasoning tasks as part of the course.

3. A positive result was reported by Thijs et al. in their paper "Research on Conceptual Understanding of Force." The study was conducted in the context of a pre-entry science course in Botswana. Common prior conceptions about force and motion (e.g., that uniform motion requires a force) were identified, and laboratory tasks were designed to address each of these conceptions. The focus of the laboratory tasks was to confront each of the prior conceptions and to provide students with opportunities for qualitative reasoning about their results. The evaluation in terms of pre- to post-test changes in the students' conceptions was most encouraging. In some cases however, some students were reported to revert to their original conceptions in a delayed post-test.

4. Although cleverly designed practical tasks were seen as an important way of stimulating conceptual change, other interventions were also reported, including thought experiments and computer simulations involving virtual worlds. A thought experiment reported by Reiner illustrates the simple elegance of such tasks. It is well known that students commonly predict that a heavy object will fall faster than a light object. Reiner's thought experiment involved asking students to consider what would happen if a heavy stone and a lighter stone were tied together with a short string and released about the ground. Would they fall even faster because of the greater combined weight? Would the lighter one pull the heavier one back?

5. In her paper "Tools for Thought Experiments in Science," Reiner explicitly addressed the issue of providing an environment in which students are encouraged to construct symbol systems as tools for communication in groups. Other studies implicitly recognized the collaborative nature of the knowledge construction process by organizing intervention tasks in small groups and involving students in discussion on critical cases.

6. The role of concept mapping in helping students to organize and make sense of new domains of knowledge was addressed in a number of stud-

ies. In a well-designed study of the domain of electricity and magnetism, Bagno and Eylon report that students who were required to construct a concept map forming explicit linkages out-performed control groups in solving standard and non-standard problems. Trowbridge and Wandersee's paper "Concept Mapping in a College Course on Evolution," incidentally, one of the few papers on a biological topic, focused on the ways in which concept mapping can be feasibly incorporated in college biology courses.

7. A range of assessment techniques for diagnostic purposes were reported as data collection techniques in particular studies. As far as summative assessment is concerned, some accounts were given of efforts being made to align assessment practices with instructional practices. Logan and Hegarty-Hazel's paper on "Language and Assessment of Students in the the Physical Sciences" reported, among other things, attempts at first-year University level to change the character of the question set, including more open-ended questions requiring qualitative reasoning. Although this was to support students whose first language was not English, the performance of all students improved.

Issues About Learning and Learners That Received Little Attention

The introductory lectures in the Conference highlighted the importance for the next century of producing a science education for all, implying the provision of a science education that addressed the needs of future citizens in a scientific and technological society, not just the training of future scientists and technologists. There was however, very little research reported on this aspect of science education (Jungwirth's paper on students' analysis of public health situations was a notable exception). If the objective of science for all is to be taken seriously, there are a number of areas of research that will require attention in the future, including the following.

1. The interests and attitudes of women toward science and technology must be studied. Why is participation in science and technology much lower for women than men, particularly in developing countries?

2. What resources do learners bring to learning science and technology from their own cultures?

3. Most research on learning to date has focused on conceptual understanding (with an emphasis on physics rather than life sciences). Little attention has yet been given to the study of the way people develop practical problem-solving capabilities or the way in which their knowledge interacts with their action.

Priorities for Research in Learning Science with Emphasis on Developing Countries

There are some outcomes of research on learning science that it may be possible to generalize to different geographical and cultural settings. To this extent science educators from around the world can benefit from and be informed by the work of others in other settings.

In education, however, the specific features of the educational system and practices have a major influence on the effective implementation of any change. Thus, there is a pressing need to take into account the specific concerns and needs of developing countries in identifying priorities for research in such settings. The following issues were identified by participants at the Conference as priorities for research:

1. Provide baseline data on the existing situation relating to the provision of science education (teaching practices, level of resources, learning outcomes, etc.);

2. Make decisions about what science is appropriate to the needs of learners;

3. Research of the resources for learning science that exist within the culture (local environment, technologies, cultural practices, etc.) and investigate how these can be drawn upon in instruction;
4. Discover strategies that can be used to promote effective learning in realistic educational settings, including limited resources, large classes, poorly trained teachers, mother tongue, and where effective learning may require significant changes in practice from role to meaningful learning, from authoritarian to participative methods; and
5. Learn how science can be communicated effectively in an informal setting to people of all ages in a society.

The Learning Profile of Somali Students

Milena Bandiera

The Italian Ministry of Foreign Affairs was engaged in a large cooperative project in Somalia, part of which was cooperation at the university level. This implied working with Somali academic authorities to establish, organize (from a methodological, scientific, and educational point of view), and manage most faculties of the National University of Somalia (UNS). From 1984 to 1991 (the period covered by the present research), between 400 and 800 students were admitted every year to the faculties concerned.

Beginning in 1984, students of UNS were requested to follow a special propaedaeutic term ("semestre linguistico-culturale") before enrolling in a scientific faculty. The curriculum of this term included Italian for scientific purposes (students having already followed a course in basic Italian during the previous 4 months) and some courses in biological, physical, and mathematical sciences (for some of them, also chemistry and technical drawing) at a ground level. According to this project, scientific courses should also represent a basic introduction into scientific logic and methodology and develop mastery in fundamental scientific concepts. The linguistic propaedeutics should assure an improvement in communicative competence and, additionally, the development of a "scientific mentality."

It was not possible to design the curriculum in a traditional way, as a "normal" didactic project, because in Somalia the situation was exceptional in many respects, especially in terms of intercultural differences and institutional setting. The latter included following conditions: the Somali government absolutely required the introduction of western cultural models (western scientific topics, a western conception of university, western-shaped university degrees); Italian was adopted as the academic language (teaching and didactic materials were in Italian); and, finally, there was no information about the Somali schools (i.e., about their curricula, textbooks, didactic methods, learning habits, etc.).

The designers of the curriculum could rely upon two solid factors: first, the Italian language being considered as the matrix of scientific thought, from the point of view of content and of structure (this was the reason the language program was assigned the task of developing the scientific mentality); second, the cultural (and, consequently, the behavioral) models conveyed by the teachers were different from the ones conveyed by the students: this implied that an analysis of the relevant aspects of both models should be performed with respect to their didactic implications. Therefore, there was a need to define the learning abilities considered indispensable by Italian university teachers, as well as the basic scientific cognitions and the specific characteristics of the didactic communication as practiced in Italy.

Furthermore, a great amount of data were collected about cognitive style, learning habits and abilities of the Somali students, their motivations and expectations, specific pieces of knowledge, general behavior, and everyday experiences; all of these delivered information about the indigenous ways of building explanations and problem-solving procedures. Finally, the characteristics of the perception of natural phenomena were explored, together with the attitudes and means for interpreting these phenomena. It was also necessary to combine the research (acquisition and analysis of data, definition of hypothesis relating to the project) with the need to deliver teaching materials for the regular activity at the university, supporting the logistic organization and the teachers' training. It seemed reasonable to approach this goal gradually: in parallel with courses, and as much as possible in a functional relationship with the courses, research was performed to define the habits and abilities of the students, students' cognitive attitudes toward experimental sciences, and the quality and the level of students' disciplinary knowledge.

Therefore, beginning in 1984, didactic activities were performed, providing a good deal of data and information. Additionally, two sets of tests were given to the students. The first test was built on items largely used in the western world when investigating people's mental representations or conceptions as different from scientific knowledge; in our particular context such items perform an exploratory function. (These tests were called "curricular tests," because they were integrated into the units of the textbook *Italian for Academic Purposes*). The second set consisted of two different multipurpose questionnaires that were administered both at the beginning and at the end of the courses with the additional aim of evaluating the efficiency of the didactic materials and, thus, providing for their gradual adaptation to the specific needs of Somali students.

Therefore, in every section of the curriculum and in the textbook it is possible to see strategies (inspired by the exigency of linguists and experts in scientific teaching) for collecting useful information for the purposes mentioned above. (The author of this paper contributed to the general design of the "semestre linguistico-culturale," to the scientific part of the textbook *Italian for Academic Purposes*, to the didactic materials of the biology courses, and to the elaboration, administration and analysis of the tests.)

Some examples of these strategies (activities, curricular tests, items on the questionnaires) will be presented, in particular, the activity concerning the concept of measure (students' investigations about the unities of space, time, weight, and volume, both as traditionally used in Somalia and as a result of western influence). The collected data allowed some generalization: usually the units of measure coincide with the instruments of measure or refer to practical operations of everyday life. Measures are, therefore, generally approximating; categories of measure and categories concerning the instruments are not systematically related. These features do not conform to the needs of a rigorous scientific conceptualization, but they represent an ideal starting point for developing a conceptual frame appropriate for academic purposes, as they are deeply rooted in the practical activities and the consciousness of the Somali students.

As an example of "curricular test" the task of drawing the Earth from above was chosen, which includes the assignment of introducing a certain number of animate and inanimate objects into the representation. This test, which is related to the teaching of physics, is also used in the western context and usually detects the conceptions of students about the form of the earth. In Somalia, instead, where people are not familiar with the technique of graphic representation, it provided interesting and unexpected information about the particular use of the graphic space and about the composition style and the skills Somali students use in processing iconic messages.

Matching Instructional Strategies to Students' Learning Styles

Richard Kempa

Rationale

It has been argued that one source of students' learning difficulties in science is a mismatch between the instructional strategies employed by teachers and lecturers, and the "natural" learning styles of the learner (Kempa, 1988). As our knowledge about students' learning styles and preferences for different instructional procedures increases, thought needs to be given to how such knowledge can be translated into positive action to bring about a closer match between teaching procedures and learning styles.

Recent studies by Kempa and Martin-Diaz (1990a, 1990b), following earlier work by Hofstein and Kempa (1985), provide one example demonstrating the relationship between pupil/student characteristics (in this case, motivational traits) and preferences for different instructional strategies. Table 1 summarizes the most important trends and differentiations we observed.

The motivational traits indicated in Table 1 were derived form the work by Adar (1969), who classified students into four groups, as follows:

1. Students driven by a desire to achieve (termed here: "achievers"),
2. Students driven by a desire to satisfy their own curiosity ("curious" students),
3. Students driven be a desire to fulfill the tasks given to them ("conscientious" students), and
4. Students driven by a desire to interact with others ("sociable" students).

Several strong relationships between motivational traits and instructional preference variables are noticeable. They include the following.

1. Formal teaching methods seem to appeal only to "conscientious" students.
2. Independent learning techniques (exemplified in the present case by "use of reference books") is strongly liked by "curious" students, but equally strongly rejected by the "conscientious" ones.
3. "Doing practical work" is an activity that appeals to the "curious" students, but not when highly prescribed. "Conscientious" students, in contrast, express a clear preference for rigorous instructions.
4. "Sociable" students display a distinct preference for group learning activities, which is coupled with an opposition to individualized work.
5. "Conscientious" students, unlike students in the other categories, show a distinct preference for having their performance and progress monitored by their teachers, which supports the idea that they are strongly "teacher-dependent."

Although in the Kempa/Diaz study the focus was on students' motivational traits, other authors have explored other student characteristics and their relationship to learning behavior. For example, Kolb developed a learning-styles inventory based on his analysis of students' personality traits (introversion and extroversion, respectively) and their inclination toward emotionality and rationality in their thinking. Figure 1 summarizes Kolb's model. On the basis of this analysis, attempts have been made to develop descriptions of the chief learning characteristics of people in the various quadrants, for example by Atkinson (1991), Stice (1987), and

Table 1. Summary of the Relationships Between Students' Motivational Traits and Preferences for Instructional Procedures

Instructional procedure	Motivational trait			
	Achiever	Curious	Conscientious	Sociable
Knowledge acquisition mode				
A.1 Formal teaching	-	-	+	
A.2 Learning from reference texts, etc.		++	-	- -
A.4 Use of discovery learning	+	++		(+)
Working arrangements				
B.1 Individual work				- -
B.2 Involvement in group work			(+)	++
Practical work				
C.1 Doing practical work		++		(+)
C.2 Practical work with instructions		- -	++	
Organization of teaching				
D.1 Pursuit of one's own enquiry	+	+		++
Evaluation				
E.1 Evaluation by teacher				
E.2 General dislike of being tested				
RT Risk-taking		+	++	++

LEGEND: Strong preference trends are indicated by '++'; '- -' denotes the opposite. Moderate preference trends are indicated by '+', with '-' denoting moderate dislike; '(+)' indicates a moderate preference trend due to an indirect, rather than a direct relationship between preference and motivational trait. An additional subdimension (A.3 = note-taking as a means of obtaining an accurate record of information) has been omitted since it produced no significant differences between motivational trait groups.

Boyle, Oakes and Hannon (SSCR, undated).

Towards the Application of Research Findings

The foregoing examples strongly suggest that learning behavior and preferences for instructional procedures are significantly influenced not only by factors that emanate from the instructional situation itself (e.g., subject matter variables and the way in which learning tasks are formulated and contextualized) but also by qualities that reside within the learners themselves.

However, a key question is whether we can translate such insights into practicable teaching strategies through which we can respond positively to the diversity in learning styles and preferences for instructional procedures in our students.

The task of translating research findings into practical instructional strategies may be broken down into two subtasks:

1. The development of instructional strategies and teaching/learning materials that reflect the research finding; and
2. The implementation of these strategies in actual teaching situations.

To illustrate how the first of these subtasks might be accomplished, our recent work into motivational traits can be examined. This work revealed that pupils with different motivational traits differ in their preferences for, or dislike of, particular instructional procedures. If the assumption is now made that, for a particular motivational group, the best instructional approach is the one that matches the learners' preferences, it follow that curious pupils should be treated differently from, for example, conscientious pupils. Thus, it is, in principle, possible to deal satisfactorily with the first of the above subtasks. What about the second, though? How feasible is it to implement multiple teaching procedures in actual teaching situations?

It is in this respect that the greatest difficulties are likely to arise. Two problems, in particular, stand out. The first is that it would seem to be impossible, in conventional teaching settings, to cater simultaneously to a variety of different learning styles and/or instructional

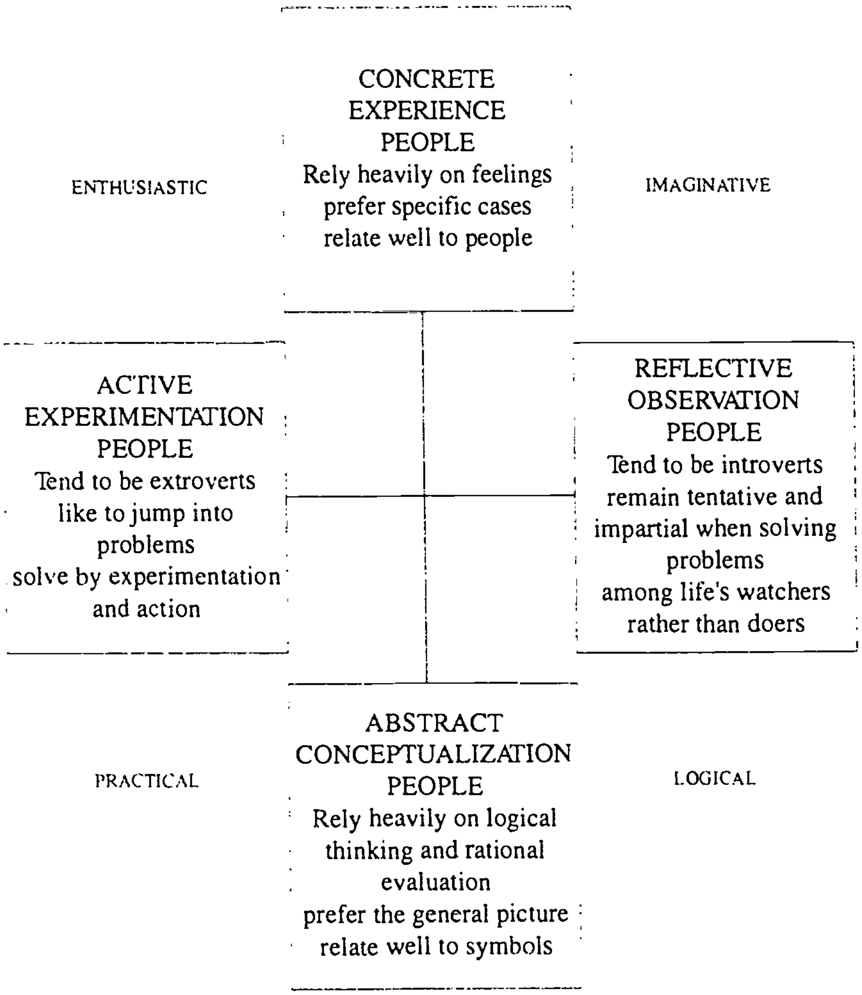

Figure 1. Schematic Representation of Kolb's Types of Learner and the Learning Styles Derived for Them (Atkinson,1991)

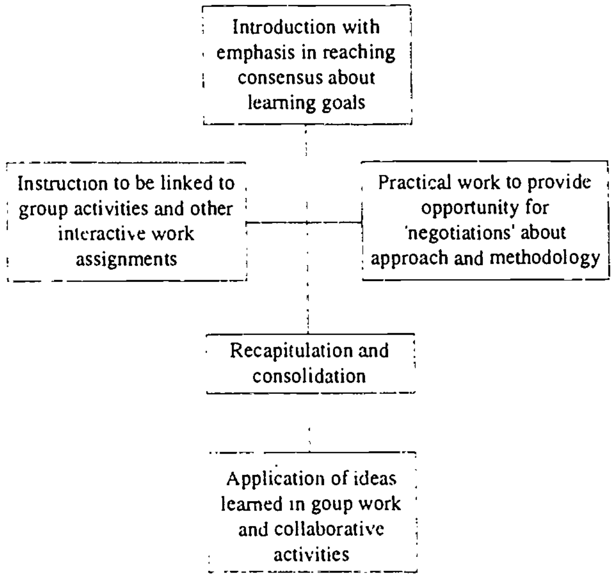

Figure 2. Strategy for the Development of Instructional Materials for "Curious" Students

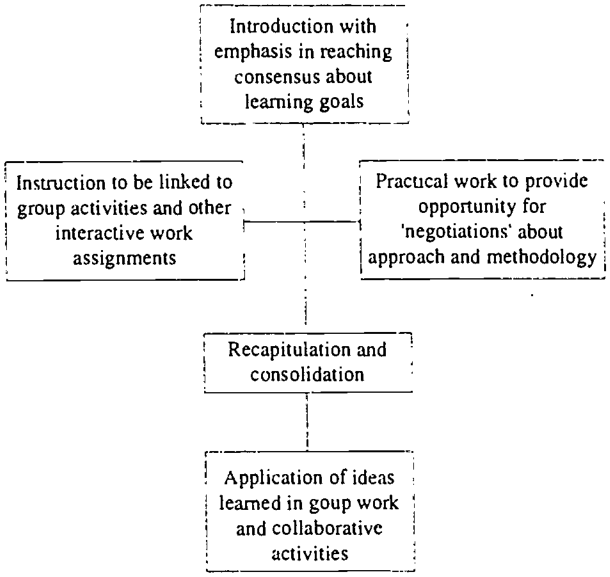

Figure 4. Strategy for the Development of Instructional Materials for "Sociable" Students

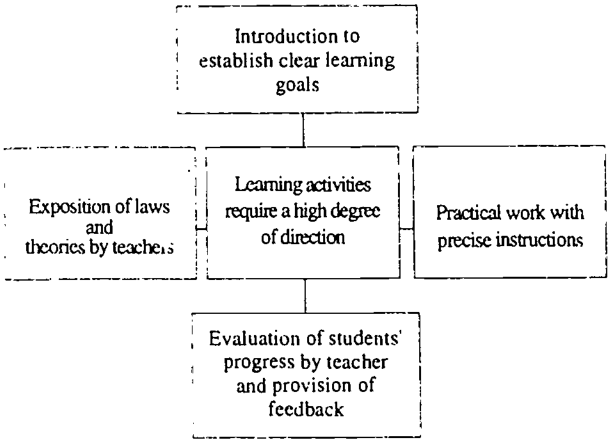

Figure 3. Strategy for the Development of Instructional Materials for "Conscientious" Students

preferences. The second is that, even if the first problem could be solved, an actual matching of learner characteristics and instructional strategy might be almost impossible to achieve: for example, the determination of learner characteristics itself may prove too difficult and/or too unreliable. Also, some teachers may see such a process as labeling and object to it on ideological grounds.

In view of these difficulties, it is perhaps appropriate not to look toward conventional teaching settings when thinking of the implementation subtask, but to consider the potential of new approaches to teaching. In this context, current attempts to introduce "flexible learning systems" come to mind, including features such as "individualized learning," "resource-based learning," "open-learning," and "distance learning." All these strategies depart significantly from the conventional "teacher-directed" approach to teaching and learning.

If a learning system is genuinely flexible, it ought to be able to respond to pupils' preferences and inclinations. It also ought to enable pupils to decide, or at least contribute to decisions about, to which teaching/

learning strategies they will be exposed. Thus, a kind of self-selection of instructional procedure should become possible in which pupils themselves are the arbiters of which approach to learning suits them best. A possible sequence for achieving this might involve the following steps:

1. Translate information about learning styles and instructional preferences into teaching approaches;
2. Develop teaching materials in accordance with learning styles and preferences
3. Offer pupils alternative learning routes, for example, in the form of resource-based learning and flexible learning packages; and
4. Allow pupils to choose their learning route in accordance with their personal preferences. (The assumption here is that pupils will choose so as to minimize the conflict between teaching approach and learning style/preference.)

Work is currently in progress to implement and evaluate this strategy in practical terms. The development of teaching materials for students having different motivational traits is based on the schemes illustrated in Figures 2 to 4, for curious, conscientious and sociable students, respectively.

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Beyond Rules: Models for Conceptual Understanding

Aletta Zietsman

Introduction

The premise here seems simple and already much discussed: people use simple, but cognitively powerful, rules to negotiate understanding in their everyday worlds. But sometimes the rules "break down"; they do not provide answers any more. People start squirming and, in this uneasiness with the old knowledge, new knowledge is created.

In this paper issues from the knowledge construction "path" of a student (Liz) are presented. The analysis is descriptive, and uses protocols from interviews conducted about physical situations (involving levers) that were arranged to encourage learning. The protocol evidence is allowed to speak for itself most of the time. My inferencing from the protocols is, in itself, a process of model construction —trying to negotiate a meaningful understanding of students' acquisition of scientific knowledge and reasoning in this limited domain.

Before Breakdown: Students Reasoning With Rules?

Initially (in pre-test interviews) students applied one of two rules to all lever situations presented to them. The rules and protocol excerpts are given in Figure 1. In all the excerpts I is the interviewer, S a student, and Liz the case study participant.

Rule 1: If the load is nearer to the man it is easier.

Liz 003: Man B, and 'cause, well, I thought like, you're nearer to the weight you know?

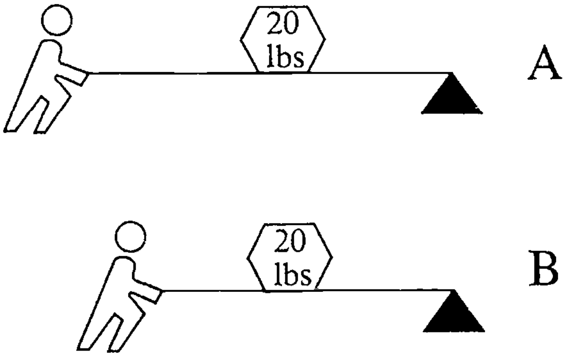

Figure 1. Comparing Class II Levers: Target Question

"Rule 1" is considered to be a control conception: students seem to think that the closer one's hand is to the load, the easier it is to control, which is true in many everyday situations. However, this reasoning leads them to the wrong answer. Students relate here the person, the load, and the load-effort separation distance.

Rule 2: If the load is farther from the man it is easier.

S 001: In case A (it is easier), because the 20 lbs is farther away from the person.

Clearly, students using this rule would get the answer "correct." However, this "non-generalizable" or limited rule can only be applied successfully to class II levers. Rule 2 also relates the person, the load, and/or the load-effort separation distances.

It is debatable whether these are simple, "if . . . then" rules. The students may have used an apparently limited rule, but they always supported the rule statement with fairly sophisticated scientific reasoning. They identified important variables, stated relationships between those variables, and used analogies to test and confirm their conclusions. For example, later in the interview (again the Figure 1 situation), Liz supported her rule with two different analogies: to a meatball on a fork and person holding a pencil in a writing situation.

Liz 021 I think B and once again I can't describe this. Uh, Ok let me put it this way, this may not make sense to you?

I 024 Ok?

Liz 025 But if you have a fork, ok? And let's say you have, like a meat ball, so that's very heavy. If you hold it near the end of the fork (near meat ball) it's a lot easier to hold than if you hold it down at the other end. This isn't a very good example, but, well (giggles).

I 030 You're doing very well explaining this to me!

Liz 031 I don't know. You just have more control over it if you're holding it closer to you. I mean if you hold the end of the pencil if you're trying to write, it doesn't really want to write but if you hold it down here—it works a lot better.

I suggest that Liz's reasoning is not simply rule-based: the use of analogical reasoning implies connections to other knowledge constructs.

Breakdown: Physical Intuitions and Conceptual Change

In the levers study, conceptual change was initiated by presenting a physical situation to students that "triggered" an intuition. The activation of this "sleeper" intuition (or *anchor*), which is in agreement with physical theory, proved to be a good mechanism by which to initiate a bridging process from the limited and often incorrect conceptions to conceptions that are in agreement with physical theory.

It is important to state that one distinguishes between "elemental, primitive physical intuitions" and "derived, learned intuitions." It is therefore suggested that one gives up the idea of "building on what the student knows" in favor of building on "what is intuitive." Very often, this last mentioned will be part of what the student already knows, but sometimes not. When it is, we gain valuable time and sometimes coherence with extensive past experience. Good anchors seem to be those that are self-discovered and self-evaluated by the student: the anchor's plausibility and perhaps even conviction have been evaluated and confirmed by the student—they make sense. This last argument is important. It suggests that much more research is needed to learn "what is intuitive" to students, particularly when we deal with students in different "cultures" and contexts.

The intuition that was "prompted" in the experimental material is that of "the fulcrum helping. This intuitive, correct conception emerged from intensive interviews in pilot studies (Zietsman, 1991). Results from written diagnostic tests confirmed the existence of this anchor (N = 158). What is interesting is that the anchor is "triggered" by a limiting case situation (Figure 2).

All students who participated in the study responded immediately with a notion of "the fulcrum helping." For those who used the control conception, this posed problems—they were contradicting previous statements. On the other hand, the extreme case situation helped the students who used the non-generalizable conception to provide a meaningful explanation for their claims. They were also able to identify new, important variables in the lever situation, such as the load-fulcrum distance. This reasoning starts to approximate that of an expert.

An example of a control conception in trouble, we

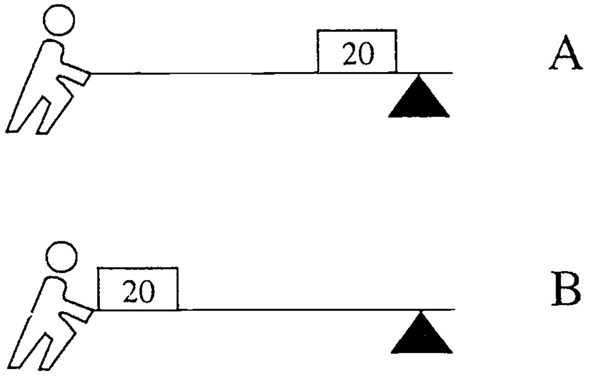

Figure 2 Extreme Cases Comparison

can consider Liz's response. Until this point, she had been using her "load closer, easier" rule consistently. She looked at his example and said:

Liz 030 And—I think that—uhm. The person A will—. And this is different than what I said before, but I think that—maybe the triangle (fulcrum) would help a little, if the 20 lbs is there (points to B) then—uh, nothing would help the person, it's like carrying the thing. And if anything could help keep the weight up, then—then I guess it would be easier (if the load is) closer to the triangle.

I 037 OK.

Liz 038 And I'm guessing that one.

I 039 A pure guess?

Liz 040 Yeah.

Liz had progressed from the "rule-like" statement to a more complex view: the "triangle helps," and I infer here that she is thinking of another force at work. She is aware that this reason is different from before (line 031), and she is not at all sure of the intuition (line 038 - 040). The reasoning processes outlined above illustrate the laborious processes at the "breakdown interface" where new models are constructed: the old rule lurks in the background, and is not rejected; but a new explanatory, causal model is suggested, but its concomitant rules, albeit uncomfortably.

After Breakdown: What Happens Then?

Our data suggest that *after* students have constructed a model compatible to the experts' (such as the "fulcrum helps model"), they operated increasingly at a "rule-based" level. It seems that, once the model was understood and confirmed, they did not need the elaborate processing required to reason by model (as shown in the protocol excerpts above). For example, Liz, in tailkng about another extreme case situation, restated her reasoning given in the excerpt above:

Liz 111 Uhm. I think that this man (b) will (find it easier), because again he's—the weight is closer to the turning point and therefore that might keep it up a little. Whereas this person is—the distance here is so far away (points to load-fulcrum distance).

I 116 Distance from the loads to the turning point you are pointing to?

Liz 118 Right. From the—ah, yeah.

I 119 And what difference does that make?

Liz 120 Uhm. Well, I guess if—if its (load) closer to the turning point then that might help keep it up.

Liz had constructed a rule—a relationship between three variables:

1. The person's effort,
2. The force exerted by the fulcrum (our inference), and
3. The load-fulcrum lever arm.

She supported her rule-like statement with her "fulcrum helps" model. Later in the interview reference to the model completely disappeared, and it was only when considering a complicated multiple levers problem that she confirmed her prediction by referring back to the fulcrum's role. Finally she had developed two rules: "longer effort leve rarm, easier," and "shorter load lever arm, easier." The long pauses and tentative explanations gave way to confident, thoughtful statements.

Revolving Doors Question

Liz	510	Uhm. I don't—Oh. I think the door will move counter-clockwise because it is easier for Ann to push even though she is exerting the same force (as Beth) because her effort turning arm is longer than Beth's.

Nutcracker Question

Liz	520	I think that it would be easier to crack the nut with A, because the effort turning arm is longer and the load turning arm is shorter.

Oars Question

Liz	568	I think it would be easier—it would be easier (her emphasis) in B, but would go farther in A.
I	570	You would go farther in A?
Liz	571	Because then it moves more distance?
I	572	Ah, I see.
Liz	573	And B it moves less, but it would be easier, because the effort turning arms are the same in both, but here (B) the load turning arm is shorter.
	576	So. I'm sure I'm right on this one.

Her final comments are particularly exciting: she understood the way levers work precisely and also discovered the distance multiplier effect of a third class lever - not an objective of the experiment.

Finally: Why Bother with Models?

Many writers have stated the power of model-based reasoning: models enable one to predict, they facilitate imaging and explanations; good models facilitate transfer—objects and actions can be visualized in decontextusalized form.

The most important findings were:

1. The model was *self-constructed,* anchored in students' intuitive notions of causality and mechanism, and provided them with a causal model to make sense of real-world situation;

2. The children's creative reasoning: one saw again how much children can do on their *own*.; and

3. Sensitivity is needed when teachers expect learning.

Finally: conventional wisdom claims that "disadvantaged" students do better in "conservative" classrooms—thus, more authoritative environments, more directive teaching. I believe that attitude is morally wrong, that we are insulting children yet again. It seems more important that we rethink curricula—not the content per se, but rather investigate what important reasoning strategies are used intuitively in which contexts by our students, as well as those student anchors (intuitive physical knowledge) in which to ground instruction.

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Research Into the Understanding of the Concept of Force Performed in Developing Countries in Cooperation With Research in the Netherlands

Gerard Thijs, Peter Dekkers, and Ubbo Smith

Introduction

During the past 15 years the Vrije Universiteit Amsterdam (VUA), together with a number of universities in Southern Africa (Botswana, Lesotho, Malawi, Mozambique, Namibia, Swaziland, Zimbabwe, and, recently, South Africa) and Indonesia, has developed a basic science program. This program refers to pre entry science courses for school leavers intending to study science based programs at tertiary level, and teacher training projects in the field of science and mathematics. Both projects aim at improving the quality and the output of secondary school education in the following subject areas: biology, chemistry, mathematics, physics, English, and study skills. Important characteristics of the basic science project's approach are moving students away from rote learning of facts and algorithms into a qualitative understanding of concepts and engaging students in laboratory/practical activities.

In the context of the basic science program, specific issues that require educational research and development of new materials have been identified. The research and development activities were mostly initiated at VUA, mainly within the Center for Development Cooperation services (CDCS), which acts as the logistical support center of the basic science program. This paper discusses developments relating to research on students' conceptual understanding, limiting ourselves to physics and the subject area of mechanics. In the past 6 years, research has led to a number of results that are summarized in this paper, in particular with reference to the Botswana project (Cantrell et al., 1993).

Research Initiated at VUA in The Netherlands

In 1986 we did a pilot study into students' learning problems in mechanics, using a questionnaire with qualitative problems on daily life situations involving force and movement. The test was administered to students in secondary schools and basic science projects in Zimbabwe, Lesotho, Indonesia and the Netherlands (Thijs, 1987). Students appeared to have greatest difficulties with (a) uniform motions that do not require a force, (b) definining motion with respect to a frame of reference other than the ground, (c) the induced character of forces such as the normal force and the force of friction, and (d) considering a force in terms of an interaction between two objects. The test results of students in Zimbabwe were analyzed in more detail. Considering various parameters such as students' age, ability, sex, rural or urban location of a school, and amount of science instruction received at school, the latter parameter appeared to account for most of the observed variation of the test scores. The parameter of schooling seemed to have the greatest impact on the students' understanding of difficult concepts. The pilot study gave us methodological experience as to how questions on student problems in mechanics, and preconceptions in particular, could be examined in further research. It set the tone for the research and development activities in the years that followed.

On the basis of the pilot study, further investigations into the persistent conceptual difficulties indicated above were started, first as a function of amounts of instruction received at secondary schools in Zimbabwe and the Netherlands. Also, a study was performed in both countries to investigate the types of alternative student ideas in more detail. Next, classroom interactions and relevant aspects of the educational system in Zimbabwe (such as textbooks used in the schools) in relation to the noted conceptual difficulties were examined. Another development was the design of a lesson series on force that could be more effective in tackling students' misconceptions. The lesson series was tried in a school in the Netherlands; part of the materials were built into the teaching materials of some basic science projects. The effectiveness of this lesson series on force was examined in detail at the school in the Netherlands. The last line of investigations to be reported here is the present focus of our research, which concerns the effectiveness of "concept labs" in the process of conceptual change of students. This research was initiated at VUA and, in parallel, a similar interest developed at PESC in Botswana (Thijs and Bosch, 1992).

Cross sectional studies were performed throughout secondary schools, both in Zimbabwe and the Netherlands. A VUA staff member became research associate of the Department of Science and Mathematics Education at the University of Zimbabwe to enable periods of fieldwork in Zimbabwe. About nine secondary schools (five in urban, four in rural areas) could be visited in the course of the periods of fieldwork, and a total of more than 1,000 students ranging from form 1 to upper 6 (A level) were tested using a questionnaire on the concept of "force" (Kuiper, 1992).

In the Netherlands, cross sectional studies were performed in two schools, showing the same picture of a transition from an intuitive stage, through an intermediate to a correct stage. However, students in the Netherlands sample had relatively few intuitive ideas and relatively many correct ideas as compared with the Zimbabwe sample. This result can be illustrated (see Figure 1) by showing the rate at which the "impetus" misconception is overcome in secondary education in Zimbabwe and the Netherlands. The coordinate "amount of instruction" corresponds to the number of school years as far as forms 1 4 are concerned. Because the amount of physics instruction in higher forms is about twice as intensive, forms 5 and 6 correspond with units 6 and 8, respectively.

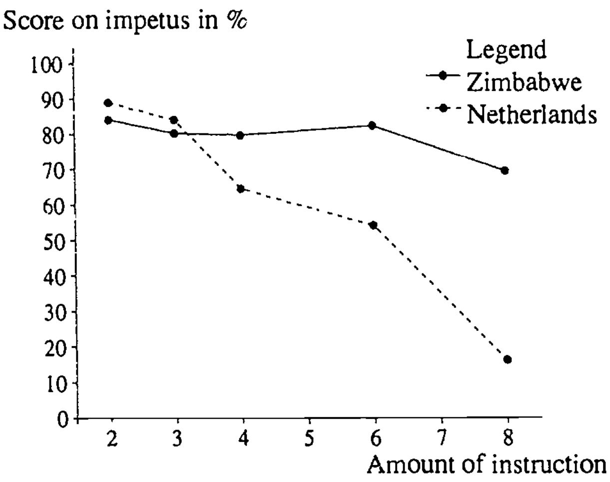

Figure 1. Presence of Impetus as Function of Amount of Instruction. Comparison of Zimbabwe With The Netherlands.

The administered test identified the same preconceptions, which were more persistent in the Zimbabwe schools. There could be a number of reasons for this difference in persistence of preconceptions between the two countries (Thijs and Kuiper, 1990), such as those listed below.

1. Language: The medium of instruction in Zimbabwe schools is English, which is mostly not the mother tongue of the students; in the Netherlands the medium of instruction in the schools is the mother tongue. Conceptual problems are often intermingled with language problems.
2. Curriculum parts devoted to the subject area of force are perhaps not equally substantial.
3. Qualifications of teachers: In Zimbabwe, a number of secondary school teachers are under qualified, whereas in the Netherlands

most physics teachers are properly qualified.

4. Teaching methodology differences: In Zimbabwe, teachers resort more to chalk and talk, and students are generally more passive in lessons, raising fewer questions of a conceptual character.

5. Differences in streaming: In Zimbabwe, all secondary school students attend O level type of instruction; in the Netherlands, secondary school students attend four types of schools: VWO (pre university stream) (20%), HAVO (general secondary education higher stream) (19%), MAVO (general secondary education lower stream) (30%), and MBO (vocational stream) (31%). Students in a VWO school can further specialize after form 3 and choose, for instance, a B stream that concentrates on natural sciences and mathematics. In Zimbabwe, specialization into three science/mathematics subjects can take place after form 4 when students enter A level.

6. Cultural differences: In Zimbabwe there are fewer technological influences in daily life and more elements of a traditional society. The types of distinctions and reasonings as made in physics are not equally supported and capitalized outside the classroom (Thijs, 1984).

Although the above factors could not be further explicated and weighted on their respective effects, the findings of the cross cultural studies have clearly contributed to our reflections on the complexity of the science education context .

Developments in the Physics Course in PESC

Students in Botswana who have completed O-levels and wish to study science at the University of Botswana apply to follow the Pre-Entry Science Course (PESC) at the University. Those that successfully complete PESC enter Year 1 in the Science Faculty.

Within the physics component, elementary mechanics constitutes an important part of the basic knowledge taught in PESC. Proper understanding of the concept of "force" is one of the main teaching aims of that part of the physics course.

It was found that the level of student understanding was low, and that in most cases the course did not result in improvement (Smith, 1989). A strong need was felt to modify the course and intensify teaching of conceptual understanding, using a constructivist approach.

To achieve this the part of PESC-physics devoted to "force and motion" has undergone a great number of modifications in the period 1988-1992, of which the most important are the following.

1. Teaching time for '"force and motion" was expanded from 2 to 5 weeks in 1989.

2. As the course books in use did not address these student ideas, teaching/learning materials were written, revised, and expanded throughout the period 1989-1992.

3. New practical work was introduced, aiming to show the discrepancy between student ideas and empirical phenomena.

4. Computer demonstration programs were used in areas where incorrect ideas are very resistant to teaching.

Among the modifications relevant to reducing "Impetus" ideas was the introduction of the following lab in 1991:

F(pull) is exerted by hand on a trolley, and a backward force is exerted by a hanging mass (big enough to make friction negligible). The yellow-black string is driven by an electromotor and given a constant speed, variable from 0 to about 2 m/s. The trolley is given the same speed as the *string, and students measure the forces, after qualitatively predicting what will be found. In the design of the lab, great care was taken to satisfy the conditions and structure of a "concept lab."*

(Van den Berg and Giddings, 1992)

A strongly teaching-resistant and highly frequent idea among students entering PESC is: "An object that moves has a force in the direction of its motion" ("impetus"-idea). To describe the changes in the understanding of Newton's Laws, it is useful to distinguish 3 different types of situations involving this idea.

1. An object moves horizontally while friction is absent; no forces act parallel to the direction of motion. Newton's First Law applies. Students would state that the object has a forward ("impetus") force, maintaining the motion.
2. The projectile is launched, forces (partly) parallel to the motion remain to be present. Newton's First Law does not apply. Students would generally identify the correct forces, but add an extra force in the direction of motion.
3. The object moves uniformly, under the influence of a forward and backward force. Newton's First Law applies. Students, however, would say the forward force is bigger than the backward force, and more so if the speed is higher.

Pre- and post-tests were administered to elicit whether students use these ideas (and various others). The change C in frequency from pre- to post-test per year is chosen here as the indicator of effectiveness of that year's course: C = (pre score) - (post score).

By averaging several questions, the effectiveness with respect to each of these student ideas can be determined. The higher C, the more effective the course is. We have chosen here to regard scores on student ideas, rather than scores on correct answers, with the idea that an improved score on the correct answer could be the effect of memorizing "what the teacher said." Similar effects can reduce the score on the student idea as well; it remains important to stay aware that such effects may occur.

Table 1 shows the reduction of scores on these 3 student ideas from pre- to post-course test. The values are based on averages of 2 or 3 questions for each idea. (In 1989 only 1 question.) Averaging pre-scores over all years yields following average entry levels: Ideas 1, 2, and 3, are used by 69%, 74% and 70% (s_{n-1}=20%, 17% and 12%), respectively.

Table 1. Reduction of Scores on Impetus Ideas From 1988-1992

(Pre - Post-) Score (%)	1988	1989	1990	1991	1992
i. Horizontal, frictionless motion			11	55	51
ii. Projectiles	-3	9	29	32	31
iii. F(forward) > F(backward) at v constant	[illegible]	29	27	32	51

The effort in modifying the course in the area of "impetus"-forces has yielded positive results. In 1992, even though in the area of Ideas i. and iii. about 25% of the students still use these ideas at the end of the course, every second student in the course changed her/his mind to what is physically correct. The contribution of the lab described above to changes in Idea 3. is illustrated in Figure 2. The Graph is based on a total of 11 questions, dealing with Idea 3.

About 1 in 4 students starts of with the correct idea of balanced forces in uniform motions. The practical convinces about 1 in 2 students of this rule. This result is retained at least up to 4 months after lab 4. Classroom

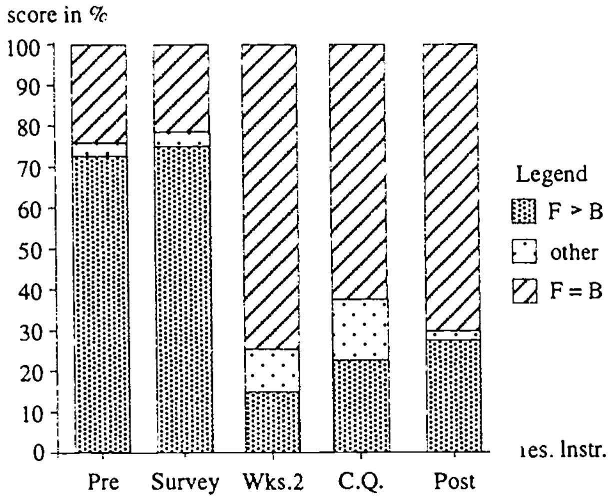

Figure 2. Comparison of Forward (f) and Backwards (b) Force

observations suggest that the main impact of the lab is due to the unexpected character of the observed results. However, comparison with results of earlier years (Table 1) shows that special care for the structure of the concept lab has further improved its effectiveness.

The data presented illustrate that the increased attention for student ideas, and the careful modifications in the teaching strategy carried out accordingly, do have positive results. However, these are limited quite narrowly to the specific situations and properties of quantities discussed. Students are virtually unable to independently transfer obtained knowledge to related areas of physical understanding.

Botswana Teachers In-service Workshop on Preconceptions

After several years of developing and testing teaching strategies in the PESC physics course, staff was confident that these experiences could be of use in teaching physics at secondary school. This section of the paper reports on four in service workshops on preconceptions in mechanics which were held in 1992. A working committee was formed to organize the workshops with input from PESC and INSET (the sister project on in-service of the Department of Mathematics and Science Education at UB). Some teachers of the capital region joined the committee to provide an input from secondary schools at an early stage. At first the teachers were not convinced that it would be realistic to tackle students' conceptual problems in O level physics. They commented: "What do you want to achieve in school physics? Understanding, or the largest number of passes in the examination? How can you teach these kids proper physics? There is no time for that and they won't understand. Concentrate on simple things and let them memorize notes." In the end, however, most teachers were prepared to support the preparation of the workshops. Four weeks prior to the workshop the participating schools received a student questionnaire to be administered by the teachers in one of their classes. The questionnaire was supposed to be marked during the workshop. This experience was expected to clear the way for fruitful discussions.

The workshops lasted 2 days; a Friday and a Saturday were used to minimize disruption of classes. The workshop started by asking the teachers to answer a questionnaire on their understanding of mechanics at O level and slightly above, covering the same topics as the students' questionnaire.

A selection of questions from the teachers' questionnaire:

Q1 What is the resultant force on a ball that has been thrown upwards at the highest point?

Correct answer: "gravity." Misconception: "no force" (motion requires force)

Q2 An object is attached to a vertical spring. The object is lifted and released: an oscillation occurs. What is the acceleration of the object when it reaches the lowest point of an oscillation. State the direction (up, down, no direction) and the magnitude (maximum, minimum, zero).

Correct answer: maximum up. Misconception: zero (acceleration as speed)

Q3 Persons A and B are each pulling at the end of a rope. A is winning and the rope moves towards A. A exerts a force on B. Choose from one of the following: B exerts a smaller/equal/ larger force than A.

Correct answer: equal to A. Misconception: smaller than A (in interactions, one object dominates the other).

Table 2. Results Obtained by 32 Physics Teachers

Question	Q1	Q2	Q3
Correct answer in %	34	38	34

The results show considerable teachers' problems, more serious than originally envisaged.

Of the series of activities: awareness, understanding student thinking, and developing teaching strategies, the last could not be given the time needed. Teachers would definitely need more time to reflect on strategies that could be used at school. The activities of the first day, in particular the marking and discussion of students' work, had created an open atmosphere. This atmosphere remained even after the teachers saw the disappointing results of their own questionnaire. Teachers started to explain to each other how to understand the physics in these questions. The workshops certainly did not remedy all misconceptions of the teachers. Only a start was made. However, one of the greatest achievements of the workshops was the professional interaction among the teachers themselves, and it is hoped that this attitude will survive once they are back in school. Also, it is expected that the booklet has provided enough materials to stimulate teachers to carry on thinking about this topic.

Concluding Remarks

Research into misconceptions on force initiated at VUA in the Netherlands has stimulated the development of PESC course materials, the design and enrichment of practicals, and the provision of meaningful in service workshops to physics teachers in Botswana. The promotion of research in the framework of the basic science projects from the side of VUA has certainly had a positive influence on the creativity and innovative mindedness of the project staff, as we have seen for case of physics in the Botswana pre entry science course. The small scale research collaboration between VUA and PESC has developed successfully in the last years. The collaboration as developed is, however, strongly person dependent. For an effective implementation of the research results into the educational practices in Botswana, it is most important that the collaboration keeps its dual character.

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Promoting Learning and Fostering Conceptual Change in Science

Vivien Talisayon

Introduction

What is learning? How do children learn? How can teachers facilitate learning? Education continue to grapple with these age-old and far-reaching questions. Learning in science has to consider, in addition, the nature of science that deals with both theory and experiment.

This symposium addresses some aspects of views of learning in science, with emphasis on approaches to promoting learning. General issues and concerns are initially discussed, followed by detailed presentations of studies and concept papers.

Learning as Conceptual Change

A widely held view of learning in science is the constructivist view. Student are believed to construct or create concepts as they learn. Learning is a process of conceptual change (West & Pines, 1985). The constructivist view underlies several studies on learning in science education in the past two decades. Descriptive studies assessed students' notions, preconceptions, misconceptions, and alternative conceptions or frameworks (Gilbert & Watts, 1983; Osborne & Freyberg, 1985; West & Pines, 1985; Driver et al., 1985; Novak, 1987; White & Gunstone, 1992). Cross-national assessment studies in physics were performed in selected Asian countries (APPTEA, 1989; ASPEN, 1990).

Across countries, cultures, ages and school systems, some patterns emerged. For example, common alternative conceptions of students in physics (APPTEA, 1989; ASPEN, 1990; Law, 1991) include:

1. A force always acts on a moving body.
2. No force acts on a body at rest.
3. Force is needed to keep a body moving.
4. Force is in the same direction as motion.
5. There is current inside a cell in an open circuit.
6. Current is used up when it passes a resistor.
7. Light is a source, effect or state.
8. The stronger the light, the greater the force produced and the farther it travels.

Among frequently used assessment methods are: (a) word association (students giving the first word associated with a science concept), (b) analysis of errors (students' answers, explanations, solutions different from scientific ones), (c) concept mapping (students making a network of concepts from general to specific ones), and (d) the predict-observe-explain method (given a laboratory setup, student predict, observe, and explain observations vis-a-vis their predictions).

Some explanations given for students' notions, preconceptions or alternative conceptions are:

1. Differences between daily life thinking and scientific thinking (Duit et al., 1992)—intuitive, cluster, context-bound, few-inference thinking in daily life vs. logical, precision, context-free, many-inference thinking in science; and

2. Greater exposure of students to daily life thinking and experiences than to scientific thinking/ experiences.

Strategies for Conceptual Change

Translation of research results into classroom use is important in the improvement of science education. Given several students' notions, preconceptions, or alternative conceptions and some possible explanations, how can the science teacher foster conceptual change?

Many researchers are agreed on the importance of assessing or eliciting students' notions about a concept before teaching it. As Ausubel (1968) puts it, "The single most important factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly." Earlier cited methods used by researchers can be employed by classroom teachers to ascertain students' notions before teaching a concept. How to teach the student accordingly is a more complex matter.

Driver et al. (1985) suggest the following procedure: (a) orientation by the teacher, (b) elicitation of student ideas, (c) clarification and exchange of ideas among students, (d) input of scientific ideas by the teacher, (e) comparison and evaluation of different ideas by students and teacher, and (f) reconciliation of conflicting ideas by students. McDermott (1992) sums up this procedure as: elicit, confront, and resolve.

Nachtigall (1992) outlines a teaching -learning model:

1. Isolate and focus on a particular phenomenon.
2. Activate preknowledge (preconceptions and misconceptions).
3. Become aware of when explanation of a phenomenin becomes a problem.
4. Assimilate and explain to show that phenomena can be explained.
5. Generate a mental conflict (existing mental structures are inadequate and impotent to assimilate stimuli).
6. Accommodate (modify, adjust and rearrange mental structures).
7. Establish cognitive harmony (new structure is applied and recognized as productive; successful in making quantitative predictions).
8. Internalize new mental structure (used in various areas; limits and extent of structure realized).
9. Become aware of the process and one's progress (aware of one's preconceptions or misconceptions and gets insight on how one learns).
10. Use new structure to discover general structure in the environment.

Assessment methods, such as concept mapping and predict-observe-explain method, have also been tried and found effective in fostering conceptual change in science (Pankratius, 1990; McDermott, 1990; White & Gunstone, 1992).

Experiential and Contextual Learning

An earlier view of learning science, prevalent from the 1960s until the present, particularly in developing countries, is that learning science is doing it. Doing science and involving all senses is superior to merely seeing or hearing about it. Doing science can be called experiential learning, drawing on the idea that experience is the best teacher. Emphasis is on practical work, scientific processes, and inquiry skills. McDermott (1990) believes in experiential learning to bring about conceptual change in physics and advocates a laboratory-based curriculum. The predict-observe-explain method for conceptual change is laboratory based. Her similar strategy is observe-recognize-apply.

In recent years, an emerging view of learning science is learning it in context (Mazzolini & Mazzolini 1992), specifically in relation to technology, society, and student's daily life and environment. The underlying principles are: (a) learning is facilitated by situations that students can relate to and appreciate; and (b) bringing the relevance of science to the fore can motivate students to study science.

Community-based science teaching (Kelly & Schaefer 1980; Penick & Meinhard-Pellens, 1984; Talisayon et al., 1984), which addresses science-related community needs and resources, is an example of an approach to promote contextual learning. Furthermore, contextual learning of science is particularly important to developing countries as this is perceived to contribute to the economic and technological development of a country (Talisayon, 1986).

Overview Of Presentations

This symposium focuses on selected aspects of experiential learning and on learning as conceptual change. Specifically, the presentations deal with concept mapping as a strategy for conceptual change, a learning model based on cognitive conflicts, and on practical work and process skills. The investigations on concept mapping deal with Israeli high school students' representation of knowledge in electromagnetism (Bagno & Eylon, 1993) and with American college students' learning of evolution (Trowbridge & Wandersee, 1992). Both studies use concept mapping as an integral instructional strategy.

The proposed learning model (Kwon, 1993) is based on three kinds of cognitive conflicts: (a) Between old (existing) cognitive structure and new phenomenon, (b) between old and new cognitive structures, and (c) between new cognitive structure and old phenomenon. The model suggests a procedure for inducing and resolving the conflicts at different phases of the learning process.

One paper on science laboratory work cites learning advantages of improvised apparatus and presents the thesis that properly organized practical work is the motivating factor for effective learning (Too, 1993). The other paper is a study on integrated process skills of Singaporean high school students comparing explicity and tacit knowledge for performing science laboratory investigations (Toh, 1993). The results show significant advantage of explicity instruction only in certain processes of practical work.

Conclusion

The discussion of the symposium is limited to some views of learning and selected strategies of promoting learning in science. With its generally accepted cognitive, psychomotor, and affective domains, learning science may well be multi-faced and complex. It is, therefore, likely that there are several pathways to learning science. Given some research findings of the persistence of alternative conceptions in science up to tertiary level, learning science may well, indeed, be a long process. The challenge remains for researchers and teachers in science to continually look for shorter pathways to learning science.

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Concept Mapping in a College Course on Evolution: Identifying Critical Junctures in Learning

John Trowbridge and James Wandersee

Prologue

The global community clearly needs competent scientists and engineers, as well as scientifically literate citizens. However, Abdus Salam has estimated that 6% of the world's scientists and engineers live in developing countries—although those same developing countries contain 77% of the world's population (Raven & Wilson, 1992). What can be done to improve science teaching worldwide and, thus, to distribute this knowledge more equitably? One possible answer is to encourage and assist science students integrating the new scientific knowledge we are teaching them with what they already know about the natural world. We see concept mapping as a fruitful teaching strategy for achieving these goals.

Purpose

Although a detailed exposition of the research study described here will appear in the Special Issue on Evolution Education of the *Journal of Research in Science Teaching*, our purpose here is of a more practical nature. We wish to suggest an instructional system by which concept mapping can be introduced into college science lecture courses and to present some evidence of its effectiveness. It might be used by teachers in developing countries to great advantage with little additional expense.

Subject Matter Context

Evolution is one of the great unifying themes of biology, yet it has proven difficult for students to understand in a meaningful way. Misconceptions abound and even when students can correctly apply evolutionary theory, their knowledge often rests on trust in the authority of the scientist, rather than on a meaningful understanding of the underlying scientific evidence. Effective instruction requires sensitive indicators of cognitive progress and simple feedback mechanisms that allow both the teacher and the learners to make "mid-course corrections" during knowledge construction.

The Decision to Use Concept Mapping

Because we were interested in monitoring changes in students' knowledge structures during a one-semester college course in evolution, we devised and tested a simple concept mapping system designed to be practical enough to use, even by instructors of large classes. Because map construction fosters reflection upon instruction, organization and semantic linking of relevant science concepts, and prioritization (ranking) of those concepts, we choose to employ concept mapping in our system.

The instructor choose one evolutionary biology lecture each week that students could concept-map for extra credit in the course. Figure 1 shows the system design in flow chart format. Figure 2 provides an example of a micromap (containing 12 elements or less), the type of concept map we suggested the evolution professor require of his students. Immediately before a mapable lecture, he would list 5 seed concepts to be introduced in the forthcoming lecture, and subsequently to be incorporated into each student's concept map of that lecture. Pupils were free to choose their own superordinate concept (found at the top of their map's hierarchy) and to add up to seven additional map elements, such as examples or related concepts. Students were asked to follow the mapping conventions illustrated by the standard concept map

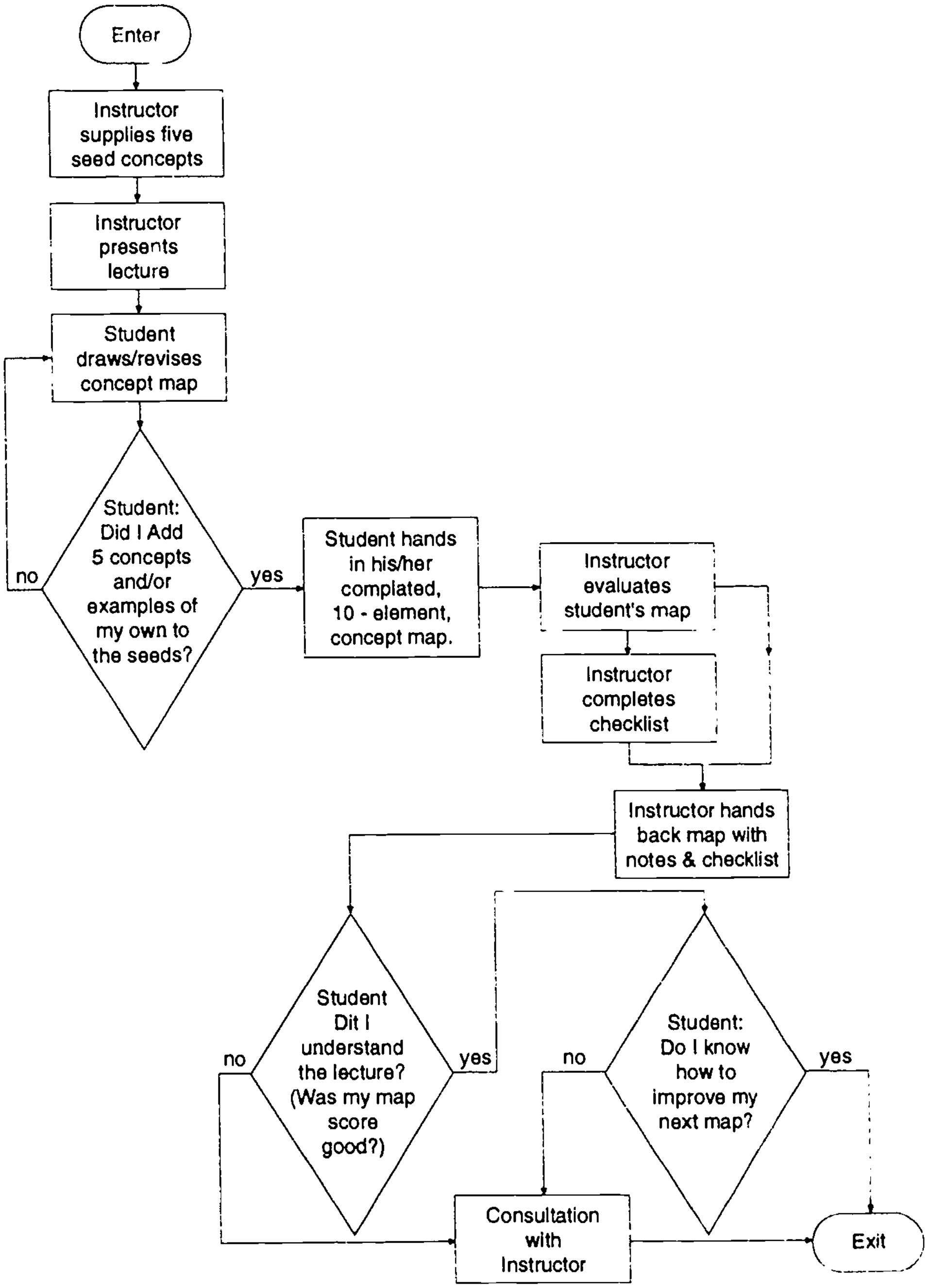

Figure 1. The System Design in Flow Chart Format

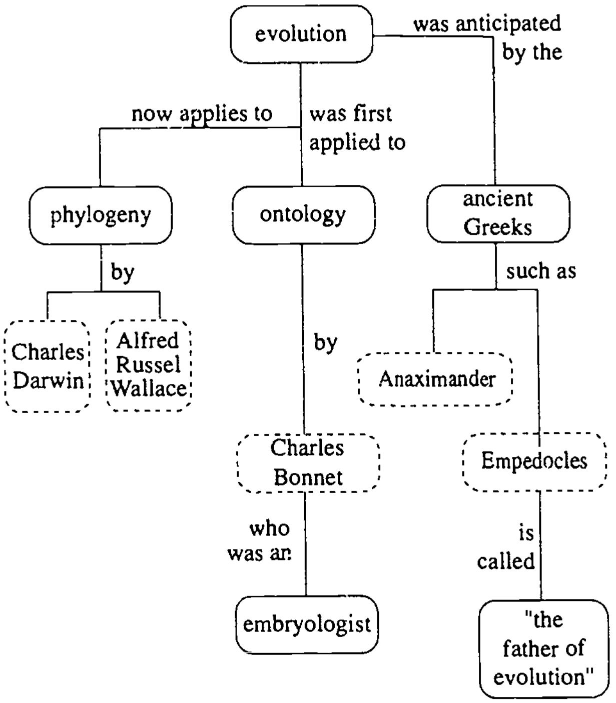

Figure 2. An Example of a Micromap

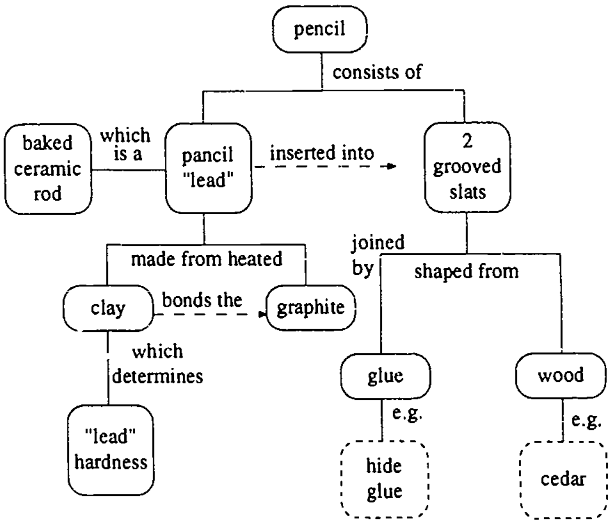

Figure 3. The Standard Concept Map

shown in Figure 3, so that maps could be easily interpreted by both the students and the professor. Their work was evaluated by the professor using the standard concept map checklist we developed (see Figure 4).

A Brief Summary of Our Research Findings

We discovered that by allowing students to choose their own superordinate concepts when mapping a lecture, we could assess the concordance of the class set of concepts selected and thereby gauge the effectiveness of instruction. The less agreement regarding a given lecture's superordinate concept, the greater the confusion students revealed about their understanding of the lecture topic.

In fact, we claimed that such difficult-to-map lectures represent critical junctures in understanding the course content—a vital building block for future learning and worthy of the professor's best instruction. Interestingly, the evolution professor in our study actually retaught parts of some lectures after he evaluated the concept maps that his students submitted for those lectures. He had not done this before—hence the potential of concept micromaps as feedback mechanism.

The instructor was able to evaluate each student's micromap in 5 minutes or less, a rate he deemed reasonable, even for larger classes. He was also pleased to learn, via our survey of his students, that because of concept mapping, his students reported spending 37% more time preparing for this course than for any of their previous college biology classes. The average time students reported for map construction was 48 minutes, and we found that time on task, not number of revisions, was the better indicator of map quality.

Students were eager to receive their annotated, graded concept maps from the instructor, and he commented that never before had students asked him penetrating questions about course content on occasions other than the eve of exams. He saw it as a way to establish an

1. Does the map contain the 5 seed concepts? ——————— Yes ————— No
2. Are all the links between concepts precisely labeled? ————— Yes ————— No
3. Does the map have labeled cross-links? ———————— Yes ————— No
4. Does the map contain examples (preferably novel examples)? — — Yes ————— No
5. Is the map treelike instead of stringy? ————————— Yes ————— No
6. Is the superordinate (top) concept the best choice, given the way the rest of the concepts are linked? ———————————— Yes ————— No
7. Are the examples included appropriate? ————————— Yes ————— No
8. Is the map of acceptable scientific quality? ———————— Yes ————— No
9. Has the mapper used the proper map symbols and followed standard mapping conventions? ——————————— Yes ————— No
10. Is the map limited to approximately 12 elements? —————— Yes ————— No

Figure 4. The Standard Concept Map Checklist

Note: *The Standard Map is found in Vol. 27 (10), page 933, of the* Journal of Research in Science Teaching, *December 20, 1990 issue. Checklist © 1992, J.H. Wandersee*

ongoing scientific dialogue with his students and to probe their understanding of what he was attempting to teach them. In fact, he was so pleased with the concept mapping approach that, upon the advice of his students, he made the maps mandatory the next semester he taught the course.

A science course such as evolutionary biology is "concept rich," and its increasingly sophisticated concepts build, relate, and integrate as the course develops. Here concept mapping seems to lend itself to such cognitive construction.

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Student Learning Processes in a Computer-based Teaching Approach of Quantum Physics

Hans Niedderer and Jürgen Petri

Approach and Development of Teaching Materials

The basic ideas of our approach to quantum physics can be summarized as follows (Niedderer et al., 1990):

From Bohr to Schrödinger

Whereas most teachers at the moment teach atomic physics on the basis of Bohr's model, the Schrödinger model within our more qualitative approach, based on the notion of *standing waves*, allows for more and better explanations, especially in relation to chemistry, and is nearer to what scientists of today believe. We use the analogy of standing waves to understand *the basic concept of state* (n, W_n, ψ_n) in atoms, molecules, and solids.

Reduce the Mathematics Involved in a Schrödinger Approach

We do not use analytic solutions of the Schrödinger equation; instead we use the Schrödinger equation in a "semi-quantitative" way to understand how the shape of ψ-functions depends on a potential $V(r)$. We use the computer to calculate ψ'' and to compute states (n, W_n, ψ_n) with correct boundary conditions.

The *analogy of standing waves* is shown in Table 1.

The concept "state" is defined by its name n, the energy eigenvalue W_n and the spatial form, given by a qualitative description, or its nodal surfaces, or the number of nodes, or the function ψ_n in an algebraic or graphical representation. Important features of a qualitative understanding of atoms in this approach are:

1. The existence of discrete states in analogy to standing waves; and
2. A spatial three-dimensional conception of size and shape of atoms, especially enforced by the notion of nodal surfaces (three-dimensional orbitals instead of two-dimensional orbits).

The teaching materials contain hands-on experiments with standing waves on an inhomogeneous string and related model building by students with computer (Macintosh with model-building software STELLA).

Table 1. The Analogy of Standing Waves

String		Atom
Standing waves		ψ - functions
numbers n		quantum numbers n
Frequency f_n		Energy W_n
	STATE n	
Amplitude $y_n(x)$		Amplitude $\psi_n(r)$
Nodal points		Nodal surfaces
Border condition: node		Border condition: $\psi \Rightarrow 0$
Inhomogeneous string		Varying potential
$m' = f(x)$ (mass density)		$V = V(r)$ ("potential well")
$y_n''(x) \sim -f_n^2 * m'(x) * y_n(x)$		$\psi_n''(r) \sim -[W_n - V(r)] * \psi_n(r)$

The model is shown in Figure 1. A string consists of a perlon filament. From 0 to 38 cm this is without beads, whereas from 38 to 53 cm yellow beads with a mass of 80 mg/cm are mounted on the perlon filament. This string gets a tension from a weight of 0.2N and is oscillated by a DC-motor and electric oscillation generator (see Figure 2).

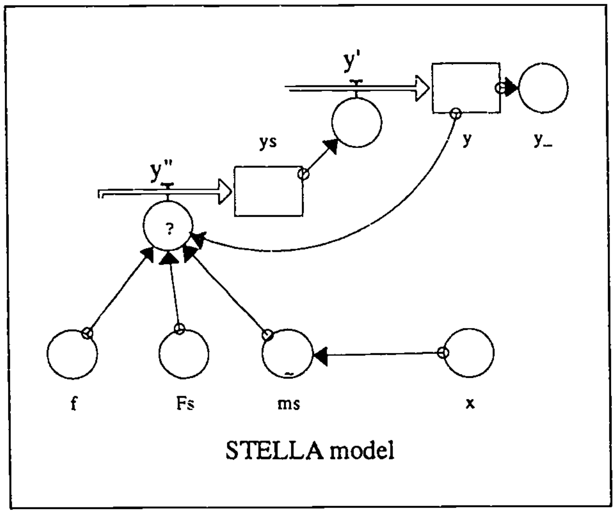


Figure 1. the STELLA Model

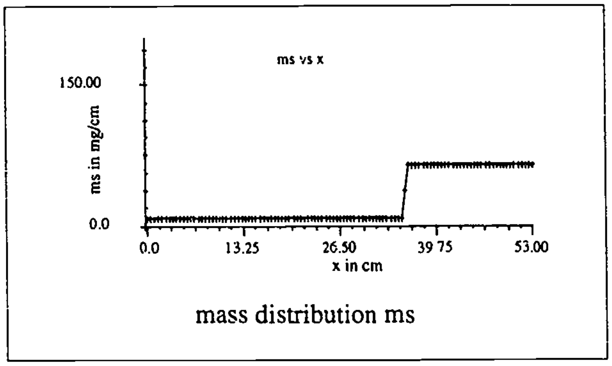
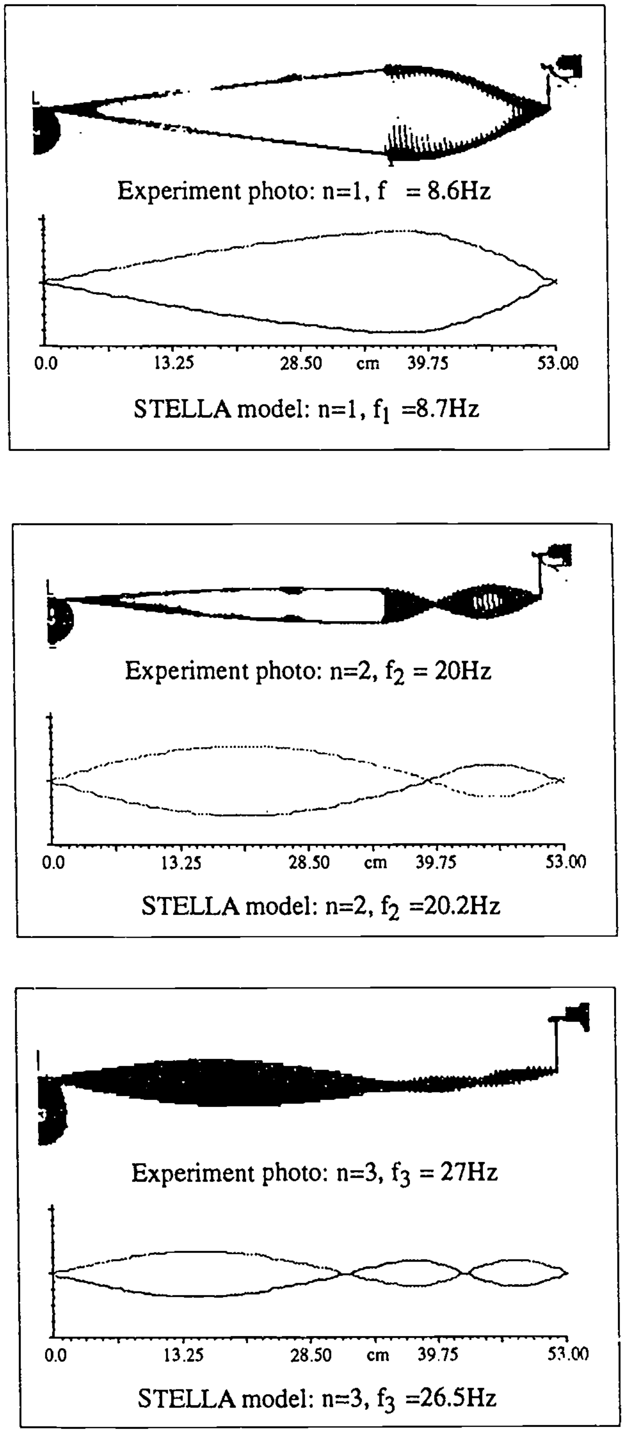


Figure 2. Mass Distribution in the String

Figure 3 shows some results:

The same approach is demonstrated with 2-dimensional standing waves on a drum and with 3-dimensional standing sound waves in spherical glass tube (analyzed with a microphone or a glowing wire). In all these cases the amplitude has a well-known physical meaning, and the graphs produced by the computer model are easily understood. The same kind of models are developed for a hydrogen atom, with V=- 1.44/r {V in eV, r in nm}. With this model you get the results


Experiment photo: n=1, f = 8.6Hz

STELLA model: n=1, f_1 =8.7Hz

Experiment photo: n=2, f_2 = 20Hz

STELLA model: n=2, f_2 =20.2Hz

Experiment photo: n=3, f_3 = 27Hz

STELLA model: n=3, f_3 =26.5Hz

Figure 3. Results of Hands-on Experiments

shown in Figure 4 for the state n=3.

These ψ-functions are discussed to evoke three-dimensional conceptions of the H-atom (Figure 5), using the previously shown nodal surfaces of standing sound waves in a spherical tube as an analogy. These conceptions can be interpreted as electron-charge distributions (chemistry) or as "regions of presence" of the electron (see concept "shell" below).

Important features of the whole approach are projects of students with hands-on experiments and "brains-on" model building for the same problems (standing waves on an inhomogeneous string, light spectra, and energy levels of a hydrogen atom).

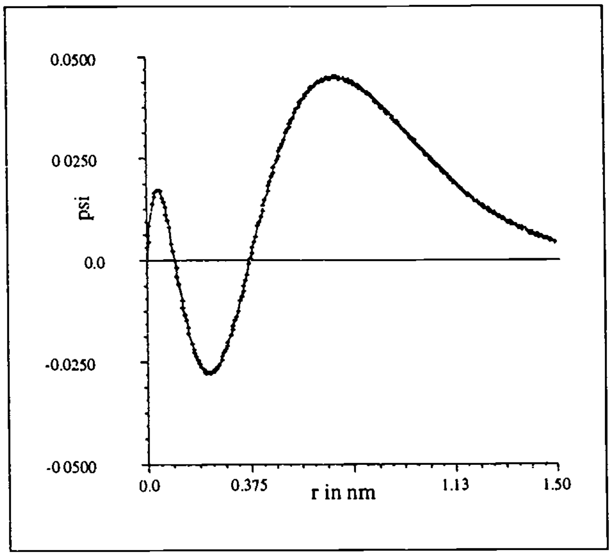


Figure 4. Models for the H-Atom: Result for State n=3

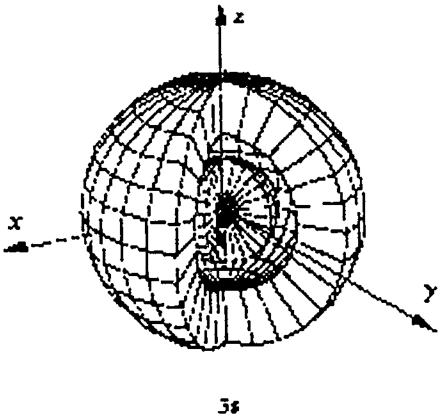
Research on Learning Processes

We aim at explicit hypothetical models (Figure 6) of what is going on in students' minds in their cognitive system (Niedderer & Schecker, 1992). All empirical evidence is gained from a qualitative interpretive analysis of student-oriented learning processes that were videotaped, transcribed, and analyzed with an iterative interpretive strategy (Niedderer, 1989). In the field of quantum physics, some research of this kind has been done in our group by Bethge (1988) and Petri (1992).

Example: One Student's Change of Meaning of the Concept "Shell"

Petri's study (1992) was done in an ordinary high school advanced physics course in grade 13. Two students were videotaped in their group activities, in additional interviews, and during class discussion. The concept of "shell" is related to one major aim of the course, namely to foster spatial conceptions about orbitals in different states of the atom.

We describe some changes with respect to the meaning of "shell" the student Sven was doing during this learning process in quantum physics during a period of 6 weeks.



(Preuβ and Reimann 1990, 27)

Figure 5. 3-Dimensional Conceptions of the H-atom

Sven here already mentions "regions of presence" of electrons, a notion not introduced by the teacher, but obviously helpful to enforce the intended spatial conceptions. These regions are limited by shell-shaped nodal surfaces.

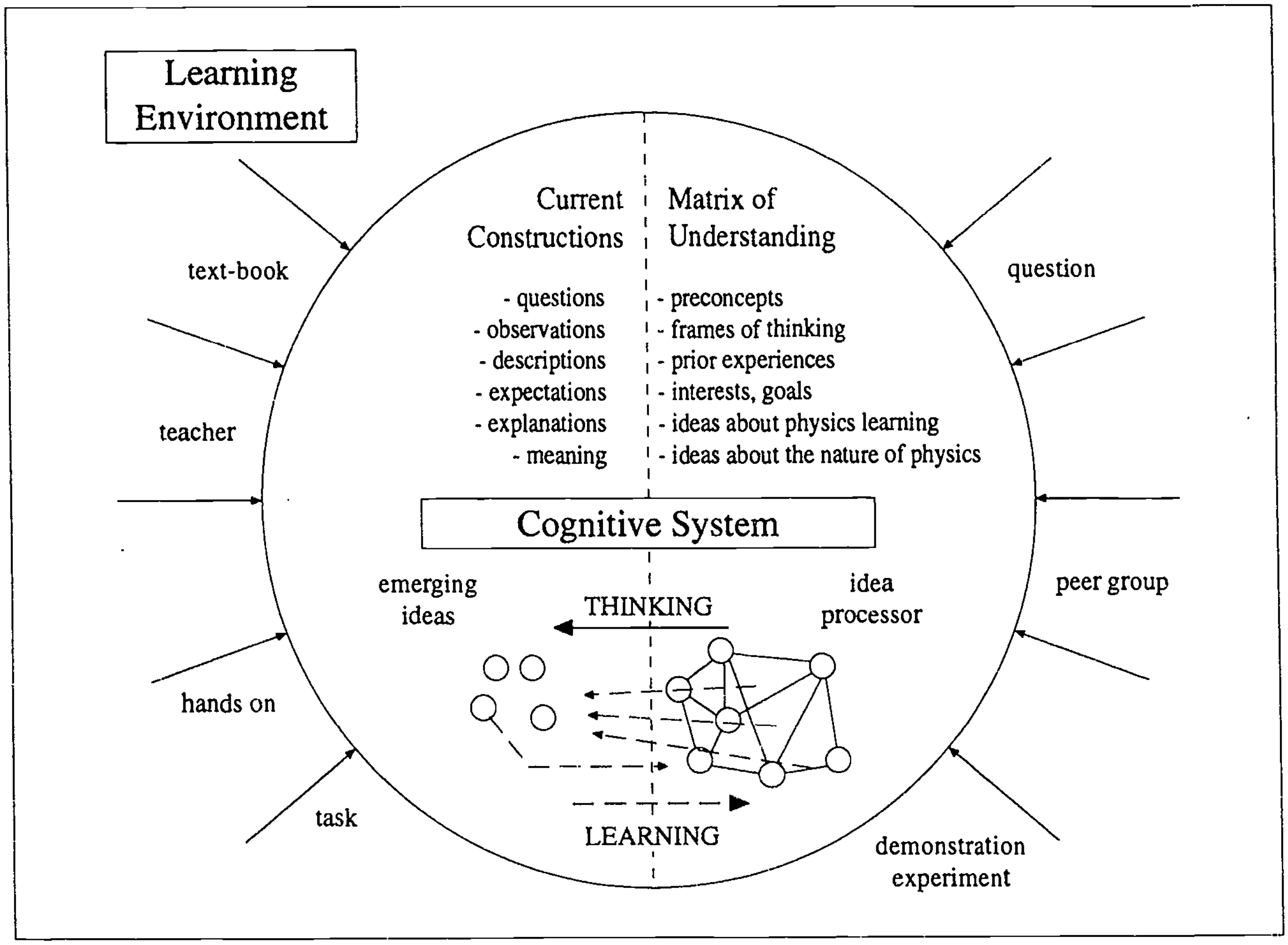


Figure 6. Explicit Hypothetical Model of the Learning Process

1. Sven at the start of instruction: "Shell" with a meaning related to radius and state of energy, similar to Bohr's planetary system. In this atomic shell model, the electrons are found in/on circular shells. Each shell, by its radius, represents a certain state of energy of the electrons.

   Sven: Starting from - that's what I read - well that the electrons - when starting from a shell model, that the electrons are raised to excited states by the energy of the electric current and, falling back, emit photons of a certain wave length. And the different shells then represent the different colors.

   Mike: . . . The shells may represent the form of the energy!

   Sven: They are energy states, these shells. The higher it jumps, the shorter the wave length of light will be.

2. Sven at a later stage: "Shell" with a meaning related to three-dimensional nodal surface

(which limits the regions of presence). Shells are nodal surfaces of standing (probability) waves, fitting onion-like into each other, limiting the regions of presence of electrons in the atom.

> Sven: We have these three-dimensional standing waves; we noted that there exist nodal surfaces; firstly, what they look like . . . and then we somewhat decided ourselves to the shell-shaped nodal surfaces and then described these - the standing waves in relation to the nodal surfaces - as a possible interpretation of regions of presence of electrons, considering the three-dimensional wave as a probability wave.

3. Sven at a third stage: "Shell" and "orbital," shells are "shell-shaped orbitals." "Shell-shaped orbitals result from the wave structure of electrons in the atom, and explain the structure of electrons in the atom " (Dorn and Bader, 1986).

> Mike: . . .and that here (the exponential part of the ψ-graph, J.P.) is the first shell, but the graph does not go back!
>
> Sven: Then this *(the first maximum, J.P.)* is the shell, the first orbit we are looking for, and that here *(the meeting point with the r-axis, J.P.)* is the limit *(of the atom, J.P.)*!
>
> Teacher: The notion "shell" seems to be rather confusing in this context!
>
> Sven: Yes, orbit!
>
> Teacher: The orbital! (. . .)
>
> Mike: Well, we cannot speak of shells. There are no real shells, but . . .
>
> Sven: Let's say, shells are shell-shaped orbitals! Such thick onion shells completely going round. . . .

In further discussions with the teacher Sven continues to prefer the notion of shell. He is even differentiating his conception of "onion shells," realizing the shells change their position and diameter from state to state.

> Sven: An orbital is shell-shaped! If there are shells it is mysterious that they become narrower in higher states . . . they are moving closer the higher the state.

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The Relevance of Differential Learning Psychology for Science Education

Evelin Witruk

The Relationship Between Differential Learning Psychology and Science Education

We can begin by asking how and why human beings differ widely, both in the manner and in the results of learning. Differential-learning psychology mainly aims to prove and explain individual characteristics and type-specific peculiarities of individuals' learning. It ought to test varieties of purposeful differentiated influences on individual learning behavior. Science education is connected with these aims of differential learning psychology, which involve the explanation of inter-individual differences in learning processes and learning effects and the differentiated optimization of individual learning behavior.

Figure 1 illustrates the desired circular process of our research strategy aimed at studying differential learning problems, especially of education practice; analyzing them based on a certain theory; and finally applying the results and conclusions in practice. This

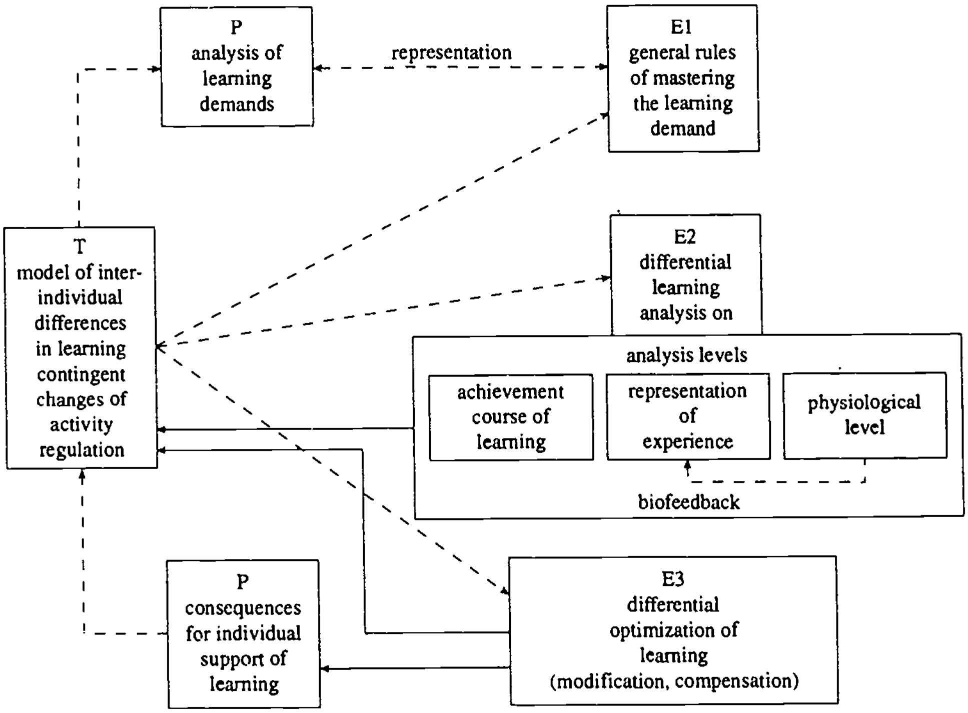


Figure 1. Research Strategy of Differential Learning Psychology

research strategy usually included the following three experimental phases, one upon the other:

1. The first experimental phase (E_1), according to general psychology, is the starting point and allows the representation of general rules for coping with demand.

2. The second experimental phase (E_2), according to differential analysis, is where phase individual and group-specific variants of demand coping are illustrated and explained, including:

   - Achievement and course of learning;
   - Representation of experience; and
   - (As to the physiological level), characterizing the psychophysiological effort.

3. On this basis, in the third experimental phase we can start to optimize the individual, especially dysfunctional activity regulation. Thereafter, one could speak of modifying optimization procedures, if regulation structures are directly changed, as, for instance, in training and promoting programs. As opposed to this, compensatory optimization methods by well-aimed creation of external conditions try to adapt dysfunctional behavior regulation to the optimum range, that is, remedy that behavior, where the foundations of regulation fundaments cannot be changed directly. Special instruction, carrying-out and feedback variants belong here, too, as application of the aptitude-treatment-interaction model.

Applying the results in practice (P) is a gradual process, which ought to be supported by validation tests. We tested this research strategy using learning conditions of widely varying complexity. In principle, five different approaches seem to exist:

1. The *process-oriented approach* starts from different problems of coping with demands in learning. Here, the problem is mainly to clear up the variability of ways and results of learning in the most profound manner. For this, time series analysis can be used, and it is possible retrospectively to determine types of learners.

2. The second approach is focused on the measurement of *learning effects*, if no information about the course of learning is available. The purpose of this approach is the optimal explanation of the inter-individual variability. The aggregation over persons can be done retrospectively also. During the last 4 years, we have developed a new pre- and post-test design, which eliminates error- and retest-effects and which makes it possible to describe the actual treatment effects and the goal-achieving effects both for the single cases and the types of learners. This allows classification of five types of learners (see Figure 2):

   - type I, having treatment and goal achieving effects
   - type II, having only treatment effects
   - type III, having goal-achieving effects
   - type IV, having neither treatment nor goal achieving effects
   - type V, showed no effects because they already achieved the goal during the pretest. There is no need for intervention.

This linear pre- and post-test design was developed by Lander (1990) and is based on splitting parts of differences in a linear regression model resulting from measurement errors and retest effects, and calculating the actual treatment effects and the goal achieving effects. The example illustrates the positive effect of motivation for orthography on learning parameters. For most training and enrichment programs, the arousal of motivation is the most essential prerequisite.

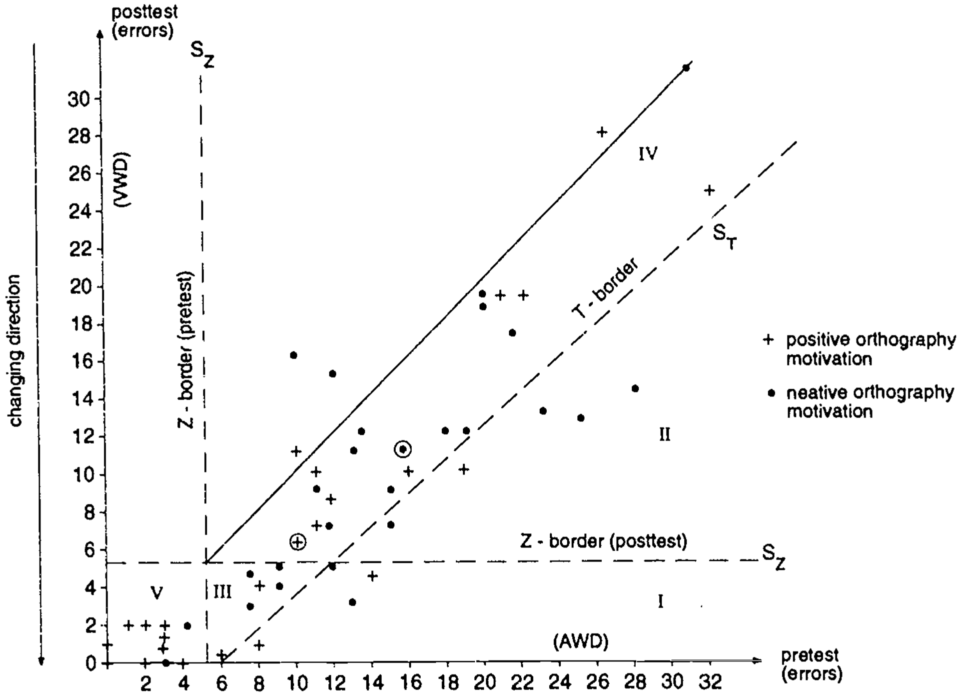


Figure 2. Differential Learning Effect Analysis of Orthography Acquisition on the Base of the Linear Pre- and Post-Test Analysis by Lander (1990)

3. The third variant of approach starts from problematic groups of learners or other specific groups of persons and seeks to determine the origin of the dysfunctions. This approach may be called *oriented toward groups* of people. As a rule, test designs for extreme groups are applied here. The optimization phase must take into account the special groups of people. In this approach, we have focused on dyslexic children and on underachievers. Many conclusions may be derived here also for the science education of children, for instance, with regard to the dyslexia-specific deficits in working memory or with regard to the specific intelligence structure and high abilities of underachievers in the field of technical giftedness.

4. The fourth approach consists in a trait- and state-orientation, that is, in investigating the influence of certain traits and states on the learning process and its results. We have analyzed the influence of certain characteristics of subjects' cognitive styles, their previous knowledge, and specific abilities on various complex learning processes. As we know, there are relationships between traits and states on the basis of combination and compensation. Some variables function to moderate or suppress the effect of other variables. We use structural models to explain these relationships.

5. The fifth approach calls for the analysis of complex interaction between traits and states of the learners and the determinants of their learning

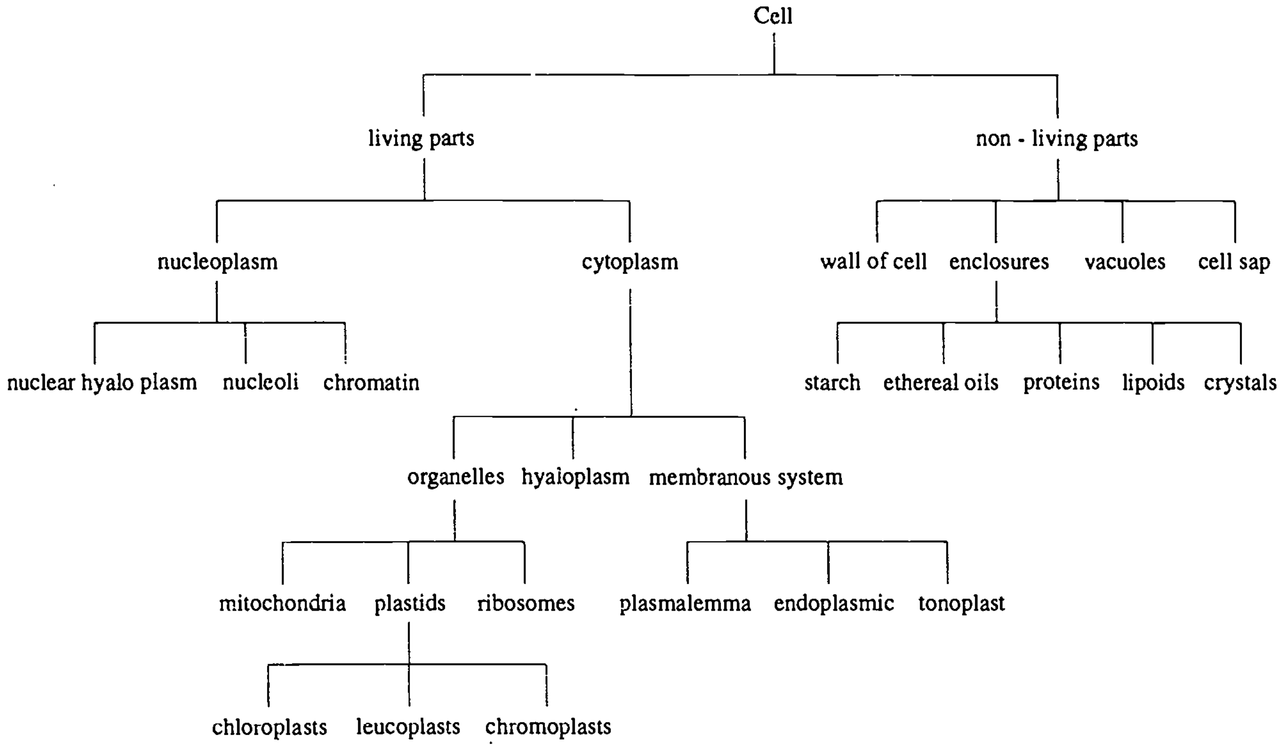
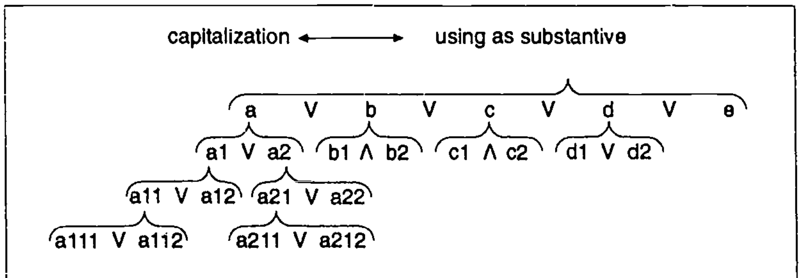


Figure 3. Teaching Cytology in Grade 12: Parts of the Cell



rules:

a) article before the verb

b) attribute before the verb

c) possessive pronoun before the verb

d) preposition before the verb

e) it is possible to write an article before the verb without changes in the sense

Figure 4. Hierarchic Structure of Rules for Capitalization of Verbs (Procedural Knowledge in German Orthography) (Witruk 1992)

and developmental environment. We use causal structural models and multi-level analysis (in the latter case, to describe the influence of levels differing in generality on the course of learning).

Recognition and Memory Performance for Hierarchic Structures of Rules and Concepts

This section describes some examples of our process-oriented approach and how they relate to science education. We investigated the spontaneous acquisition and use of hierarchical systems of rules and concepts, found in mathematics, and orthography. Figure 3 shows a hierarchical concept structure from biology about the parts of the cell, which is taught in grade 12. Figure 4 shows a hierarchical rule structure of German orthography for the capitalization of verbs, which was studied among 8th graders. Figure 5 shows hierarchically structured, non-verbal material, which we investigated in a differential learning process analysis on university students.

We analyzed the spontaneous acquisition of the rule structure in a free reproduction format involving the structure of material (stone for stone). We can describe the process of learning during four phases, using four different material structures and the parameter errors, reaction time, necessary inspections of the standards and psychophysiological effort. Our assumption is that the generation of hierarchical structure is a working principle of our memory. It is directed toward using relationships between neighboring events in the spatio-temporal sense to generate partial structures that will be reassembled on the basis of their relations. A sequence of events is then transformed into a hierarchical structure, which makes it easier for our memory to retrieve the events. We also see a differential optimization effect of verbalization, especially for impulsive students (Figure 6).

We found a dynamic learning progress with high interindividual variability. This involved variously combined strategies of recognition of single rules and

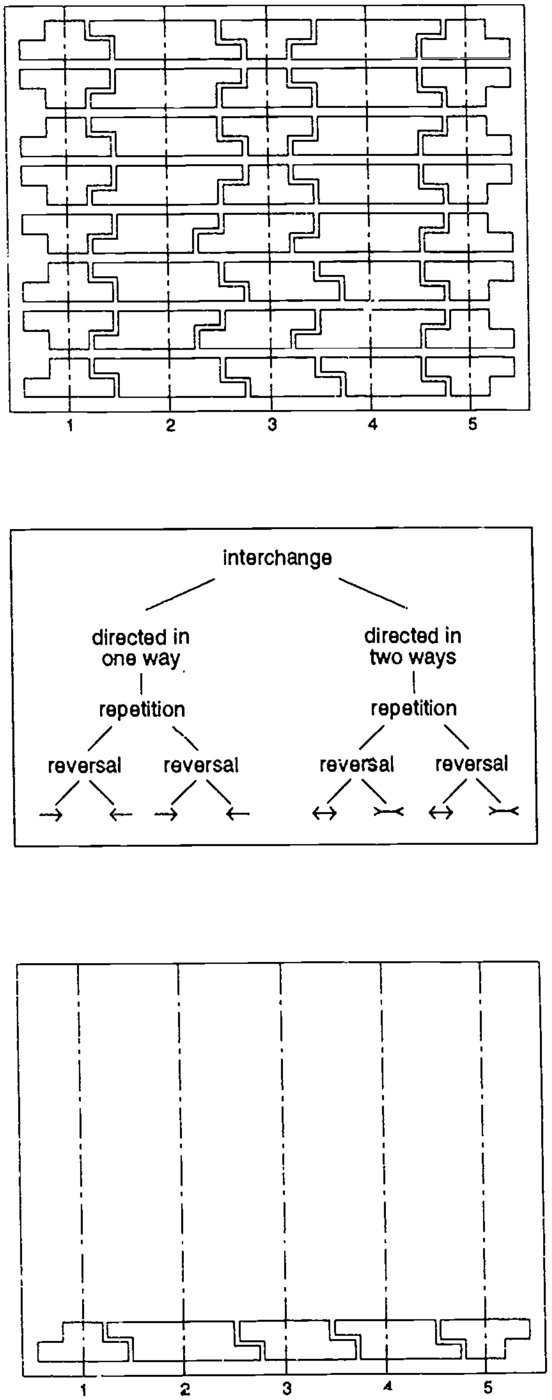


Figure 5. Example of an Item Representing a Sequential Structure on the Basis of a Hierarchical Rule System

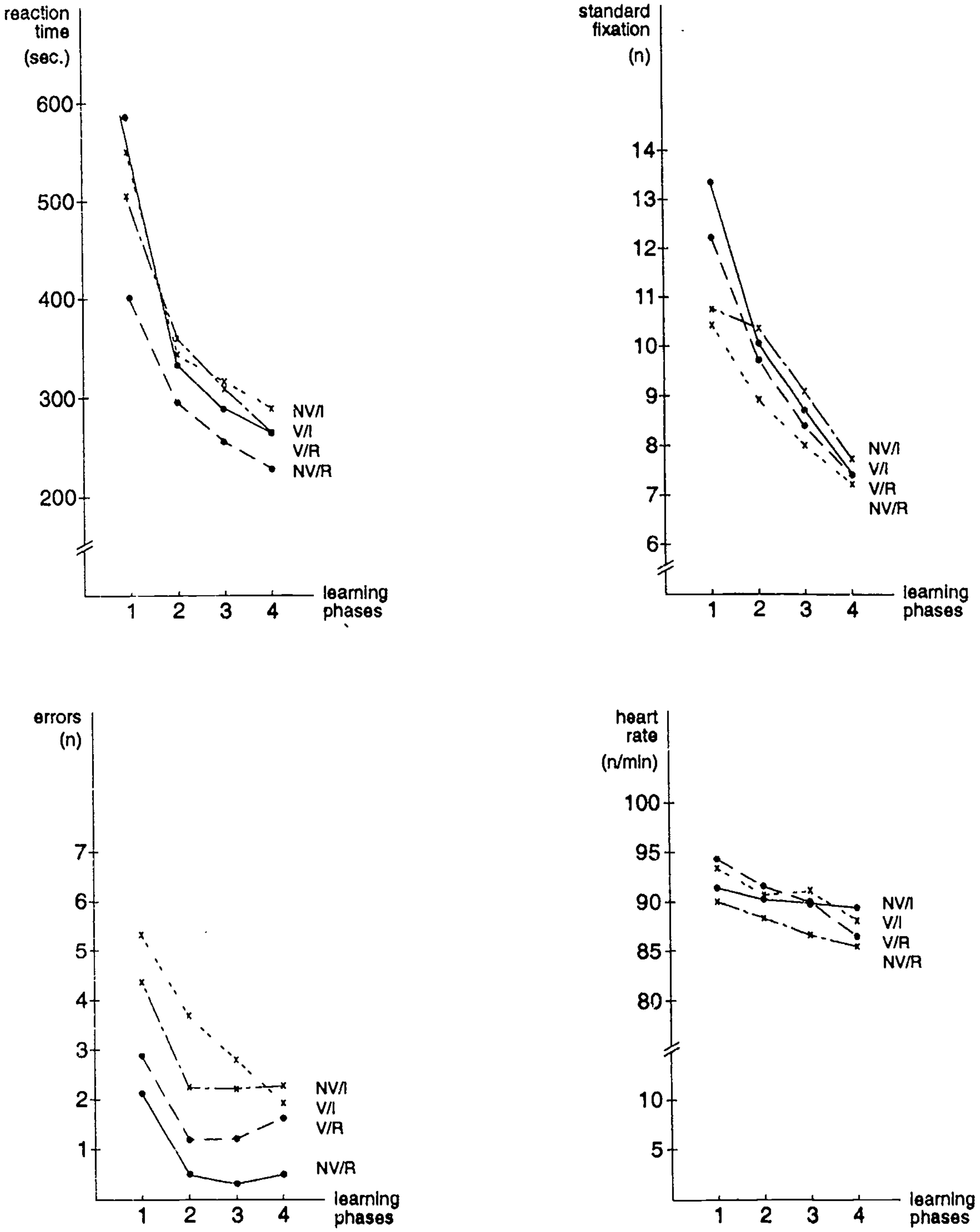


Figure 6. Differential Analysis of Learning Courses of Impulsive (I) and Reflexive (R) Students on the Demands of Verbalization (V) and No Verbalization (NV)

memory for single item patterns. We explain this with the tendency of minimization of the cognition and memory effort to an individual optimum. The other two possible strategies involve a higher effort: the recognition of all rules and the rule structure makes high demands on working memory and on cognitive processing.

The third strategy of learning all single items involves a high demand on our long-term memory. The individual solving strategy for the actual task will be selected with a minimal effort on long-term and working memory and on the cognitive processing demands that are connected with negative consequences for the long-term memory. For all subjects, the verbalization effects were, in general, positive. As compared with the non-verbalization group, these subjects showed significantly better recognition of the rule system based on a higher degree of awareness during the learning process. However, we did not find the expected differential optimization for impulsive students. The time parameters of the learning process is significantly related to recognition time for the hierarchical structure "cell" (Figure 3). There was also a significant correlation for the general intelligence factor (figure reasoning). The practical conclusion we may derive from thes findings for science education is that the spontaneous recognition of implicit hierarchic structure of rules and concepts cannot be expected for all students. However, the teacher can optimize and support this learning process by verbalization and by explicit generation of the structure on the basis of student-teacher interaction.

The results of the third experiment points in the same direction. For normal and dyslexic students the number of errors is highly dependent on motivation and gender differences. Classroom work was not concerned with the structure of rules.

In summary, the aim of this paper was to point to the relationship between science education and differential learning psychology with reference to the recognition of hierarchical structures of rules and concepts.

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Language, Gender, and Assessment in Physics

Peter Logan, Elizabeth Hegarty-Hazel, and Patricia Gallagher

Introduction

Research on student learning has shown that assessment is one of the most powerful determinants of students' approaches to study and, arguably, of decisions to continue enrollment. In this paper, we report on the interaction of language, gender, and assessment of students in physics at an Australian university.

Strong arguments have been made by Murphy (1988) that an equitable assessment of knowledge assumes that question cues are understood in the same way by all students, the task perceived by students matches the assessor's perception, failure on a task reflects a lack of the knowledge being tested, and that the form of expression selected is appropriate to skills/knowledge being tested and is unproblematic for all students. These assumptions are not always valid because students do not necessarily have similar out-of-school experiences and, therefore, have differences in learning styles. Rennie and Parker (1991) synthesized research findings at high-school level with reference to the mode of testing, the item format, and the item context. They argued that assessment procedures are invalid if they fail to elicit knowledge from students who in fact possess the knowledge; for assessment to satisfy both construct and content validity, a variety of forms of written and oral communication is required to enable students to demonstrate their knowledge of subject matter and problem-solving abilities.

We have found the literature on the role of language background in science assessment at university level to be sparse, with few studies addressing the issues of importance to our project. Horton (1971) compared patterns in traditional African thought and western science. He found a difference to be that in traditional cultures there was less-developed awareness of alternatives to the established body of theoretical tenets. In scientifically oriented cultures, there is a highly developed awareness of alternatives. Consequently, qualitative assessment questions asking for alternatives to be presented and discussed may be to the disadvantage of students from traditional cultures. In an overview of language and physics, Logan (1981) raised concern that if the students translate questions into their own language there is likely to be considerable language and cultural interference. Logan and Bailey (1989) showed that students of non-English speaking background (NESB) have trouble with some of the non-technical words in science such as "in terms of," "further," "hence," "conversely," "indeed," "apparently," "randomly" and "theory." We believe that NESB students may prefer questions with clear explanations, preferably with a diagram and a unique mathematical answer. Cassels and Johnstone (1984) found that the effect of language on student performance in science operated at a subtle level where, for example, positive measures of magnitude were more uniformly understood than negative ones.

Scheuneman (1987) clarified two major sources of assessment bias—the characteristics of examinees that manifest group differences and the characteristics of tests or test items that have different effects or create different demands between groups. For the British 16+ exams, Harding (1979) found sex differences, with boys performing better on multiple-choice questions and girls performing better on essay-type questions. Scheuneman and Gerritz (1990) concluded that women and minorities are not disadvantaged by the MCQ format itself, but by a combination of item features that produce an accumulation of small effects, each of which is related to the weaknesses of one of the groups being compared with the strengths of the other. They used the phrase "test-wiseness" to denote students' appreciation of what is expected in a test or item and found test-wiseness to be a function of race (but it seems that in other settings it could be a function of gender or class). Hegarty-Hazel, Gallagher and Logan (1992) recently reported that traditional university physics assessments may be biased in favor of male students, if their preference for short quantitative questions or MCQ is mirrored by performance.

We conclude that the range and form of assessment questions is potentially contentious from the perspectives of both language and gender in the physical sciences.

The Project Setting and the Students

The project was carried out with all physical science students enrolled in first-year physics. There were 128 students, with 48 (38%) female; 34 (36%) were students with NESB. For this study, NESB students were defined as those who were born in a non-English-speaking country, had undertaken at least primary education there, and who speak a language other than English for more than 25% of the time at home. There were four groups for comparison: male and female students with English Speaking Background (ESB), and NESB male and female students. For this paper the four comparisons of special interest are NESB/ESB, male ESB/male NESB, female ESB/female NESB, male NESB/female NESB.

There were two dimensions to the project. The first is the diagnostic testing administered during students' first week at university. These tests included mathematics readiness, language, and physics concepts readiness tests, as well as approaches to learning and attitudes to different science subjects. Some paired test questions were used in these tests to investigate the effect of context, diagrams, negative statements and concepts, use of Plain English, and use of everyday rather than textbook situations. The second dimension included various forms of continuous assessment (40%) administered during the semester and a final examination (60%). To provide variety of assessment, multiple-choice questions were added to the traditional class tests and the final examination. Qualitative questions, including mini-essays were added to the class tests, the laboratory examination, and the final examination. The laboratory report form was modified to require full discussion of results.

Student Results on Different Forms of Questions

Results from the paired questions used in the diagnostic test were as follows.

All students performed better with questions using Plain English (as distinct from academic or verbose). Plain English is to be preferred. Any use of negatives, whether in the question itself or using a negative concept like "smallest" or "lowest," disadvantages all students. Diagrams helped all students. Therefore, we conclude that unless there is a point in having the student translate the question from a written form into an illustration, diagrams should be used where possible.

Surprisingly, students performed better on "no context" (abstract) questions. In a number of questions, context references were added that would aid understanding and convey to the students an idea of where the abstract question would be applicable in everyday life. This resulted in poorer performances, possibly because the students were more familiar with the abstract question types from their secondary school studies. Many students could not go from the abstract to the concrete. We had expected that all students, but especially female students, would perform better at the specific question "in context" than at the matching decontextualised abstract question. This was not the case. In many cases the students could answer questions on basic principles but could not apply them to a real-life situation. This suggests students had only a superficial understanding of the principles.

Content Analysis of Assessment Items

Content analysis perfomed on all the items used in

Table 1. Content Analysis of Assessment Items

	Class	Tests	Practical	Exam	Final	Exam	Total	
	1991	1992	1991	1992	1991	1992	1991	1992
	%	%	%	%	%	%	%	%
TYPE								
quantitative	94	70	40	33	85	57	78	62
qualitative	6	32	60	67	15	43	22	38
STRUCTURE								
MCQ	0	47	0	0	3	31	2	36
short definite	97	32	40	33	85	49	84	40
short flexible	3	21	40	50	12	20	11	22
report	0	0	20	17	0	0	3	2
CONTEXT								
none	49	62	20	33	62	59	52	57
masculine	19	6	20	33	22	10	17	10
feminine	4	2	0	0	0	4	1	2
neutral	29	30	60	33	16	27	30	31
STYLE								
plain English	90	98	100	100	97	92	81	86
academic	10	2	0	0	3	8	19	14
diagram	25	21	40	17	37	24	46	33

the continuous assessment and the final examination for Physics 1 in 1991 and 1992 are shown in Table 1 (in this table the percentages are based on the number of questions). The categories used were as follows (for more detail, see Hegarty-Hazel, Gallagher and Logan (1992).

1. Type: A question was coded as *quantitative* if the required answer was numeric or algebraic. If the required answer was verbal, the question was coded as *qualitative.*
2. Structure: This concerned the format of the questions, which were assigned to one of the following four categories: the *multiple-choice* question (MCQ), the *short-definite* question, the *short-flexible* question and the *report.*
3. Context: This concerned whether the question was set in a context, and if so whether it was masculine, feminine, or gender neutral.
4. Linguistic Style: The different linguistic styles include *Plain English* or *Academic Language, Concrete* or *Abstract* questions and questions with or without diagrams.

Student Performance

Table 2 shows students' overall performance on three

Table 2. Student Performance on Different Types of Assessment

	MCQ %	Flexible %	Quant %	Total %
Class	58	53	50	57
Women	52	50	45	52
Men	61	54	53	60
NESB	56	48	50	56
HP - W - ESB	57	62	56	63
HP - M - ESB	65	55	56	63
HP - W - NESB	55	44	50	54
HP - M - NESB	62	55	58	64

different question types—multiple choice, short flexible and standard quantitative (thus, it does not include weekly laboratory mark and laboratory report mark). Comparisons are made by gender and by language background (ESB and NESB), with further comparisons for those students who had completed the same higher school certificate examination the previous year (HP). The men performed significantly better on the multiple choice questions and the women on the short flexible questions (t test, 5% level).

Table 3 shows numbers of students and their grades using the new type of assessment package introduced in 1992. The grades are H (high distinction), D (distinction), C (credit), P (pass), F (fail). The table also shows predictions of 1992 results based on 1991 assessment package (row 2). It is seen that fewer students obtained a distinction on the new pattern because the new pattern required a greater breadth of understanding to obtain high marks. However, we see a different effect near the pass mark. Seven students who had an adequate knowledge to pass the course when a range of assessment types was used, would have failed if the older, highly quantitative pattern had been used.

Discussion and Implications for Teachers

In the past, quantitative questions had been used extensively for assessment in the course described here, as it was felt that those were the types of problems a physics graduate would encounter. It had not been recognized that students might be able to perform well on quantitative questions without a good qualitative understanding of the issues. There was probably an implicit understanding by staff that students who could perform well on the quantitative questions would also perform well on qualitative questions and on the MCQs. However, we found students who did very well on quantitative questions but could not explain the concept correctly. Others could explain concepts but were not able to apply them to quantitative problems.

Table 3. Student Grades With Different Assessment Patterns

		H	D	C	P	F
1992	Assessment Pattern	7	9	23	53	22
1991	Assessment Pattern	7	13	21	44	29

Our findings on language background were that although the male NESB students performed less well than the male ESB students in the diagnostic language items on arrival at university, their performance in the course overall was equivalent to that of the male ESB students. However, female NESB students performed poorly in the diagnostic language items and poorly throughout the semester, including on the qualitative questions (where the female ESB students excelled). This resulted in similar performance overall of male-NESB, male-ESB and female-ESB, but female NESB students performed 10% below the other groups overall. We believe that NESB students, especially the women, should be strongly encouraged to utilize the university English-language support facilities for assistance with their language difficulties. More should be done to help with language and communication within physics.

Findings for different question formats suggested that diagrams should be used wherever possible. Negative statements and concepts should be avoided. Plain English should be used wherever possible. Questions in context and transferring from abstract-to-concrete produced difficulties for all students. We do not suggest that this important link be abandoned but rather that questions in context should be introduced gradually and that students should be provided with examples.

We expect that quantitative questions should still play an important part. But we believe that quantitative questions should be supplemented by short, flexible questions or essays that ask students to explain and discuss concepts and their applications; it is important to explain the working involved in a quantitative question and to encourage students to link the abstract to the concrete. Male students may perform slightly better on MCQs than female students. However, some of the research on student learning links the use of MCQs with students taking a surface approach to their study. We believe that MCQs, if used at all, should be used to differentiate concepts rather than for numerical problems.

Overall, our research findings, suggest that a range of assessment types should be used.

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An Integrative Approach to the Treatment of Learning Difficulties in Electricity and Magnetism

Esther Bagno and Bat-Sheva Eylon

Introduction

Advanced courses on electricity and magnetism at the high school level present a difficult challenge to students because the concepts are abstract and removed from students' experience. Unlike introductory courses in electricity or magnetism, which stress phenomena and simple calculations, advanced courses usually involve a mathematical treatment of central relationships (e.g., Maxwell's equations in integral or differential form) and sophisticated problem-solving tasks. The mathematical aspects only form another obstacle to those who are unsophisticated mathematically.

Previous studies on students' learning of DC circuits show difficulties such as the inability to conceive the electric circuit globally as a system and adopting instead local and sequential views (Cohen, Eylon, & Ganiel,1983; Closset,1983); difficulties with the concept of potential and potential difference; the causal relationships of voltage and current (Cohen, Eylon, & Ganiel,1983); inability of students to relate macro and micro relationships in electric circuits; the missing link between electrostatic and electrodynamics (Eylon & Ganiel,1990); and the dominating effects of misleading visual appearances of electric circuit (Caillot, 1985).

This paper consists of three parts. The first part briefly summarizes a diagnostic study that investigated students' knowledge representation in the domain of electromagnetism. The results of the study highlight deficiencies in students' knowledge representation. Following an analysis of the sources for the observed deficiencies, the second part of the paper suggests an integrative model of instruction to remedy students' learning difficulties in the domain. The model includes a proposed knowledge structure and a didactic approach. The approach treats, in an integrative manner, conceptual and procedural knowledge and relates them to the proposed knowledge structure that is formed actively by the students. The third part describes an instructional study that evaluates the efficacy of the integrative model of instruction and compares it with an approach that treats the learning difficulties without linking conceptual and procedural knowledge to the proposed knowledge structure.

The Diagnostic Study

In a diagnostic study (Bagno,1986), students' representation of knowledge in electromagnetism was investigated. The study was conducted among high school students who study physics as a main subject. The sample consisted of nine 12th grade classes (about 250 students, ages 17-18). These students had completed their course in electricity and magnetism and were preparing for their matriculation examination in physics. The level required in such classes is roughly that of first year college in the U.S. or the A-level course in the UK. All classes belonged to good high schools and the physics teachers were experienced.

Four aspects of students' knowledge representation were investigated.

1. *Content*: What is represented? Do students represent the main relationships and procedures in the domain? More specifically, do they represent in some form Maxwell's equations?

2. *Form*: How is the knowledge represented?

What degree of importance do students attach to different ideas in the domain? How do the students represent the information? More specifically, do students represent ideas qualitatively or only in mathematical symbolic representation?

3. *Conceptual understanding*: How accurate is the representation? It is well established today that even students who can correctly quote key ideas in a certain domain and can solve routine problems might hold inaccurate understandings of central concepts and relationships.

4. *Procedural knowledge*: How do the aspects listed above affect students' problem solving performance?

The results of the diagnostic study suggest that students' knowledge representation after conventional instruction is deficient in each of the aspects listed above. 1 and 2: Students' knowledge does not include the "key relationships"; there is an overemphasis of subsidiary ideas (for instance, many students consider Ohm's law to be of central importance); the relationships are represented mainly in mathematical form. 3. Students hold many incorrect ideas. 4. Students' knowledge representation does not support recall and more complex problem-solving tasks that require comprehensive retrieval of information.

These results fall into line with many other studies that indicate that students leave our courses in about the same status as they entered. They have the same misconceptions as when they started (McDermott, 1984; Halloun & Hestenes,1985a, 1985b; Eylon & Ganiel,1990; McDermott & Shaffer, 1992; Reif & Allen,1992). In addition, they still use formula-centered problem-solving methods (Caillot,1985; Larkin et al., 1980) and do not have access to more qualitative representations that are important in experts' reasoning. More specifically, this diagnostic study highlights some difficulties students have in understanding the relationship of an electric field to its sources, motion of charges in magnetic fields, and interpretations of electromagnetic induction.

An Integrative Model of Instruction

Some deficiencies in students' knowledge found in the diagnostic study can be related to the characteristics of instruction found in standard courses, namely to textbooks, exercises and examinations:

1. Some of the over-emphasis and de-emphasis of topics in students' representation reflects the same phenomenon found in the instructional materials.

2. Typically, textbooks provide an overall picture at the local level, namely within a chapter or several chapters, but not a more global view. Thus, the absence of structure in students' representation is not surprising.

3. Most standard textbooks do not emphasize qualitative representations of central relationships. Thus, a summary of the knowledge in electromagnetism traditionally culminates with a mathematical statement of Maxwell's equations.

4. There is no systematic treatment of students' difficulties. Moreover, some of the explanations are misleading and may even lead to erroneous interpretations.

It should be noted that in our analysis of instructional materials we analyzed only the sources that are mutual to many classes—namely, the written materials—and not teachers' practices. We are aware that good teachers supplement exactly these missing features of instruction. However, many studies have shown a close link between the approach of textbooks to those of most teachers.

The implication of the results in the diagnostic study suggest is that there is a need either to redesign existing courses of electromagnetism or to design auxiliary instructional materials that enable students to:

1. Construct an overall structure of knowledge in this domain. In particular, organization should highlight the relationships summarized by Maxwell's equations.
2. Develop understanding of concepts and relationships of electromagnetism that have been diagnosed as difficult.
3. Relate these aspects to procedural knowledge.

These instructional materials should enable students to form qualitative representations in addition to the mathematical representation of these equations.

In principle, one could treat each of these aspects separately, that is, to work with students on diagnosed misconceptions, on the understanding of important relationships, and on difficulties that they have in solving problems. We suggest that the old saying, "the whole is larger that the sum of its parts," also holds in treating these three aspects, and we claim that an integrative treatment that relates the aspects to a central structure of knowledge in a domain leads to better learning than an isolated treatment of each component.

Ausubel's learning theory (Ausubel,1968) suggests that hierarchical structures should be useful in promoting understanding and recall. More recently, Novak and co-workers have developed the idea of "concept maps" as an exemplary learning/teaching strategy (Novak,1981). Many other studies have also shown the utility of such maps in diagnosis and in promoting meaningful learning.

On the basis of previous instructional research, Eylon and Reif (Eylon & Reif, 1984) suggest that the following general features are important in achieving a useful representation of knowledge.

1. The representation should include central information in the domain (e.g., principles associated with Maxwell's equations in electromagnetism).
2. The knowledge should be represented hierarchically. The top levels of the hierarchy should include "general" ideas, whereas the lower levels should include details that are elaborations of these general ideas. Thus, the concepts and the relationships should be represented from the general to the specific.
3. Hierarchical organization can facilitate the retrieval process if it is properly adapted to the task domain. Namely, the top levels of the hierarchy have to include knowledge that is more important for the domain of tasks that are used frequently, or that are most useful for retrieving other frequently used knowledge. Furthermore, each subsequent elaboration should add the next most useful knowledge for the task domain. Thus the resulting hierarchy is organized according to "importance" of the knowledge for the tasks.
4. The hierarchical organization should have an economical representation of important ideas and the relationships among them. In particular, visual representations such as concept maps (Novak,1981) have this property. This feature is most important in light of memory limitations.
5. The representation should highlight important features of knowledge in the domain (e.g., parallelism between electric and magnetic fields in vacuum).
6. It is not sufficient to present a structure. It is also essential to provide methods illustrating how to use the hierarchical structure so that both the structure and the methods will be assimilated actively.

In accordance with the principles outlined above and the idea that the instruction should be applied in an integrative manner, we have designed a hierarchical knowledge structure in electromagnetism.

The proposed structure has, in principle, properties that facilitate an easy linkage of conceptual and procedural aspects. This linkage can be obtained through an appropriate didactic approach in which students actively develop the concept map by themselves through a problem-solving approach.

Design of the Structure

As a first step, *important key relationships* were identified. These relationships essentially summarize principles associated with Maxwell's equations. These relationships were then represented in *a hierarchical structure* that includes several interconnected layers. The different layers constitute the different levels of the hierarchy. The first layer presents a skeleton of the domain at the most general level and consists of a two-dimensional map with key concepts and relationships among them (see Figure 1). Four key concepts (electric charge, electric current, electric field, and magnetic field) and the key relationships between them form the skeleton of the map. The arrows represent relationships. For example, q —> E represents the relationship: "A charged particle produces an electric field"(Gauss's law).

Additional layers represent progressively more specific information about the concepts and the relationships. While the global first layer only states that there is *some* relationship between an electric charge and the electric field that it produces, the next levels specify this relationship in greater detail, including accurate formulae, characteristic examples of how this formula is being derived and used, and so forth.

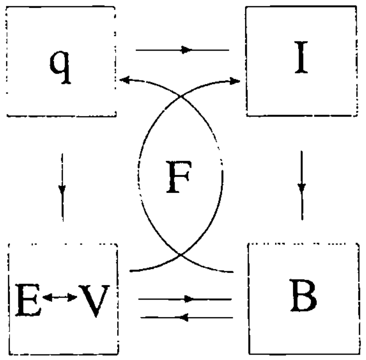

Figure 1. A Concept map for Electromagnetism

The Didactic Approach

The various relationships were introduced *through active problem solving*. As a result, the concepts and relationships were directly linked to characteristic tasks that the students encounter in the study of electromagnetism. Figure 2 shows a representative sequence of learning events in which the understanding of two concepts is improved while they are also related to the central structure. The use of problems that deal with the relevant concepts and relationships in the development of the map, and the explicit linkage of the problems to the structure, enables treatment of the procedural aspect.

As can be seen from the figure the learning sequence consists of several stages:

1. Stage 1—The student is asked to solve a problem (or problems) in which the relevant relationship between A and B plays a central role. These problems can be chosen from standard problems that are used in regular instruction.

2. Stage 2—A written discussion follows in which the relationship is identified and compared with other relevant relationships. Differences and similarities are pointed out, and finally the relationship is formulated verbally, symbolically, and visually. For example, a bi-directional arrow between the electric field and potential difference is used (E <—> V) to emphasize that the first concept can be defined by the second and vice versa. In addition to the relationship, the characteristic properties of the concepts in-

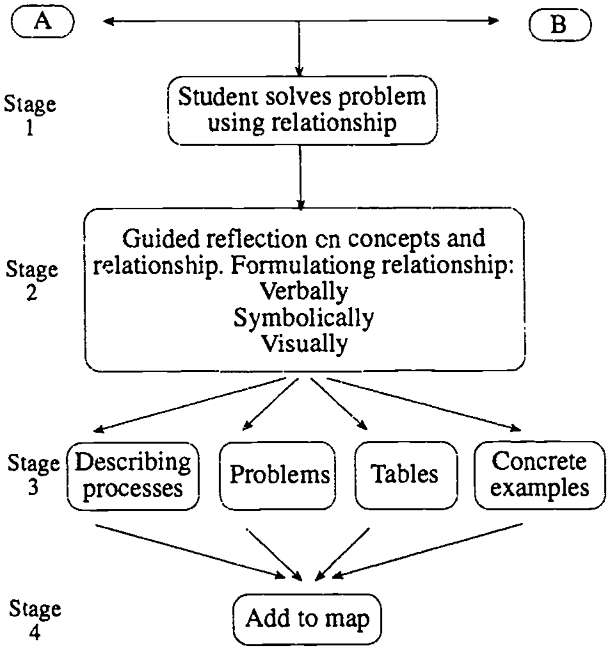

Figure 2. A Representative Sequence of Learning Events in Which the Relationship Between Two Concepts is Constructed

volved are illuminated and the concepts are developed and elaborated. This is the stage in which common misconceptions are pointed out. For example, students tend to mix up the concepts of "potential" and "potential difference," and, therefore, the treatment can clarify the meaning of these two concepts.

3. Stage 3—In this stage the following means are used to help students to create an improved knowledge structure

   a. Concrete examples including non-routine situations illustrate the relationship.

   b. Compact tables are provided to facilitate retention and retrieval.

   c. Students are asked to apply the already defined relationships in non-standard problem solving. For example, from a plot of the electric potential vs. the distance, the plot of the electric field vs. the distance has to be derived.

   d. Students are asked to use the concept map to describe various physical processes. Special attention is given to misconceptions. Non-routine problems that create conflicts are used in each chapter to highlight inconsistencies.

4. Stage 4—The new part of the concept map including A and B and the relevant relationship is added to the previously existing concept map.

The proposed structure and didactic approach were realized in an integrative instructional unit in electromagnetism (Bagno & Eylon,1988), and its design is described in greater detail in Bagno's M.Sc. thesis (Bagno,1986).

The Instructional Study

In the integrative approach that was described in the last section, there were, among other things, two important aspects:

1. Formation of an explicit relationship between problems and a knowledge structure, and

2. Treatment of conceptual difficulties in relationship to a knowledge structure.

It was hypothesized that the linkage to the knowledge structure is essential. In other words, it was expected that if students solve the same problems in isolation from the structure, and if the same difficulties are treated in isolation from the structure, the resulting learning outcomes both in problem-solving and conceptual understanding would be worse than if an integrative approach is adapted.

Method

In the present study we attempted to investigate this hypothesis by comparing the effects of three treatments: One treatment (E) consisted of studying, in addition to regular instruction, the integrative unit in electromagnetism that was designed according to the approach described previously. A second treatment (C1) consisted of studying an alternative instructional unit that included all the exercises and problems given to E, together with a treatment of conceptual difficulties and the same feedback. It did not include the development of the concept map, and, thus, problems and concepts were not related explicitly to a knowledge structure. The third treatment (C2) served as a comparison, and students received only the regular instruction of the teacher. E and C_1 were administered as self-instructional units at the end of regular instruction of the topics.

The sample consisted of nine 12th grade classes (about 235 students, ages 17-18) who studied physics as a main subject. These students had completed their course in electricity and magnetism and were preparing for their matriculation examination in physics. All classes belonged to good high schools and had experienced physics teachers.

All students were given a pre-test in class after they finished their regular course of electromagnetism but before they started studying the self-instructional units; students were given a post-test about a month thereafter.

The tests examined four aspects: (a) content and form of knowledge representation, (b) conceptual understanding, (c) application, and (d) transfer.

Results

Content and Form

Students were asked "to summarize in a few sentences the main ideas in electromagnetism in order of their importance." It was found that in the post-test, students in E, as compared with students in C_1 and C_2, recalled more key relationships (see Figure 3), the information was more accurate (number of correct statements), and more qualitative in form (number of verbal statements vs. a list of equations). Similar results were found on a cued recall task, although the differences were smaller. This is not surprising, since cues help retrieve relevant information and thus the structure is less important.

Conceptual Understanding

Students in E and C_1 whose treatment dealt with some conceptual difficulties demonstrated a significantly better conceptual understanding than students in C_2 (see figure 4).

Application

Two problems were given. The first was a standard problem in which students were asked to find the direction of an induced electric current and to provide an explanation for their choice. The second problem

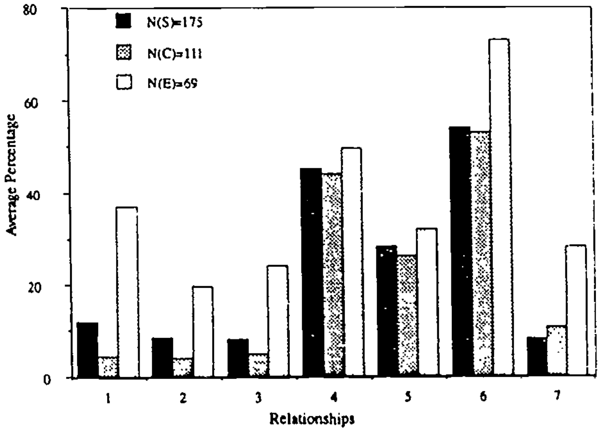

Figure 3. Relative Distribution of The Key Relationships in the Free Recall Task in the Pre-test for the Whole Sample (S) and in the Post-test for Treatments $C=C_1+C_2$ and E.

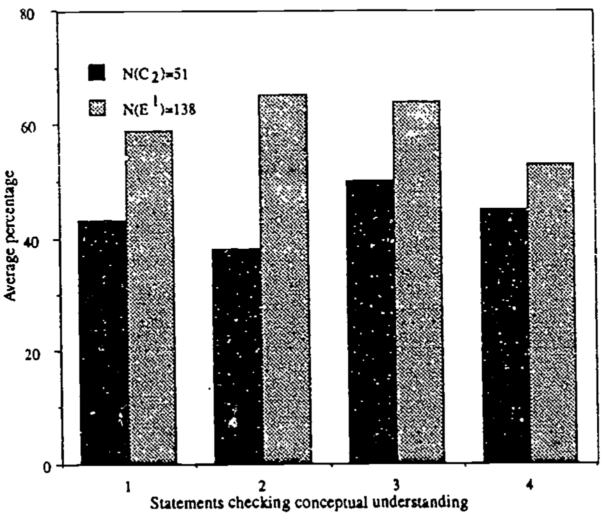

Figure 4. Average Percentage of Students in C_2 and $E^1=E+C_1$ Who Succeeded in the Conceptual Understanding Task

described a complicated unfamiliar physical system in which a certain switch was being closed at some point.

The students were asked to describe the sequence of events that would follow. This problem required a comprehensive search of the whole domain and a selection of relevant information. Thus, it was expected that the performance of students in the E group whose treatment included both organization and conceptual treatment would be better than the performance of students in C_1, or C_2.

The problem was quite difficult, and we did not expect that students would provide a completely correct analysis. We were interested in the following aspects.

1. How "rich" is their analysis of the situation? (how many correct statements can they give about the situation?)

2. What kind of considerations do they employ? (e.g., do they use an energy consideration?)

A significant effect of the treatment (E vs. C_1 and C_2) was found for both the standard and non-standard problems. In particular, the organizing structure helped students retrieve the information necessary for analyzing complex situations.

Transfer

Students were presented with a paragraph taken from an unfamiliar discipline and were asked to write the main concepts and relationships in it. Students in E identified significantly more main concepts and relationships than students in C_1 and C_2.

Conclusions

This study proposes an integrative instructional approach that is centered around the construction of a hierarchical concept map by students. The map is constructed by students in stages. At each stage students add to the map certain concepts and the relationships between them, in conjunction with solving problems that use these concepts and relationships. As a result a linkage is formed naturally between procedural and conceptual knowledge that is well organized. When new concepts are added to the map, the relevant conceptual issues and difficulties are treated, and thus conceptual knowledge is naturally linked to the structure. The hierarchical design of the map at different levels of detail is helpful for recall and problem-solving: higher level information helps retrieve more detailed information.

The results show clearly an overall advantage of students in E over students in C_1 and C_2 in all aspects: recall, conceptual understanding, and problem-solving. There was also a transfer effect—students in E have learned how to identify important ideas and relationships in a presentation about an unfamiliar topic. It is plausible to assume that these learning outcomes result from a useful knowledge representation formed by students in E. The effect of an isolated treatment of conceptual difficulties like in C_1 seems to be limited to the particular aspects that are treated and has limited effect on recall and problem-solving. Deliberate effort is necessary to connect the new understanding of concepts to an overall structure and to procedural knowledge.

The proposed approach has several practical advantages.

1. It can be given after students have finished a regular course in the domain and makes no assumptions as to the didactic approach that is used in the course. Thus, the same unit can be used with different courses (as was the case in the present study) as long as the syllabus is similar.

2. It is designed as a self-study unit that takes relatively short time (an average of about four Hrs).

3. In the process of creating the map, the students experience, in a systematic manner, problems in the whole domain and get an overview of all the material that they have learned. Thus, the unit can serve also as part of a review that teachers do anyway in the end of a course.

Considering the fact that the time spent by students in E and C_1 was about the same, it is recommended that teachers adopt the integrative approach that can lead, in relatively little investment of time, to considerable gains in learning.

Several questions can be raised considering the instructional approach that is proposed.

1. Would it be useful to integrate such a treatment as part of the regular teaching of the course?

2. Would it be useful to allow students to design their own representation of the domain?

3. What is the long-term effect of the treatment?

These questions require further investigation.

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Chapter 3

The Teacher

Introduction to Strand B: A Focus on the Teacher

Euwe van den Berg, Vincent Lunetta, and Menachem Finegold

Science Teaching in Developing Countries: The Context

To provide perspective for the "Teacher Strand" of the Science Education in Developing Countries Conference, the first section of this chapter reviews circumstances typically faced by science educators in developing countries (DCs). School situations vary greatly within most countries, and differences are especially great from one country to another. Variations are especially dependent upon the economics and level of development of the country and region. State education systems are complex amalgamations of sociocultural and idiosyncratic historical and political factors that make understanding difficult. Expert expatriates sometimes feel they understand relatively little even after 5 years of residence and study. Visitors may sometimes think they understand the educational situation in a particular country after a relatively short visit, but superficial impressions are often deceptive. We know that students tend to "understand" science through naive preconceptions, unaware that their science does not match the conceptions of expert scientists; similarly, science educators from industrial countries (ICs) may look at science education in a developing country through their IC preconceptions and be unaware that their experiences and models may not "fit" the reality of that developing country. Many development projects, put together intelligently, using all the knowledge and expertise available, have failed because they did not take factors into account that, during planning, seemed trivial. Sam Bajah's plenary address: "Goals and Needs in Science Education—Past and Future" suggested similar caution.

Teacher Retention

In some countries in Africa (e.g., Botswana and Zimbabwe) more than 30% of the senior high school science lessons are taught by expatriates who are on 2- or 3-year contracts. (In Botswana 80% has been reported.) In Lesotho, a country surrounded by South Africa, many indigenous teachers leave the profession after only 1 or 2 years of teaching because jobs in South Africa are more lucrative. In Swaziland, Lubben (1993) estimated a 2- to 3-year "half life" for indigenous Swazi teachers. In Malawi 13% of the teachers leave teaching each year and the number of unqualified teachers is increasing. In other countries (such as Indonesia and the Philippines) teachers may stay with their profession for a lifetime. Improving teacher retention should be a major factor in planning pre-service and in-service teacher education and in formulating teacher education policy.

Teacher Status and Remuneration

Originally, teacher status was relatively high in most developing countries because the teaching profession was one of the few "learned" professions and because education was oriented toward the elite. A number of well known past and present African presidents started their careers as teachers. However, with the expansion of modern economies, after better paying jobs become available, serving as a teacher is considered by many to be a second choice career, as is the case in most industrial countries. Typical teacher salaries in government schools in the Philippines and Indonesia are low, at $50 to $120 per month. However, in the top private schools in the capitals teachers may receive up to $500 per month, and in poor private schools in the province salaries may be $20 per month and even less. In response, many government teachers supplement their incomes by teaching at private schools or by teaching private lessons. In southeast Asia, economic conditions for teachers have improved during the past decade, whereas in Africa they have deteriorated sharply (Fuller & Heyneman, 1989; ILO, 1992).

Teacher Background in Science and Science Pedagogy

Teacher preparation and skill levels are often quite limited in developing countries. Many countries employ teachers who are not qualified in terms of the standards of the particular country . For example, 8,500 of the 12,000 science teachers in Namibia are reported as not qualified to teach science (Peek, 1993). In the Philippines (population of about 60 million), the pre-service physics teacher preparation enrollment has been less than 10 per year for many years (Philippines, 1985). The production of B.S. Physics graduates is at the same order of magnitude. In other words, the production of physics teachers in the Philippines is almost entirely dependent on in-service education. In Israel, to cite another example, the number of candidates for pre-service education in physics teaching is well below the estimated need. One result of the recognition of these statistics is an extension program now being planned to re-train junior high school teachers. Similarly, in Pakistan many teachers, including elementary school teachers, receive their first teacher education through in-service rather than pre-service programs. This reality is not unique to developing countries; it is also common in some industrial countries.

In many countries pre-service education programs are of limited quality, resulting in the preparation of certificated teachers who may be ill prepared for their tasks, including science teachers. Lucas et al. (in this book) found serious problems in the (school) science mastery of teacher educators. Such results have been reported from many developing countries in Africa, Asia, and Latin America. A recent study in the republic of South Africa (Finegold & Gorsky, 1992) showed an alarmingly low level of understanding of the concepts of force held by teachers in non-white schools. This is not surprising, considering the underprivileged position of non-white education systems in South Africa (Kahn & Rollnick, 1993).

In some countries top government officials have blamed science teachers and science teacher educators openly (in national newspapers) for poor overall results on national matriculation exams. In one large country there was even serious discussion about closing science education departments of teachers colleges and transferring all science teacher education programs to universities. However, some pilot programs at universities did not result in better quality. The rapid expansion of enrollments at all levels and the lack of status of the teaching profession have been cited as among the reasons for limitations in the quality of graduates of teacher education programs. Inadequate collaboration among scientists and science educators has also been cited as a source of these problems. In industrial countries a focus on research at the expense of teaching in universities has also been cited as a probable contributor to the problem. In some developing countries, poor communities have sometimes founded their own schools and then forced recognition from their Ministry of Education or from private school organizations.

The demand for teachers (and other professional manpower) has led to unsustainable expansion of tertiary programs in some countries. In the process, there may have been insufficient attention to program quality control. One example of a by-product problem is the fact that many certificated science teachers have had little or no special preparation for using the laboratory to promote science learning. For an extensive survey of teacher qualifications and how they may be interpreted, a World Bank publication (Ware, 1992) reports on the status of science education in developing countries.

Classroom Conditions

Though conditions vary greatly, schools in developing countries are less well equipped, in general, than are schools in industrial countries. A recent report on

Pakistan estimated that in 1986, 20% of the elementary schools were "shelterless" (Bhatti, 1988). Some of these "shelterless" schools operate in buildings that are not government owned, and other schools are truly shelterless with no school building (Warwick & Reimers, 1989). Typical class size in secondary schools in DCs (and ICs in East Asia) is 45 students and higher in elementary schools. Usually classrooms are open for ventilation, and the walls are thin so noise from neighboring classrooms penetrates easily. In many classrooms around the world only 5 or 6 of 45 students have a textbook. In many developing countries this may be the case in up to 50% of the schools. In response, teachers may dictate for over half the lesson time, and students study their dictated "abstracts" rather than appropriate books. *Classroom conditions put limits on the kinds of teaching methods that are appropriate or even possible.* Unique climatic conditions put further constraints on instructional possibilities. Storage, maintenance, and repair of equipment, for example, are important in every school laboratory, but humid, tropical climates and dusty desert climates are particularly problematic for school labs with conventional equipment.

Finance

Spending on classroom materials and other non-salary recurrent expenditures per student enrolled in primary school in various countries is as follows (Fuller & Heyneman, 1989): Bolivia—$0.80 per year per pupil; Malawi—$1.24; Indonesia—$2.24; Brazil—$4.00; U.S.A. $230.00; Scandinavian countries—more than $300.00. It is easy to say that good education costs money and that governments should spend more, but in many countries there are very limited economic resources available for educational improvement even if the government were to decide to place a higher priority on education. This problem is especially acute in Sub-Saharan Africa where per capita gross national products (GNPs) fell in the 1980s and total annual education expenditures per capita (including salaries) went down from $32 to $ 15 between 1980 and 1987 (UNESCO 1989, Table 2.12; also quoted in Lewin, 1993).

Schools and Improvement Possibilities

Clearly, schools vary widely within countries as well as from one country to another. In most countries an upper layer of top schools is well organized and disciplined with a professional teacher corps. Below that layer there is a much broader layer of "average" schools that experience the typical problems of developing countries: low budgets and teaching staffs with limited motivation and outside jobs to supplement low incomes. In such schools the teaching can be improved, but one should set realistic goals for such improvement. Below the middle layer of "average" schools, there is often another large layer of schools that may enroll as many as 50% of the most deprived students. These very poor quality schools are generally very inadequately financed, they employ underqualified staffs, and they often suffer from poor management and discipline, and so forth. Such schools are very difficult to upgrade as major management overhauls and partial changes in staffing may be needed.

Each of these kinds of schools needs a very different kind of assistance. In the first type, aid can be most effective but will tend to serve an elitist population. The third type of school needs assistance most of all, but may be too deprived to be able to take much advantage of external assistance unless the whole school can be overhauled. Zymelman (1990) in a World Bank report strongly suggests that some of the aid be targeted to centers of excellence rather than spread over all schools to enforce equity.

Student Background

Many students in DCs live in low technology, poor, rural areas. They may have extensive domestic duties such as getting water or firewood or taking care of animals. Their parents may have gone to school briefly if at all. Many other students are from poor urban areas that are, in many ways, quite different from slums in ICs. A smaller group of students comes from middle class backgrounds and whose parents who very actively supervise their education. Relationships of children with adults are generally much more respectful in DCs so students are easier to control, even in large classes. Yet, classroom discipline sometimes is based on fear in these environments, reducing the possibility of intellectual discourse and often resulting in relatively passive student response and limited engagement of the students. This may especially be a problem in the classrooms of underqualified teachers. As Finegold (1992) found when teaching in a South African weekend school for black students, it is extremely difficult to cajole students into intellectual discourse, even in the absence of fear. This probably results from the notion that it is impolite to doubt, question, or even discuss statements made by an older person. Furthermore, in most student homes it would be very difficult to find a quiet place for homework because of the large number of people living in a small house. On the other hand, students are not as likely to be distracted by the many activities of their peers that are so prevalent in industrial countries (sports, McDonald's jobs, cars, television, etc.).

Strand Papers: General Characteristics

The papers presented in the teacher education strand generally were sensitive to local and regional problems, and authors did report efforts to respond to these problems and to be attentive to broader issues and organizers. However, many of the papers were reports of relatively short-term efforts responding to elements of complex problems. People laboring for between 1 and 5 years in a project are almost certain to perceive that the project extends across a considerable period of time. Yet, when one considers the difficulty and complexity of life-long teacher development, of institutional change, and of the development of infrastructures to support these efforts, 5 years is a relatively brief time. Lasting, institutional and systemic changes are among the goals that are sought, but changes of this kind occur across time spans that are longer than the normal life cycle of conventional projects. Goals statements and assessments should reflect this reality. Project planners and donors must look at longer time scales and with broader perspectives. Many presenters in the Teacher Strand of the Conference did not show how their projects fit into an overall development plan for science teacher education. Barak's (1993) report of an in-service project in Israel describes one of the few programs that appears to be founded in an assessment of national needs. On the other hand, in his keynote speech, Waddington (in this book) named some characteristics of the most successful long-term projects he had seen. A major characteristic was a clear and narrow focus and a determined individual.

Many presentations and papers (from ICs) identified grand goals and dreams that seemed to be very distant from the local school realities perceived by many participants. Certainly, it is important before beginning an educational venture or a research and development project to clarify and explicate the goals of that effort. We also know that the related human and institutional problems to be addressed are often very complex and difficult to comprehend, let alone remediate. At times it may be prudent, then, to establish more attainable, intermediate term goals (for example, see the In-service Education section below). Presenters provided little evidence of formative project assessment that could enable project directors to make adjustments in the ongoing project to reach stated project goals. The papers as a whole also revealed only limited efforts to integrate theory and practice that is essential to the long-term change in educational institutions that is sought.

Problems related to teaching in developing country environments are associated with a variety of factors including: socioeconomic biases; community diversity; centralized decision-making; political instability; inadequate finance, resources, and facilities; limited levels of teacher preparation; inappropriate external exams; poor communication; and insufficient adaptation of curricula to local culture. One must be cautious in generalizing about the nature of problems across cultures and countries. Some educational problems in ICs and DCs may look similar, however, underlying causes may differ and mechanisms for solutions almost certainly would have to differ because of the idiosyncratic differences in education systems and boundary conditions described in the introduction of this chapter. Thus, it is prudent to be cautious in generalizing about remediation strategies and solution alternatives. Some papers and presentations and especially remarks in discussions were criticized for undocumented and unjustified implications of generalizability.

Although most school problems have roots in the culture and the political context in which they are set, it is important to distinguish between those problems that schools can be expected to address using their own internal resources and those problems that are beyond the school's ability to address. For example, teachers can be helped to identify locally available materials for use in science lab activities when equipment and materials are in short supply, but they alone can do little to help students who come to school hungry and in poor health. Good health and good nutrition are prerequisites to good education (research on health and achievement is summarized in Fuller, 1987). It is important for educators and educational organizations to assist in clarifying that reality for policy makers.

Much can be done to improve the quality of education in a low budget environment. The commitment of people to high quality education is probably at least as important as the expenditures of funds. For example, in many schools just enforcing some discipline in checking homework assignments and attendance (by teachers and students) might have measurable results (Walberg, 1991). Nevertheless, even when people are dedicated and good ideas are present, educational goals can be better accomplished with appropriate financial support. Educators must study the effects of educational funding patterns and policies to make thoughtful assessments and recommendations that can inform school policy and decisions by school administrators and communities. In short, to narrow the great gaps between visions and realities, scholars in education must be sensitive to regional, cultural, and physical settings while developing and examining more systemic theoretical and practical conceptualizations of cognition, learning, and teaching; teacher development; curriculum development; and school and infrastructure development.

Implications for teacher licensing and institutional support systems derived from broader conceptualizations could be more powerful in promoting needed structural changes in education systems than the current, well-intentioned but often somewhat random, local attempts to remediate elements of complex problems. To cite but one example, although teacher education today is handled differently from one country to another, many different institutions within a country are often involved in the pre-service, induction, in-service, and graduate education of teachers. Frequently, these institutions do not collaborate or coordinate their teacher education-related activities, resulting in development opportunities for teachers that are usually geographically biased at best and often inadequate for most teachers. Science teachers, for example, frequently have inadequate, regular access to further education in science and in science teaching, should they wish to remain in the classroom. Licensing and the education of a science teacher from a holistic perspective supports growth and development of diverse knowledge and skills across a lifetime.

Research to Inform Decision Making

Many papers in this strand reported conventional research and development activities in science education, but few (Walberg, 1991) examined the larger issues relating to the productivity and effectiveness of science education and of teacher education based upon long-term outcomes in the society. Scholars in science education and related fields need to examine broad policy-related questions and issues that can inform national, regional, and local decision making. Databases need to be developed that can serve as bases for scholarly inquiry into the nature of complex educational problems and their resolution.

Understanding the nature of the problems in which science education is embedded can be facilitated by several research methodologies. Large databases incorporating population and demographic information can now be gathered and organized with the help of existing data processing systems and methodologies. Secondary analyses of large databases already gathered in ministries of education and organizations like UNESCO and the World Bank can assist in the understanding of these problems. In addition, research of this kind can assist such organizations to ask better questions and to gather more appropriate data to support the analyses that are needed. A variety of research methodologies in the social sciences have the potential to assist in the study of the important and complex problems relating to science education.

Although the study of cognition and the effects of teaching on learning are very important, they are embedded inevitably in the context of larger problems. These problems too must be studied with care so that policy makers can be informed about the effects of their actions in the administration of ministries, educational systems, and schools. One of the complex cultural, contextual problems for science education is the relationship among the several institutions in teacher education, higher education, public education, private education, and departments within ministries of education that discourage integration and holistic attention to teacher development and to the explication of regional problems. Systemic problems inhibit significant progress in school change and teacher education. They also have inhibited the study of these barriers to change. Scholars must examine these social/cultural/institutional problems as well as those that are more clearly connected to the day-to-day business of teaching and learning science in the classroom. What are the cultural and regional differences that are significant to the teaching and learning of science? What is the nature of these problems? What remediation strategies are appropriate? What are the effects of the implementation of such strategies?

Issues and Research Questions in Science Teacher Education

The strand papers and commentary raised many important questions that warrant careful scholarly attention so as to better inform educational policy. Perhaps the most visible questions raised in the strand related to the effects of cultural contexts on learning outcomes and on appropriate teacher education. Many participants expressed caution about over generalizing implications for teaching and for teacher education from one cultural context to another. The papers and dialogue highlighted the need to clarify and develop:

1. Holistic models for life-long teacher education and development;
2. Licensing systems consistent with appropriate, long-term teacher development;
3. Organized, integrated infrastructures that support teacher development from preservice through continuing, long-term in-service education;
4. Systems for the recognition and empowerment of teachers and for the involvement of successful and experienced master teachers in leadership roles in teacher development.

Blue ribbon panels have suggested that to attain more effective science teaching and learning, science teachers must become better informed about discipline-specific science concepts and teaching strategies. Almost simultaneously, others have called for more interdisciplinary science curricula often with an emphasis on applications of science (STS, for example). What is the appropriate specialization in a 4- or 5-year preparation program for science teachers? For prospective secondary school teachers, should certification standards specify how much depth in a discipline and how much breadth and interdisciplinarity are appropriate? What should be the licensing expectations following teacher preparation? What should be the licensing expectations at successive 5 year intervals? Where should responsibility reside for the continuing scientific education of teachers in their disciplines and in discipline focused pedagogy? What are the responsibilities of colleges and universities for the education in science of pre-service and in-service teachers? How effectively are contemporary institutions meeting their responsibilities? What other institutions should provide appropriate support?

During the past 30 years many have talked about the importance of reducing the curriculum gap between primary and secondary education. Ideally, what should be the interface or the relationship between science curricula in the primary and secondary schools? Similarly, how should science preparation programs for primary school teachers differ from programs for secondary school teachers or for middle school teachers (grades 5-8)? What are minimum essentials in science and in science pedagogy? How should the nature of science and its philosophical, historical, and sociological contexts be integrated in the education of science teachers? How should the uncertainty and tentative nature of science be incorporated in the curriculum of science teacher preparation?

Teacher Development and Professional Improvement

On several occasions participants in the strand pointed out that problems in education could not be solved properly unless local teachers were engaged in the problem-identification and resolving process. The message in the conference about the importance of educating and empowering local teachers was clear and powerful. At the same time, it was made clear that many institutional factors mitigate against appropriate teacher involvement in school problem-solving processes. The status of teaching in the schools, the self-esteem of the teacher, and the (lack of) power normally delegated to teachers to be agents for change are major factors contributing to the inertia of the system.

Some of these problems can be addressed by well-designed, long-term, teacher-development projects that incorporate systemic change among their goals. Treatment of teachers as second class citizens results from many factors including the attitudes and dispositions of those in tertiary education, those who sometimes lead teacher education programs, and those who administer. (Using the term "teacher training" is just one among many factors that tends to perpetuate an image of low status and limited empowerment). Research and practice in other fields has resulted in the awareness that corporate employees are often more aware of the specific nature of their production problems than are their supervisors. Similarly, teachers generally know what some of the special problems are that inhibit the effectiveness of school classes; they often know how to teach more effectively than they actually do. They must be engaged in problem identification as part of the problem-solving process. Working models of "bottom up" administration and leadership are needed to complement the "top down" systems that are so pervasive.

Teacher engagement in decision making and in professional development can be enhanced by the development of schemes and technologies enabling consistent networking of colleagues for developing curriculum and for sharing resources and ideas. Papers in this strand reported that some regional centers and networks appeared to be effective in promoting teacher development and regional curriculum development. In some countries, such networks have been (Indonesia; van den Berg, in this book) or are being (Namibia, Peek, 1993) set up on a national scale. For example, in almost every town (district level and up) in Indonesia one finds groups of science teachers spending one day a week in training and discussion of common teaching problems. Such a network has great potential for professionalizing the teaching force. In developing countries the situation is even more complex because there are many unqualified teachers and administrative systems are frequently relatively hierarchical. There teacher educators and teachers may have to find their own ways of cooperation, starting at the current level of teachers and leading eventually to cooperation among competent professionals.

In-service Teacher Education

Varied In-service Goals

In-service teacher education can have many different goals. Perhaps a new science topic has entered the syllabus (e.g., AIDS or Biotechnology), and teachers need to learn about the topic and how to teach it. Perhaps schools have received science equipment, and teachers need to learn how to use it. Or there may be many uncertificated teachers who are offered in-service certification courses. Perhaps the Ministry or Department of Education has heard complaints about the subject matter mastery of teachers, or perhaps it wants to improve the nature or the quality of the teaching. Frequently, in-service education is linked to a new curriculum that will be "hands-on" or "laboratory-based" or "constructivist," requiring very different teaching from traditional practices. Sometimes the goals for inservice education require different strategies and techniques. Acquainting teachers with a new topic like AIDS or Biotechnology can be done in a short intensive course. However, improving the subject matter mastery of teachers requires a much longer process. Changing the way teachers teach is also a much longer process that will result in attitude change as well as behavior change. For success, such programs must include supervised practice on the job and preferably a school-based approach. An example is found in Barak (1993) who reports on a long term project in which a university department of teacher education takes up the task of improving teaching and learning in an educationally deprived area in Israel.

Conference Papers

Many papers in the conference addressed the issue of in-service teacher education from one perspective or another: Barak discussed a school-based improvement project (1993); de Feiter talked about variables to be considered in national planning for in-service (1993); Fensham & Gunstone conducted a 10- month program for in-service educators in the Philippines (1993); Goodwin & Taylor were consultants on an in-service program in Kenya (1993); Lucas & Cook (1993) and Lucas et al. (1993) discussed programs in Fiji and Papua, New Guinea; Lubben (1993) talked about various in-service programs in several countries in Southern Africa; and Smit and Finegold (1993) reported on a study of conceptions of models held by students and teachers and upon how their concepts affect the teaching/learning process.

Investment Choices

All developing countries have programs for educational development. Often such programs are national in scope, for example, aiming to "in-service" 50-100% of the teachers in a certain subject. Such programs are not aimed at the highly motivated volunteer schools and teachers, but at the "average" schools and teachers. Development funds can be spent in many ways: for upgrading school buildings, buying equipment, changing curricula, producing textbooks, and educating teachers; for that reason, educational policy makers have to make choices on where investment would generate the best return, and donor agencies have to choose which initiatives to support. Unfortunately, research in DCs that can guide such policy choices on these issues is very limited, but some relevant studies are available (Fuller 1987; Fuller & Heyneman, 1989; Verspoor, 1989; Walberg, 1991). For example, in a study of 282 World Bank education projects, Verspoor (1989) concluded that the more successful programs were not those limited to curriculum change, but more comprehensive in nature with a phased implementation and much experimentation (and formative evaluation) in the early phases. In the successful programs the "usual curriculum and teacher training interventions continue to be included [in World Bank projects], but they are usually combined with support for administrative and management training or the provision of educational materials." Projects including only in-service education or a new curriculum are less likely to be successful than those with more inclusive agendas and constituencies. For example, investment in laboratory equipment unaccompanied by school-based teacher education has resulted largely in wasted efforts.

One of the conclusions drawn by Fuller (1987) in his review is that school effects on achievement in DCs are stronger than in ICs. The literature on investment alternatives in improving DC education can contribute to setting more realistic goals and practices. Considering the boundary conditions such as school/classroom facilities and teacher realities, which teaching methods are likely to be most effective? Who should be trained in what to achieve maximum effect with the very limited money and resources that are available ?

Realistic Goals for Improving Teaching

Many in-service teacher education programs aim to change the teaching methods of teachers: to "convert" teachers from "teacher-centered" to "student-centered," from "show and tell" to "activity based/ laboratory based," or from didactic teaching to "constructivist" listening and responding to student ideas to promote the construction of science concepts, and so forth. Many such programs have had only limited success with the "average" teacher. In DCs many more factors mitigate against implementation of innovative methods than in ICs (see the introduction of this chapter). For example, in many schools, laboratory equipment, if there is any, remains in the cabinets. Frequently cited reasons include: overloaded national syllabi, national examination systems that require a lot of factual knowledge and do not asses the typical goals of inquiry-based (process skills) or constructivist (higher conceptual understanding) teaching methods, socio-economic conditions of teachers, classroom facilities, class size, cultural expectations of teacher behavior (Lucas et al., in this book), weak subject matter mastery, lack of confidence of teachers, and so forth. In spite of the lack of success of such efforts, many in-service teacher education projects described in the various conference papers were of the kind just referenced (intending to change the teaching from teacher-centered to student-centered, etc.). Some projects were targeted to leading teachers and were very intensive in nature (Fensham and Gunstone's (in this book) 10-month full-time program for Filipino in-service trainers; Lucas' et al. (in this book) 2 x 2 week program for community college teacher educators). Longer time frames and more selective groups greatly increase chances of success. However, most other in-service courses discussed at the conference were targeted at "average" teachers and measured contact time in days rather than months. Is it realistic in these circumstances to expect long-term changes in teachers' attitudes and behaviors? Is it not more realistic and consistent with the constructivist paradigm to start where the teachers are, by helping them improve the conventional methods they use?

Following Gage and Needels, Walberg (1991) wrote:

> *It is important to retain well implemented conventional teaching as a major option for improving education. It works moderately well in attaining conventional criteria of academic progress, and it does not require extraordinary teacher preparation, materials, and facilities. Although other methods have shown larger effects on specific criteria they are designed to accomplish, they lack conventional teaching's long history. Many such innovations have come and gone, and conventional teaching remains the pervasive method in schools in low- and high-income countries.*

Considering the many problems facing teachers in developing countries, their big classes and their need to supplement income with other jobs, this might indeed be the wisest approach unless one has an opportunity to work in a school-based approach with a small number of schools and abundant funding. In Pakistan some Aga Khan Foundation projects have achieved great changes at the classroom level (in a small number of schools), although they have been more successful at the elementary than secondary level (Heneveld & Hasan, 1989; Bude, 1989). Working for improvement of conventional teaching can be criticized as a neocolonialist, or second best, approach to teacher education in DCs. Yet, the Gage/Needels quotation in Walberg (cited above) concerned education in the U.S., as in the U.S. and other industrialized countries many innovations have been difficult to implement by the "average" teacher. DCs may not want to replicate the unsuccessful innovations of ICs.

Improving Conventional Teaching

What are the improvements in conventional teaching for which one could strive? Van den Berg (1993) mentions the following: making conventional teaching more interactive through questioning, making conventional teaching more concrete through interactive demonstrations, making conventional teaching pay more attention to student conceptions through the use of counterintuitive demonstrations using Gunstone and White's (1992) Predict-Observe-Explain method (a good source is Liem's 1981 book with over 400 counterintuitive demonstrations that do not need special equipment), and so forth. Furthermore, supervised and regular student seat work and homework could make quite a difference in achievement (Walberg, 1991). Education to improve such teaching skills will also help improve the subject matter mastery of underqualified teachers. In a workshop (Maarschalk et al., 1993), Tamir showed how process skills can be practiced in whole class demonstrations. For biology, BSCS produced film loops in the 1970s for exactly this purpose. However, in physics one could easily conduct the investigations in real time as demonstrations in the classroom. No film would be needed. What one needs is good questioning technique and classroom control. Predict-Observe-Explain conceptual demonstrations and demonstrations exercising process skills could replace part of the laboratory work without any negative effects on achievement (Garrett & Roberts, 1982).

Role of the Laboratory

Several papers described ways to introduce more laboratory work in developing country classrooms. The projects described are interesting; however, most laboratory projects are based on the tacit assumption that laboratory work will lead to better understanding of concepts and to better mastery of process skills. In industrial countries that assumption does not hold, as amply demonstrated in the literature (Garrett & Roberts, 1982). In many cases there are no differences in subject-matter mastery and process-skill mastery between students who have ample experience in the laboratory and students who don't. Explanations (van den Berg & Giddings, 1992) for those results could be sought in (a) a mix of mutually exclusive goals for laboratory lessons, (b) not taking preconceptions into account, (c) cookbook-type instructions, (d) guidance that reduces the cognitive level of lab tasks, and (e) assessment practices that favor science "content" mastery.

The question of course is whether conclusions of research on laboratory teaching are valid for developing countries. For example, Kahn (1990) points out that for many students in developing countries dealing with equipment is much more special than for students from industrial countries. However, considering the questions about the effectiveness of the laboratory, considering the large classes and the expense of laboratory lessons, and considering the poor record of large equipment projects in developing countries, developing country schools and Ministries of Education would do well to weigh investments in equipment very carefully against other investments. Teachers and teacher educators would do well to rethink the goals and methods of laboratory lessons. For example, constructivism has a lot to say about how to use the laboratory to support concept development: criteria for choosing experiments, teaching strategies, integration of experiments in lessons, and so forth. Experiments promoted by constructivists tend to require relatively simple equipment, but becoming a constructivist teacher is difficult, especially for teachers with limited preparation and experience.

In-service Models

Several papers discussed models for inservice education. Should one "cover a country" by organizing short workshops everywhere? Is it better to train a few teachers or trainers extensively rather than travel around the country for short workshops? What about the cascade model (Peek, 1993) where local or expatriate specialists train mentors, mentors and specialists train resource teachers, and resource teachers are supposed to train their peers? Does the training still succeed at the grassroots level, or does it get too diluted? Can a cascade model work in a country with sparsely populated areas. What are the preconditions for it to work? Many answers can only be given after a thorough comparison and evaluation of in-service projects in DCs. Barak's (in this book) school-based model for assisting below average schools in the Galilee is another one to consider and seems quite strong on starting where the teachers and schools are, going forward step by step. This model, which also includes on-the-job, in-school guidance has the additional advantage that it calls upon the expertise and experience of the whole faculty of a university department of education.

Networks for Life-long Teacher Support

Many in-service projects are set up as a one-time event with a life time of a few years. It would be better if in-service projects would lead to permanent networks where teachers could plan, discuss, and evaluate lessons together and could provide feedback on policies. A nationwide in-service project in Indonesia resulted in local groups of physics, chemistry, or biology teachers in every major town all across the archipelago (van den Berg, in this book). The groups meet 1 day a week, led by a government-trained resource teacher. In some countries such groups of teachers are conducting action research. Feldman (1993) presented an example of such a program at the conference. Another important ingredient of in-service models is on-the-job supervision of skills learned in more formal workshop experiences. Such supervision is expensive but it appears to be essential and is applied in the Indonesian project referenced above.

Introduction

The first years of teaching are the most eventful and by far the most difficult in most teaching careers. It is during the first years that teachers' beliefs about learning, teaching, and students are molded. In later years, change is often limited (Kahn, 1990). Klindt (1993) described a national induction program for teachers in Lesotho. Newly graduated teachers voluntarily sign up for the induction program (now 85-90% do so). When they sign up, they commit themselves to participation in the program's activities. The program also signs a contract with a mentor teacher and the principal of the new teacher's school. The program consists of a package of activities in school (guidance by mentor, logbooks, pupils' questionnaires, lesson observations by the mentor and by induction program faculty) and activities out of school (peer meetings, workshops, and seminars). Pre-service faculty is involved in the workshops and seminars. Voluntary enrollment in the program has increased quite rapidly. It will be interesting to see whether a program like this is able to speed up adjustment and increase quality of new teachers, and increase retention of teachers in Lesotho schools where attrition has been a big problem.

Pre-service Education

In pre-service education one can be more ambitious in setting goals than in in-service education. Yet one has to keep "average" school conditions in mind. There is no point in educating teachers for ideal teaching with nice facilities when upon graduation they have to work in a very poor school. The range of credits available for science, science education, and other subjects varies greatly between countries. So too does the duration of teacher education programs (Ware, 1992) and the degree of integration of the science, science education, and general education components of the programs. Even within a small country the range of courses and the length of teacher education programs offered by universities and smaller colleges involved in teacher preparation may vary greatly, as it does in Israel.

Obviously the extent of integration of science, science education, and general studies puts strict limits toward which one can strive in the education of science teachers. If the role of science educators is limited to teaching a few science methods courses scattered through a B.S. degree course, one's goals would have to be much more limited than one's goals in a program in which science educators are responsible for the science as well as the science education component of an integrated 4-year teacher education program. Ideally, a pre-service program should involve the components shown in Table 1. Very few conference papers dealt with pre-service teacher education (Gunstone, 1993; Wright, 1993; van den Berg, 1993), and discussion here will be limited to only a few of the components presented in Table 1.

Table 1. Broad Teacher Competencies

Knowledge and skills in:	Science disciplines School science Science teaching Generic and discipline-specific pedagogy
Understanding of:	Models of students' cognitive and affective development The nature of science and of its relationship to society
Sensitivity to individual and cultural difference	
Knowledge of the national educational system and curricula	

In a keynote lecture entitled "Can We Prepare Teachers to Teach in the Way That Students Learn?", Gunstone (1993) began by contrasting discovery methods with constructivist methods of teaching and learning. Constructivist methods involve much more teacher control, without being didactic, and therefore put much greater demands on the teachers. In a constructivist classroom, the emphasis is on students struggling with ideas rather than with equipment. Monash university science educators have put great emphasis on the role of meta-cognition in the construction of science concepts. Learners' attitudes are also very important, as constructivist learning requires great effort from the learner. In Gunstone's (1993) words: "We know much about making learners more able to learn with understanding but little about making them willing and able." Perhaps one could say we know little about motivating students to develop and use meta-cognitive skills.

Another point made in the keynote speech concerned the nature of conceptual change. Recently Gunstone and others have concluded that new conceptions do not replace "old" ones (preconceptions), but coexist with old ones: conceptual addition rather than replacement. The key point then becomes for the student to become aware of the different conceptions and to learn when to use which conception. For prospective teachers, implications are that they have to learn to recognize their own ideas and beliefs about science content and about learning and teaching and to evaluate the appropriateness of these ideas and beliefs. "For teachers to teach in ways students learn, requires that the teachers understand the science they are to teach, understand how students learn, and have a wide repertoire of pedagogic strategies from which they can select . . ." The teachers' judgments are informed by their content understanding, pedagogical understanding and understanding of student learning. Important implications for teacher education are outlined in Gunstone's paper (in this book). The question now is whether faculty in typical teacher education institutions in DCs and ICs are able to implement the strategies proposed by Gunstone and if so, whether their pre-service students upon graduation will be able to apply what they have learned. Many teacher preparation programs in industrial countries may not yet be able to implement Gunstone's recommendations. In many DC (and IC) teacher education programs, faculty will have to work on many basics (subject matter mastery, basic teaching skills, facilities, organization) before trying an integrative "constructivist" approach to teacher education.

Science in Science Teacher Education

Mastery of school science concepts and skills is a prerequisite for almost all teaching skills, from preparing a lesson to writing and grading test questions, and should receive top priority. A teacher's knowledge of common student alternative conceptions may guide the teaching and remediation of school science concepts in the pre-service program as well as in in-service programs. Yet, school science should be taught so that the university instruction is not perceived as a repetition of school science courses. The science teaching should reflect what is known about teaching and learning and should clearly deviate from less appropriate though dominant instructional modes. Teaching science in the university presents many opportunities to enable students to experience alternative teaching methods and to model the ways pre-service students are expected to teach following graduation. Furthermore, pedagogical courses can also be used to improve school science mastery. In micro-teaching lessons, deficient subject matter mastery shows clearly.

Special courses on alternative conceptions and implications for teaching could be helpful in remediating school science concepts in pre-service students (Lucas, et al., 1993; van den Berg, 1993b). University-level science courses, including some with rather heavy mathematics, are expected in all science teacher education programs. The teacher educator should continually try to make conceptual sense out of formulas when teaching science. Laboratory work should provide for simple as well as sophisticated experiments. This would make it possible for pre-service students to learn versions of experiments that can be done in any school while also developing confidence with more sophisticated equipment. Some of the laboratory work can be qualitative in preparation for demonstrations in the secondary school classroom. Laboratory work can be reinforced in helping teachers use labs and demonstrations more effectively through microteaching.

Level of Discipline Specialization

An area unaddressed by papers in the teacher education strand relates to the nature of discipline specificity that is appropriate for the preparation of science teachers. Much has been said about the importance of disciplinary expertise. Teachers of a discipline need to have a well-developed knowledge of that discipline. Conference papers (including the STS Symposium) and recent goals statements of major curriculum projects, however, have emphasized the importance of breaking down barriers between the disciplines and of developing transdisciplinary or interdisciplinary themes. The implications of these interdisciplinary goals for the education of teachers has not been addressed sufficiently. Our limited data suggest that in some parts of the world, teacher preparation programs are moving toward more discipline specific preparation for teachers, for example, in the Netherlands and Indonesia.

In some other parts of the world, including the United States, there are tendencies toward greater breadth of preparation in multiple science disciplines. In Israel, as an outcome of the recommendations set out in "Tomorrow '98," (1993) plans are now being put into effect to upgrade education in mathematics, science, and technology, and to introduce an integrated science-technology course for all. Greater breadth of preparation necessarily limits the depth of preparation that is possible in any one discipline in a 4- or 5-year teacher preparation program. A significant problem in many parts of the world is that most teachers, especially those in rural areas, have little or no opportunity for enhancing their science discipline knowledge while they serve as teachers. There are many complex reasons for these pervasive but limiting realities, but if teachers are to grow professionally, they must have access throughout their careers to education in science and in science pedagogy. That access must be easily available to them in formal or informal settings.

Science and Community

Several conference papers paid attention to preparing teachers to make science relevant for their students and the community. In many schools science is taught as a set of facts to be memorized for an exam. What can teachers do within existing science syllabi to make students recognize the linkages of science with their daily lives and to show the power of science to assist them in responding to everyday needs? Gonthi et al. (1993) produced video tapes of village science (pottery making, distilling, gardening) and written support materials for use in Malawi elementary teacher education and in elementary schools. Tapes were also produced of elementary school lessons where official syllabus topics (mushrooms, weevils, brick making) were linked to the children's environments and needs. The practical relevance of science is especially important in a country where 70% of the primary school leavers stay in the informal economic sector and cannot continue their education. The use of video tapes to introduce new classroom materials and methods in inservice workshops for teachers were also used by Barufaldi (in this book). The videos can help teachers get a more realistic idea of appropriate applications of new teaching methods. Van den Berg (1993b) described courses in which pre-service students study and practice physics with special community relevance, including community work such as teaching about electrical installation in a village to be electrified and helping to set up water tanks to bridge dry seasons. Sometimes such work can even be integrated into regular science courses. For more information on this type of activities in science teacher education see Swift (1983, 1992) and Knamiller (1984).

The moral and ethical development of students is frequently identified as an important outcome of primary and secondary education. Many countries have their own versions of civics or moral education, frequently blending religion (also in state schools), ethics, and nation building. Science teachers have their own specific responsibilities related to environmental problems and health education, including the prevention of AIDS, family planning, and other aspects of development. Methods for raising such issues in science lessons should take full account of religious-cultural/national/local sensitivities. Thus, the teaching method/approach to such issues should be indigenous and creative.

Educating Teacher Educators

Two papers (Gaulin, 1993; Lunetta & van den Berg, 1993) dealt with "tailoring science education graduate programs to the needs of students from developing countries." Frequently advanced students in science education graduate programs are preparing to become teacher educators. This tailoring involves (a) being especially sensitive to gaps in student preparation for graduate programs and to differences in culture and educational experiences; and (b) focusing projects and research on the special needs of the student's home country, with an emphasis upon doing thesis research in the home country. Recommended boundary conditions for such research were specified. Some conference participants from developing countries expressed concern that the resulting degrees would be second class. However, the presenters emphasized the need to apply the same standard of intellectual rigor for all students. On the other hand, some of the same participants also admitted that they had experienced some serious adaptation problems and reported that academic advisors had substantially underestimated them because the advisors did not sufficiently understand the students' backgrounds and cultures. Fensham and Gunstone (in this book) described a 10-month residential program for prospective Filipino in-service teacher educators. The program was unique in that a very consistent constructivist and meta cognitive approach was used, such as forcing students to reflect (in writing) from day to day upon their own conceptual development. After a real struggle through the first 3 months, the participants made great progress and started the development of constructivist methods and activities for Filipino classrooms normally having very large class size and only the most marginal resources. Whether these in-service educators will be able to get their less well-informed peers to adapt and adopt their methods is not yet known.

Van den Berg (in this book) described faculty development in a newly established teacher education program in Indonesia. Team teaching between senior and junior faculty there was a major means for both course and faculty development; it proved to be successful in improving subject matter mastery and the teaching skills of junior faculty and in preparing them for further degree study abroad. However, the method is expensive because it schedules two faculty members for a course instead of one and requires commitment and sensitivity on the part of the senior partner.

Concluding Remarks

The title of this conference on science education in developing countries suggests that there is a movement from theory to practice in science education and that this movement can fruitfully be examined through the eyes of researchers and developers. Presentations in the "Focus on the Teacher" strand do not, however, support the assumption that contemporary science education as a whole is proceeding from theory to practice either in industrialized or in developing countries. In a plenary session, (Chen, 1993) suggested that knowledge about the practical enterprise of science education is slowly emerging as a discipline in its own right. In summary, these assertions suggest that in a complex social science field like science education there may well be a complex interchange between theory and practice. Although it is unrealistic to expect practice in such a diverse field to be discernibly informed by a unifying theory, it is appropriate to search for theoretical organizers that can guide practice, policy, and development. Yet for the present, the preponderance of activity reported in the Teacher Strand was driven more by perceived needs and practical constraints than by theories.

The conference goals as set out in the call for papers relate to four aspects of science education in developing countries. They called for a review of past experiences about theory and practice, the identification of factors influencing successful practice, the identification of priorities for science education, and the development of a plan of action for the twenty-first century. While each of the presentations in this strand dealt with a real issue and reported on a significant research or development project, the strand presentations as a whole painted a picture of what is happening rather than responding directly to the conference goals.

The validity of this picture of science education, and of any conclusions drawn from it, clearly depends upon the validity of the relationships between conference presentations on the one hand and the science education contexts in which the reported research projects were conducted. The opening section of this chapter, describing the environment in which the science teacher works in developing countries, is intended to provide a context for the presentations and discussions. In that context the problems of teacher retention, teacher status, teacher expertise in science and in pedagogy, classroom conditions, and the practical difficulties involved in teacher education as a mechanism for change must all be taken into account in attempting to meaningfully interpret the conference presentations. Issues raised in these presentations, as well as the comments made in this chapter, lead to the following conclusions.

The "Focus on the Teacher" strand devoted more time to the description of ongoing activities than to the need for long-term vision in planning the development of science education. More attention must be paid to the development of long-term vision that, informed by research and development, must guide the science education policies of developing as well as of industrial countries. This does not mean that we must attempt to create an ideal program of science education. Rather, it is a call for the definition of intermediate goals that can be attained in the foreseeable future. Such intermediate goals for in-service science teacher education could include improving conventional teaching rather than attempting to introduce teaching methods that constitute too big a break with conventional school practices and with the knowledge and skills teachers already have developed. To expect revolutionary changes in school science will require new skills and commitments of time and resources that go significantly beyond those that are currently available. School science improvement projects should differentiate their goals according to school, teacher, and student characteristics.

Upgrading the education provided by schools in the lower achievement percentiles will often require quite different policies and investments than upgrading schools and teachers in upper percentiles. In developing as well as in industrial countries there is a need for caution in investing in school laboratory equipment. Far too many cases have been reported in which schools are provided with laboratory equipment but insufficient steps are taken to ensure that teachers are able to use the equipment properly and that they perceive that the equipment is needed. Furthermore, a major rethinking of laboratory goals and teaching methods is needed. This is not a call to reduce school laboratory time, nor is it a suggestion that we do without laboratory-based science teaching. It is a proposal that we start looking for more effective ways to use the laboratory appropriately and to persuade teachers that the school laboratory has an important role to play in science learning, in conceptual development, and in the development of science problem-solving skills.

Educators in developing countries must use extreme care in attempting to apply (in their own countries) research findings and theories of education developed in industrial countries. This is not simply a matter of overcoming language barriers but of understanding the differences between more- and less-developed (or just "different") educational systems and of appreciating that these differences call for diverse developmental strategies.

It is part of accepted educational wisdom that in our rapidly changing world, teacher education should be a life-long process. This means that the various components of teacher education, (pre-service, induction, in-service support) should be planned as a whole and be widely available. This calls for considerable change in our systems of teacher education, for the integration of in-service and pre-service efforts, for integration and engagement between science discipline specialists and those concerned with pedagogy, and for the reform of schools to promote more active engagement and leadership for competent, professional teachers.

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Rethinking Science Education: Knowledge, Power, Cultural Struggle, and Possibility

William Kyle

Introduction

Science educators must begin to critically examine the prevailing issues in curriculum theory and practice. Among curriculurists there is agreement that the rise of curriculum studies is a phenomenon of this century. Today, curriculum studies includes historical studies, critical theories, feminist theories, literary analysis, philosophical examinations, as well as hermeneutic, phenomenological, narrative, autobiographical, political, economic, cultural, artistic, and interpretive investigations of curriculum and its meaning.

Recent developments in post-modern and post-structuralist thought have had a significant impact on the human science, and—not surprisingly—curriculum theory has been drawn into the debates generated by this new discourse. Where are the voices of science educators in the discourse of contemporary curricularists? Why have science educators failed to give serious attention to certain approaches to research and educational change?

Mainstream Educational Discourse vs. Critical Pedagogy

For several decades science educators have been engaged in the process of curriculum reform. The obstreperous calls for reform persist. Historically, science educators, for the most part, have engaged in mainstream reform (e.g., teaching the structure of the discipline's critical thinking, process skills, search for excellence, STS). Even current initiatives in the United States adhere to mainstream reform premises (i.e., NSTA's Scope, Sequence, and Coordination of Secondary School Science Project; see NSTA, 1992a and 1992b). Mainstream educational discourse is "constructed within the parameters of our dominant social, economic, cultural and political arrangements, including the limits of certain research traditions," (Stanley, 1992, p. 2). The discourse of critical pedagogy challenges the basic assumptions of mainstream reform initiatives; draws upon other research traditions, and poses an alternative reform agenda (e.g., Apple, 1985, 1986, 1990, 1992; Freire, 1985; Giroux, 1988, 1992; Giroux & McLaren, 1989, Crumet, 1988; Pinar, 1988; Pinar & Reynolds, 1992). Educators have the fundamental obligation to explore divergent ideas, including those that are radical.

Critical pedagogy includes, but is not restricted to the "new sociology" of education, reconceptualist curriculum theory, cultural studies, feminist theories, critical theory, and various forms of post-modern and post-structuralist analysis. This scholarship, although far from monolithic, represents a significant knowledge base to orient the reform of education; still, this discourse tends to remain on the periphery of the debate over educational reform. Why? How can we ensure that the questions of human empowerment and social justice are addressed among educational theorists so that the theoretical and ethical debates within curriculum theory will be advanced?

Are there persistent goals, issues, and problems that science educators ought to be debating in the context of current calls for reform? Science educators ought to investigate the relationship between contemporary forms of critical pedagogy and social reconstructionism as they relate and contribute to the construction of a radical theory of education. Central to the reform of science education should be an articulated language of possibility and the critical competence necessary to reveal and reconstruct forms of oppression.

It is time for a change. Science educators ought to ensure that their efforts to reform science are ultimately oriented towards self- and social-empowerment. This would contrast with the technical, rational, objectivist perspective that has dominated science education reform and science education research to date. With this radical turn, science-educators would need to "raise important questions regarding the relationship among knowledge and power, learning and possibility, social criticism and human dignity, and how these can be understood in relation to rather than in isolation from those practices of domination, privilege, and resistance" (Giroux, 1988) that are at work in the context of students' daily lives.

Science education reform and associated research should be focused upon issues that really matter. What follows is a brief synthesis of issues that are discussed more fully elsewhere (Kyle, 1991, 1992; Kyle, Abell, Roth, & Gallagher, 1992; Kyle et al., 1991; Shymansky & Kyle, 1992).

Issues that Matter

Theme 1: The Purpose of Schooling, the Process of Teaching and Learning, and the Role of Research Must Be Reconceptualized

A technical, rational, objectivist perspective has dominated science education reform and research. Such a perspective maintains the status quo. A reconceptualized science education research agenda should transform schools and classrooms. There is a clear need to articulate a systemic plan for science education research oriented toward the improvement of science teaching and learning.

We must being to ask questions oriented toward self- and social-empowerment. What skills and understandings should students entering the kindergarten class of 1993 construct by the time they graduate from high school in 2006? What are the skills and knowledge that will enable today's kindergarten students to function as concerned citizens in a democratic society when they are critical decision-makers of 35 years of age in 2023? We must accept the notion that establishing empirically-based technical goals oriented toward the world view of 1950 is incongruent with an emerging world view oriented toward cooperation, collaboration, practical understanding, and emancipatory reflection. We can not seek to establish goals oriented toward emancipation and continue to utilize the empirical-analytical sciences to guide our inquiry (see Kyle et al., 1992). More research must be oriented toward the hermeneutic and critical sciences, utilizing the full range of research methodologies. Two theoretical frameworks appeal as being suitable for research related to this issue: radical constructivism and the theory of knowledge constitutive interests (see Shymansky & Kyle, 1992).

We should re-examine the moral choice put before us as educators and citizens, a choice that John Dewey suggested is the distinction between "education as a function of society" and "society as a function of education." In the process of re-examining that choice, we need to ask the following two questions:

1. Should schools serve and reproduce the existing society or challenge the social order so as to develop and advance its democratic responsibility?
2. Do we desire schools to create a passive, risk-free citizenry, or a politicized citizenry capable of assuming social responsibility, informed by a concern for equality, social justice, and civic rigor?

If the ultimate goal of a K-12 science education is to ensure that students develop the scientific and technological literacy for self- and social-empowerment, then the answer to each of the above questions should be indisputable. Research must purposefully assess whether students have acquired skills and knowledge associated with citizenship and social responsibility.

It should be clear that the purpose of school is not merely to help students achieve academically, but to prepare students to lead fulfilling lives. The true manifestation of successful schooling is not how well students perform on in-school assessments: How citizens think, what they value, how analytical and critical they can be, how they question and reflect—these are among the true measures of successful schooling. The most valid measures of the effectiveness of today's school science experiences might not be available for 30 years. For example, "How creative, imaginative, and resourceful will citizens be in resolving science and technology-oriented community-based issues that are unimaginable today?" A broader vision of assessment is imperative. Rather than focusing upon the narrow and shortsighted priorities of education, assessment should begin to focus upon the issues that really count.

Theme 2: Research Should Play a Key Role in Advancing Science Education

Shymansky and Kyle (1992) note that "research should be for educational reform, not about educational reform; it should unify—not separate—the work of educational theorizing and practice" (p. 758). Although researchers in science education have attempted to "improve" science teaching and learning through research, they have not often succeeded. Why does so much effort result in such little apparent benefit? First, most research in science education bears little relevance to the context of the lived experiences of teachers and students. Researchers have paid little attention to the historical, cultural, social, economic, and political aspects of schooling. It should not be surprising, then, when isolated instances of significant differences in highly controlled "laboratory environments" are not translated into practice. More research, in and of itself, is not needed to improve the condition of science education. Rather, attention must be paid to the wider socio-cultural, economic, and political contexts in which schools function. Second, historically, it has been difficult for researchers to engage in substantive educational reform. Most science education research produces knowledge in the context of a system clinging to tradition (Kyle, 1991). The production of knowledge in such a context perpetuates the social, economic, and political ideologies of the dominant culture and fails to contribute to a vision of social transformation.

Can research in science education contribute to the process of reform and social transformation, thereby enhancing science teaching and learning? In my view, research in science education is a center component of achieving sustainable reform. The NSTA Theme Paper on *The Role of Research in Science Teaching* declares that research should guide and inform policy formation and decision making regarding science teaching and recommends that "a more reasoned and reasonable approach to curricular, instructional, and evaluative decisions must be undertaken" (Kyle et al. 1991, p. 414). Thus, there is a critical need for the science education community—researchers, practitioners, and policy makers—to construct a comprehensive image of the purposes to be served by reform. This image must be intellectually honest and pedagogically valid.

Theme 3: Equity—Ensuring Scientific Literacy For All Students Is Imperative

Current science education reform initiatives stress the importance of ensuring scientific literacy for all students. The phrase *all students* embraces the many cultural groups throughout our global community—the many race, ethnic, social class, and religious groups, as well as both genders, the young and the old, and persons with disabilities.

Education that is multicultural recognizes, accepts, values, affirms, and promotes individual diversity in a pluralistic society. The misguided notion that individuals melt into a homogenous group divesting themselves of their heritage is rejected. Instead, education that is multicultural prizes similarities and differences as valued resources for all students.

Unfortunately, rather than ensuring equity, the present science curriculum perpetuates the race, class, and gender inequities of the past. Clear and consistent patterns of unequal opportunities to learn science and to participate in science-oriented careers are the results of tracking, socio-cultural and economic bias. Educators must possess a theoretical understanding of the ways in which difference is constructed through various representations and practices that name, legitimate, marginalize, and exclude the voices of subordinate groups in society. The present era of science education reform must eliminate the disenfranchisement of minorities, women, the poor, and persons with disabilities, as well as eliminate their underepresentation in science- and technology-oriented careers.

Past research on inequalities ought to inform practice. Interpretive and emancipatory research that focused on equity issues must be initiated. The educational discourses that view schooling as a decontextualized site free from social, political, and racial tensions must be challenged. The primacy of the political and the contextual must be stressed in analyzing issues of culture, language, and voice. Students' access to knowledge, resources, teachers, technology, and effective classroom practices must be equalized.

An increasing body of literature addresses equitable teaching behaviors and instructional strategies. Educators need to be aware of and use such strategies. We must no longer reproduce the social ills of the past by consistently undervaluing the scientific potential of a significant majority of our population. As educators, we must begin to transform science education, and, therefore, society. By addressing these issues through research, science educators have the opportunity to investigate domination, cultural struggle, power relations, empowerment, and the links to education. Research oriented toward transformation and critical democracy is imperative.

Theme 4: The Critical Issues and Questions of Science Curriculum Reform and Science Teacher Education: The Need for Research and Debate in the Context of an Adequate Understanding of the Cutting-Edge Developments in Research on Teaching and Learning

The prevailing policy maker and legislative focus upon achievement, assessment, and accountability has neither identified the problems of schooling, nor offered solutions that are pedagogically valid. The ever-changing, quick-fix, technical approach to resolving nontechnical issues of schooling fosters confusion and inaction.

By now it ought to be apparent that curriculum, instruction, assessment, and research in science education must be re-formed. The reform must set standards, it must involve teachers in the process of advancing new research policies and practices, and it must ensure that all students are the benefactors of a reformed curriculum. Research that integrates these conditions would be most fruitful in advancing our understanding of the entire process of curriculum reform. Our understanding of science teaching and learning would be enhanced by practitioners and researchers theorizing, planning, conducting, and interpreting research that is pedagogically relevant. Further, teacher education programs would benefit from collaboration with schools through the establishment of Professional Development Schools, in which closer links between the process of K-12 science education reform and research, and science teacher education reform and research, could be established.

Theme 5: The Reform of Schools and Teacher Education Must Be in Harmony

If reform means transforming schools and classrooms, then it must be guided by an understanding of the process of change and a vision for the future. Similarly, the reform of K-12 science education and associated research must be in harmony with the reform of science teacher education.

The reform of schools requires nothing less than the transformation of the way prospective teachers are educated. We must begin to articulate models of teacher preparation and enhancement that enable teachers to construct understandings of science and teaching based upon our understandings of how students learn. In a transformed instructional environment, research related to the issues of teaching for critical democracy, the process of transforming power, and the issues of empowerment become fruitful areas of inquiry.

Thus, a new image of the role of the teacher is emerging. In addition to possessing discipline-specific knowledge and knowledge about effective pedagogy, teachers must be afforded the time to share ideas with colleagues, participate in professional development, and inquire about teaching and learning. Teachers must be active, reflective practitioners. Toward that end, Kyle et al. (1991) offered the following recommendations:

1. Research should be a collaborative endeavor.
2. Teachers should be action-researchers.
3. Research must be close to the classroom.
4. An investigative society should be created.
5. Research should inform policy.

Schools need prospective teachers who can combine theory, imagination, and techniques. School systems should sever their relationships with teacher preparation institutions that fail to prepare teachers with the ability to assume their full potential as active, reflective scholars and practitioners. Within the context of the new image of teachers and research being offered, teachers must assume responsibility for raising serious questions about what they teach, how they teach, and the larger goals toward which they strive. Teachers must become collaborative partners in shaping the purposes and conditions of schooling. We must rethink and reform the traditions and conditions that have prevented teachers from assuming their full potential as active, reflective scholars and practitioners. Research on the process of transforming power is an emerging area of interest and would facilitate the reform of teacher education.

Summary

I have identified five major themes, which I believe represent fruitful domains of research in science education for the next 5 years. The domains are not traditional. However, I believe the domains represent issues that we have failed to address in the past and that we must address now if we wish to reform science education.

Historically, efforts to improve science teaching through research typically have failed. Why? I believe such efforts have failed because inquiry and debate have not addressed the issues of sustainable reform, the process of change, the culture of schools, the context of classrooms, and the content of the curriculum. The domains of research that I have offered acknowledge that curriculum, instruction, assessment, and research in science education must be reformed. We must construct a comprehensive, intellectually honest, and pedagogically valid image of reform. This emerging image must:

1. Ensure that citizens develop scientific and technological literacy for self- and social-empowerment;
2. Address the wider socio-cultural, economic, and political contexts in which schooling transpires; and
3. Ensure that scientific literacy for all means just that—literacy for all.

Past and present notions of science curriculum reform seek to appropriate children and adults to take part in life as it is today. This flawed orientation ignores the reality of rapid social and cultural change. Further, this orientation perpetuates dominating ideological discourses, thereby enabling educational systems to function as a political means to maintain and appropriate knowledge and power.

Central to the post-structuralist analysis is the concept of textuality. Textuality refers to the material nature of our human existence as manifested in our institutions, discursive practices, and power arrangements as each of these operates in the textual context of diverse and dynamic structural systems of signs and codes. Stanley contends that "By employing poststructuralist insights, critical pedagogy is a far better position to uncover those intrinsic structural dimensions of education that function as forms of domination" (1992, p. 205). Further, he (Stanley, 1992) maintains that

> *poststructuralism reveals how the apparent opposition between human agency and social structures is, in fact, part of the wider hegemonic ideology that limits our knowledge of the essential interweaving and interdependency of agency and structure within the textuality of our existence.*
> (p. 205)

It is this sort of post-structuralist understanding that is essential to the counterhegemonic praxis at the core of critical pedagogy. Critical science educators must reconstruct the goals of science education to advance a broader discourse oriented toward cultural struggle and possibility.

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The Fiji Science Education Practical Optimization Project

Alan Cook, John Stir, and Neil Russell

Introduction

In November 1990, biology and chemistry teachers in an in-service program of the Fiji Ministry of Education reported that their students were able to perform relatively little practical work. They indicated that this was partly because of the lack of equipment in their schools. Breakage, wear and corrosion, scarcity of some materials, the spiralling cost of chemicals and equipment, and the apparent absence of a culture of maintenance in schools had combined to create shortages. Shortages of chemicals and equipment mean that teachers replace student experiments by teacher demonstrations or that teachers merely describe experiments and their outcomes. Such practices are at odds with the expressed aim of science education in Fiji to be more student-centred (Muralidhar, 1990). For instance, practice with manipulative skills can lead to a growth in confidence and self-respect. Laboratory exercises in which students get a feel for phenomena provide them with better opportunities to understand key concepts. Practice in the use of processes such as hypothesis-forming, the identification of variables, and basing conclusions on evidence gives students the opportunity to better understand the nature of science and is a crucial component of a balanced general education. This knowledge and these skills and attitudes can best be learned by students performing experiments themselves. Not only are these activities necessary for academic success but for developing the ability to adjust to changes inherent in increasing urbanization and development.

This paper describes findings from a three-phase project to review existing resources and to develop procedures to address the problem of lack of science equipment in secondary schools.

Phase 1: The Creation of an Equipment and Chemicals Database

The first phase of this project involved the development of a database to compare the syllabus requirements for equipment and chemicals with current inventories reported by schools.

The database was designed for the following purposes:

1. To enable the Curriculum Development Unit (CDU) to provide schools with an inventory form listing the essential resources necessary to fulfill Ministry of Education requirements for science practical work as well as suggested resources for extension work;
2. To enable schools to provide the CDU with up-to-date information about chemicals, equipment, and materials in the school inventory;
3. To enable the CDU to obtain, from suppliers, competitive quotes for the supply of items required in the prescription; and
4. To enable the CDU to provide schools with up-to-date information about prices of chemicals and equipment that schools indicate they wish to purchase.

Comparison of Inventory Data

As of November 1992, 131 inventories had been received from schools. The range in comprehensiveness of inventories, especially in secondary schools, is quite marked. A selection of items essential for student practical work in basic science is listed in

Table 1. Equipment Inventory: Fiji Secondary Schools

Item	School					
	F	G	H	I	J	K
Basins (Evaporating)	0	0	0	4	0	0
Beakers (Assorted)	22	42	27	118	37	80
Bunsen Burners	20	0	4	12	0	14
Compasses (Magnetic)	0	0	0	27	5	9
Electroscopes	1	0	0	0	0	0
Microscopes	7	0	2	9	7	2
Test Tubes	20	35	30	1018	121	238
Thermomenters	5	5	2	22	6	19
Triple Beam Balance	2	4	1	2	3	2
Voltmeters	2	0	0	7	12	5

Table 1. Secondary schools with a reported lack of equipment are labelled F, G, and H; better equipped schools are labelled I, J, and K. Even the better equipped schools had insufficient supplies of certain items, such as evaporating basins and electroscopes. The chemicals inventories (Table 2) show a similar trend.

Analysis of the prescription for basic science indicated that 52 chemicals are required to conduct the recommended practical exercises. Only half of the secondary schools in Table 2 have more than 50% of the chemicals in the junior prescription. The populations of students serviced by these schools were not insubstantial with schools F, G, I, J and K having 386, 131, 507, 213 and 630 students respectively. Statistics for school H were unavailable.

Table 2. Chemicals Inventories for Secondary Schools

Item	School					
	F	G	H	I	J	K
Chemicals in stock that meet junior secondary prescription requirements	3	12	18	50	34	42

Once the database is fully operational, the CDU will have the ability to make appropriate recommendations for future purchase of equipment and chemicals. Inquiries of the database could, for instance, be made to advise schools which equipment should be given highest priority when placing orders. The database will provide the science teachers of Fiji with the means to more efficiently make choices between the many alternatives open to them.

Phase 2: Development of Teacher Manuals of Low Cost Practicals

The aim of the second phase of the project was to write methods for experiments using inexpensively produced materials that could be used as alternatives to those found in current manuals. Writing the manual in a 2-week workshop, the team, consisting of local teachers, CDU officers, other specialists, and the research team, made use of a wide variety of existing materials (Unesco, 1973, 1985; Lowe, 1985; Universtudents to recall knowledge. Among many students who strive for advancement, the need to do well in external examinations is of paramount importance. They require easy and efficient ways of obtaining that knowledge. Experiments, especially those that foster skill development, manipulative or mental, will not be considered important by students. They would prefer to spend their time in making sure they understand what they have read or been told. Understandably there are teachers who think and therefore, teach, the same way. It is likely, therefore, that change will occur in the system (i.e., teachers will ensure that their students perform practical activities) only if it is in some way legislated by the Ministry.

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sity of Maryland, 1972; Joseph et al., 1961). It was decided by the CDU to limit the number of practical activities to between 20 and 30 key experiments in each of the 3 disciplines for Form Five and about the same number for Form Six. This would be set as a mandatory minimum of experiments that students would be required to perform each year. The manuals will be trialed in selected schools in Fiji in 1993.

Phase 3: Maintenance

The first two phases of the project would be of little use, if materials purchased by schools or produced by teachers were not maintained in working order. The third phase of the project therefore seeks to address the very difficult problem of maintenance. A survey of science teachers and heads of departments about maintenance problems has been conducted. Forty-two percent of the teachers in the survey indicated that they were often unable to organize laboratory lessons, and only 2% said that they had no problems with equipment and supplies. Twenty-five percent of the teachers reported that maintenance problems occurred often; 12% said that maintenance was not a problem.

Teachers indicated that cost was a prime consideration in finding solutions. Teachers agreed that the employment of an itinerant laboratory technician could be cost effective but was unlikely in the short term, given the current financial climate. Many respondents believed that a change in teacher attitude was necessary. A number of teachers felt that a basic step-by-step maintenance manual would be useful. The issue of maintenance was pursued in follow-up interviews with Fiji teachers and others in November 1992.

Some Reflections on the Project

1. Local Ownership for Sustainability

Ownership of the project is crucial to sustainability. Thus, although the overall plan was initiated in Australia, it was written based on the expressed needs of Fiji teachers who discussed problems during in-service workshops. In all phases of the project, CDU personnel and local teachers were major participants. For instance, in the second phase of the project, the teachers and CDU representatives were the major authors of the materials produced.

2. "Need to Know" Knowledge and Communication

The ultimate success of initiatives such as the Optimization Project depends on the flow of quality information between participants. It is therefore the task of project organizers to promote continuous information transfer between all concerned. In particular, Australian personnel needed to emphasise that Fiji personnel were the key participants in such enterprises because they have crucial local knowledge.

3. Local Commitment to Change

The project has been fashioned by Australians as a result of their experiences with Fiji teachers and as a result of discussions with Ministry officials. The conceptualization of the project has inevitably been influenced by contemporary Western thought about such features as the nature of learning and the role of practical activities in students gaining meaning about science. The assumption has been made that such thinking is applicable in the multiple cultures that compose Fiji.

There could be problems with such assumptions. Not only are there substantial differences between the philosophies and mores of Fijians and the Indians of Fiji, there are also cultural differences between rural and urban students. Besides the availability of equipment, the question must be asked as to whether an approach that emphasizes practical experiences is appropriate in these cultures and within the physical constraints of schools. Those with a knowledge of these cultures and of the nature of science education say that a constructivist approach is essential for real understanding (Walberg, 1991). However, there are some codicils. Exams in Fiji mainly emphasise the need for

The Convergence of Teachers and Providers Views on Inset Needs: The Case of the Non-Specialist Physics Teacher in Swaziland

Fred Lubben

Introduction

In-service education and training (INSET) activities are most effective if the participating teachers are "ready" for the topics addressed, and if they feel that these topics are high on their priority list of problems. Seldom, however, are structured surveys undertaken by INSET providers to identify the INSET priorities of their target groups. This is particularly so in Third World centralized, "top-down" education systems with chronic shortages of time, funds, and expertise. INSET programs are usually structured on the basis of the observations of INSET providers and the requests of educational administrators. This study sets out to establish the in-service needs as perceived by teachers and to compare these with the views of INSET providers. The in-service needs of non-specialist physics teachers in Swaziland were used for such a comparison.

Farah and Tarvin (1989) make a useful distinction between two types of in-service programs. First are the *ad hoc* programs to facilitate the introduction of a new curriculum, or to strengthen a particular curriculum aspect, such as an environmental emphasis or an open-ended approach to practical work. The second type is the on-going in-service program for continual teacher development. This paper limits itself to the latter type of INSET program.

The Educational Context for the Study

The presence of a large number of non-specialist physics teachers in Swazi high schools is a direct result of the mismatch between teacher supply and demand. An open shortage of specialist physics teachers is temporarily "solved" through recruitment of foreign teachers, resulting in a destabilizing high turn-over (Manyatsi, 1987). In addition, a sizable hidden shortage is created by allocating 40% of the physics classes to non-physics specialists (IMSTIP, 1988). Alonge (1988) notes that African schools tend to have more biologists than chemists, and physicists are the fewest among the science staff. For Swaziland this pattern is confirmed by tracer studies of graduate teachers, which also show that cohorts of indigenous Swazi science teachers have a "half-life" of 2.5-3.0 years (Lubben & Mdluli, 1988). This results in a young and multicultural teaching force, required to teach in isolation (usually one teacher of each science subject per school), without relevant teaching materials and often lacking facilities and equipment.

In this environment, teacher support has been provided, for several years, through the In-service Mathematics and Science Teaching Improvement Programme (IMSTIP). It aims to improve the professional performance of teachers of mathematics and science by stimulating and sustaining teachers' self-confidence. Activities include the organization of frequent national workshops for the development of teaching materials for practical classes and seminars for improved laboratory management and improvisation of equipment and other teaching resources. Close follow-up is provided through school visits to selected priority schools, where teachers are helped with specific problems ranging from teachers' misconceptions of science content, to lesson planning, assessment, safety, class management, or procurement and use of teaching equipment. Although many of these activities are performed by a small number of full-time staff based at the University, other science educators often participate in such INSET delivery, and constantly have a say in the type and emphasis of IMSTIP activities through the National Science Panel. This direct influence on both INSET policy and delivery highlights the importance of the extent to which the views of these INSET providers overlap with the INSET target group.

Reports on INSET Needs of Non-Specialist Teachers

A search of the literature does not reveal any previous studies on INSET needs of non-specialist teachers (of any subject) in the Third World comparing their views with those of their INSET providers. In a separate study (Lubben, 1991), the in-service needs *per se* for specialist and non-specialist physics teachers in Swaziland are reported. This shows that the considerable problems with physics topics and equipment can be categorized as unfamiliarity, mathematical demands, conceptual problems for both teacher and students, everyday applications, and constraints on doing practical work. Only the first two types of problems are specific to non-specialists. Many inexperienced non-specialists are discouraged by the requirement to prepare physics practicals thoroughly, but more experienced non-specialists are attracted by the illustrative and applied nature of physics practicals.

Research findings on the perceived INSET needs of non-specialist physics teachers in England (Millar, 1988; Parson & Birley, 1989) suggest that they are mainly concerned about handling complex or "hazardous" apparatus, about methods of student assessment, and about the depth and breadth of their own knowledge, particularly when dealing with open-ended investigations. The difference in emphasis illustrates that the concerns of teachers in industrialized and Third World countries should not be equated lightly.

This literature overview may have given some suggestions on the INSET needs of non-specialist physics teachers. The present paper does not intend to analyze these needs in more detail, but to contrast the perceptions of the non-specialists and the providers on these INSET needs.

Research Method

Data were collected from all six physics teacher educators in Swaziland, all of whom participate in INSET provision. Four of them are men, and two are women. On average, they have been involved in teacher education in Swaziland for 4 years. The number of physics teachers in the whole country totals 61, of whom almost half (29) are non-specialists. Only two of these could not be reached, because of flooding of the roads during the rainy season, so data were obtained from 93% of the total target group. Their average teaching experience is 3.5 years, and only five of these teachers are women.

Using a postal questionnaire, the INSET providers were asked for their views on the help needed by non-specialist physics teachers in (a) teaching specific physics topics, (b) handling apparatus, and (c) teaching of practical manipulative skills. Answers were requested on a four-point scale from "no help needed" to "lots of help needed." Each section included an open-ended item with space for additional comments.

From the teachers, data were collected through structured interviews following the outline of the questionnaire mentioned above. Past research (Manana, 1988) on a similar group of teachers has shown a preference for oral rather than written communication. An advantage of the interview format is that it allowed follow-up questions to explore teachers' perceptions of the source of difficulty.

The questionnaire responses of the INSET providers indicated a rate of help needed, from 0 (no help needed) to 3 (lots of help needed). The accumulated rate of help needed (maximum = 18) as projected by all INSET providers is used to determine the observed difficulty ranking of the various topics, apparatus and skills. On the other hand, the frequency with which non-specialist teachers indicated problems provides the equivalent perceived difficulty ranking of the same topics, apparatus, or skills.

The data from the INSET providers on "topics where help is needed" are compared with teachers' views on "topics which are difficult to teach." The validity of such a comparison is based on the assumption that teaching difficulties identified by the teachers need to be resolved through help from a third party. Teachers might, of course, perceive problems in their teaching as insoluble. Also, problems in teaching might be seen as resolving themselves without "help," for instance through time, or by just "going over it once more."

Results: Difficult Topics

Out of a total of 40 topics covering the whole syllabus, the INSET providers and the teachers identified an average of 23 and 12 topics, respectively, as difficult to teach. This may, however, tell us more about the number of items that are considered reasonable to be perceived as problematic, than about the topic difficulty in an absolute sense. It is therefore more revealing to compare the difficulty ranking of individual, or clusters of, topics.

The extent of overlap of the ranking of the five clusters of most problematic topics is remarkable. Both non-specialist teachers and INSET providers ranked the following topic clusters in decreasing order of difficulty:

1. Modern physics (thermionic emission, diode);
2. Electromagnetic induction (magnetic fields, the AC generator and transformer);
3. Nuclear physics (radioactivity, half-life and isotopes);
4. Waves (sound and water waves, the electromagnetic spectrum); and
5. Heat (specific heat capacity and latent heat)

Only within the area of electromagnetic induction did the perceptions of the two groups deviate in detail: the INSET providers were less concerned about teaching magnetic fields. Similarly, a few aspects of light, such as ray diagrams, prisms, and spectra, were reported as presenting a moderate level of difficulty to non-specialists. INSET providers ranked these topics very low on their priority list, in line with the concerns of specialist teachers (Lubben, 1991) rather than non-specialists.

It is striking that very few non-specialist teachers of physics reported problems with dynamics, whereas teaching of both acceleration and, particularly, velocity-time graphs were seen by INSET providers as requiring a lot of help. Although circuit electricity was seen by the non-specialist teachers as posing problems only in the area of applications, such as house wiring, the INSET providers strongly felt that various concepts, such as voltage and resistance, and the related circuit calculations provided serious difficulties. Some topic clusters were seen by both groups as posing very few problems, such as mass-weight-density, pressure-force-moments and force-work-power.

Results: Problematic Equipment

Of a total of 22 pieces of equipment, the non-specialists and INSET providers perceive problems with an average of 6.5 and 10.3 items, respectively. As in the case of the problematic topics, the data will be reported in terms of difficulty ranking for the various pieces of equipment.

The major problems identified by the non-specialists and the INSET providers are again almost identical. Both groups allocate priority to the *more sophisticated and expensive items*, such as radioactive sources, high tension supplies, Teltron tubes, signal generators, and Van de Graaff generators. However, the nature of the problems with handling these pieces of equipment is explained quite differently. The non-specialist teachers indicate some "fear of the unknown." The listed equipment is expensive and rare in the schools. Non-specialists have been exposed to few of these items during their training. As one teacher says:

> *In the last school I was in we had some of these Teltron tubes, but they never got out of their boxes. I would not know where to start: they looked delicate and complicated, so I never used them in class: the experiments are clear in the book, I think.*

INSET providers place the same pieces of apparatus at the top of the difficulty list, but for completely different reasons. The providers are concerned not with unfamiliarity, but with safety and proper connections.

Both non-specialists and INSET providers perceive moderate difficulty with setting up particular pieces of more common equipment, like the oscilloscope, smoke cell, and the electromagnetic kit. A non-specialist teacher explains:

> *The oscilloscope we have, you see, it just has too many knobs and I hardly know where to start fiddling with them. I would really need a manual to begin with. The other thing is that I find it difficult to connect the oscilloscope to a diode, or a signal generator. I'm not sure which terminals to use.*

In addition to the pieces of apparatus listed above, the INSET providers identified problems in setting up the ripple tank, much in line with the perceptions of the specialist teachers (Lubben, 1991). Non-specialists identify a third group of problems. It concerns the ticker timer, electroscope, smoke cell, ripple tank, and the electromagnetic kit. These were all said to provide: experimental results which are "unreliable or difficult to interpret."

> *No, I've stopped using the electroscope, since some don't work and you can't really prepare for the experiments. You're so dependent on the humidity that I don't want to take the risk.*

A few teachers, but none of the INSET providers, went so far as to doubt the educational usefulness of some pieces of equipment. They wondered if a ticker timer or a smoke cell really helps to illustrate the relevant concept.

In contrast to the INSET providers, only a handful of non-specialist teachers reported that they "feel uncomfortable with some of the hazardous apparatus," such as radioactive sources, high tension supplies and the Van de Graaff generator. Both groups agree that very little help is needed in handling various pieces of equipment used for circuit electricity (ammeter, voltmeter, circuit board, and rheostat). The same applies to calorimeters, optics kits and stop clocks.

Results: Practical Manipulative Skills

Non-specialist teachers of physics perceive few problems in teaching manipulative skills involved in working with basic physics equipment. From a list of 18 manipulative skills, they indicate on average only 2 to be problematic. The INSET providers, however, suggest that the non-specialists need help with teaching, on average, 7 of these skills. The very low numbers of teachers who perceive these manipulative skills as problematic does not allow for differentiation in the difficulty ranking. Conclusions on the convergence of views on INSET needs in this area have to be rather tentative.

Both non-specialists and INSET providers agree on the INSET priority for the teaching of skills involved in recognizing sources of experimental error, plotting speed-time graphs from ticker tapes, and constructing model electric motors.

Interpreting diagrams to construct electric circuits, together with skills involved in plotting magnetic field lines, are perceived as of moderate difficulty by the non-specialists. Their concerns contrast markedly with the low ranking of these skills by the INSET providers. On the other hand, the INSET providers, but not the non-specialists, identify a considerable need for help in teaching the skills involved in using a micrometer, and the combination of ammeter and volt meter to measure resistance. In both cases, the deviating views of the INSET providers coincide with the specialist, rather than the non-specialist teachers (Lubben, 1991). Neither non-specialists nor INSET providers consider the use of simple apparatus such as measuring cylinder, stop watch, and spring/beam balance to present many teaching problems.

Discussion and Implications

The results of this study show that the INSET priorities of non-specialist teachers and INSET providers coincide to a marked extent. The large degree of overlap of the INSET needs as perceived by INSET providers and teachers seems to justify, in principle, a continuation of present practices whereby INSET providers propose on priorities of INSET activities, which are endorsed by the national subject panels. In fact, this structure is a loose form of the "educational consortium" described by Neel and Monroe (1988). Such a structure brings together the views of teachers, teacher educators, and administrators on individual and institutional staff development needs. It also identifies the expertise for providing agreed priority INSET activities among the group.

However, this study provides evidence that the views of INSET providers deviate from the needs perceived by the non-specialist teachers in a number of important cases. Reasons for these differences may be grouped in three areas: specialist training, professional development, and views on the goals of science education. Each of these areas will be discussed below, together with their implications for INSET.

Differences Attributed to Specialist Training

In several instances, the INSET providers' ranking of INSET needs coincides more with that of the specialist, than with the non-specialist, physics teachers. Therefore, a number of INSET needs seen by non-specialist teachers are not identified by the providers. This suggests that their training and experience in physics teaching has "blinded" them to these difficulties. Examples are the lower priority given by INSET providers to the concepts of magnetic fields, including the skills involved in plotting these with compasses, and the skills of connecting an electric circuit from a diagram. Closely related is the striking unawareness of non-specialist teachers' "fear of the unknown" in relation to handling various pieces of physics equipment. Although both teachers and providers put handling of items like radioactive sources and Teltron tubes at the top of their lists, INSET activities need to be significantly different if the problems are perceived as unfamiliarity (as by the teachers), or as concerns of safety or data interpretation (as by the INSET providers). It should be noted that in Third World schools the "fear of the unknown" is often aggravated by the absence of laboratory technicians and specialist colleagues for consultation. It seems clear that any INSET effort for non-specialist teachers needs to include hands-on practice with subject-specific apparatus for its own sake.

This type of perceived need may be uncovered through regular surveys as part of a proper "educational consortium" strategy, or through structured group brainstorming aimed at formulating (Beauchamp & Borys, 1982). However, both methods are time consuming and are likely to result only in relatively few additional perceived needs. In these circumstances, it may be more efficient to use evaluation tools of on-going INSET activities as instruments for assessing further needs (for example, see Fresco & Ben-Chaim, 1986).

Differences Attributed to Professional Development

A second set of differences in the views of the non-specialist teachers and their INSET providers seems to relate to professional development. For instance, the INSET providers see a great need for help with safety aspects when handling various pieces of equipment. In contrast, non-specialist teachers in Swaziland do not perceive safety as a problem. This difference may arise from the INSET providers' familiarity with the literature, reflecting the Western emphasis on teacher accountability. In practice, safety aspects can easily be inserted in INSET activities that otherwise address teacher-felt needs.

More importantly, the INSET providers express a consistently higher level of concern with teaching of conceptually demanding areas of physics, such as circuit electricity and dynamics. It seems that their awareness of research reports on misconceptions in these areas amongst African students (Ivowi, 1984; Thijs, 1988) and teachers (Rollnick & Rutherford, 1990), and the involvement of several of the INSET providers in research in these areas has made them more sensitive as to "what should be the problem" in class teaching.

When planning INSET activities aimed at these conceptual problem areas, it is possible that no change in teacher behavior can be expected if the suggested change is not perceived as a need by the teacher. To make some English teachers aware of their misconceptions, Kruger et. al. (1990) used one-to-one in-depth interviews with non-specialists on everyday science situations to probe their personal ideas and understanding of various physics concepts. Although the teachers reveal feelings of anxiety and inadequacy, they also change their perception of their needs and show a strong motivation to improve their conceptual understanding. In an African context, Rollnick and Rutherford (1990) suggest the use of group interviews for documenting teachers' misconceptions and conceptual INSET needs. These processes of raising self-awareness of teachers' INSET needs may be seen as the first step of a constructivist model of teacher learning as suggested by Millar (1988).

Differences Attributed to Views on the Aims of Science Education

The emphasis of the INSET providers on teachers' need for help with the teaching of manipulative skills, contrasted strongly with the low number of problems identified by the non-specialists themselves. At the time of the study, the physics syllabi used in Swazi schools did not specify any practical skills objectives. Such skills were not assessed on a continuous basis, nor through a practical examination. Independent research (Campbell & Lubben, 1992) shows that Swazi teachers consider that the main purpose of practical work in science teaching is to support students' theoretical understanding, rather than the development of any type of skills. These results are in line with many other research reports concluding that Third World education is assessment directed (*e.g.* Crossley & Guthrie, 1987; Rogan & MacDonald, 1985). The INSET providers, however, wish to look beyond the strictly examinable objectives of the present syllabus and, therefore, highlight the need to teach manipulative skills and, consequently, the need for help with teaching these skills. It should be noted that another function of practical work, such as the development of investigative, problem-solving skills (Woolnough and Allsop, 1985) is not seen as an INSET priority by the providers or the teachers.

Before teachers, specialist and non-specialist, change their class teaching to include manipulative and problem-solving skills, they will need to perceive the assessment system to include these skills (Harlen, 1990). Only after such curriculum and assessment change would they perceive the need for INSET efforts in this area.

Wider Applicability

The applicability of the results of this study to developing countries other than Swaziland and to school subjects different from physics is pertinent. There is no doubt that the phenomenon of the non-specialist teacher extends to the other sciences, mathematics, and the technical subjects in schools in most countries in Sub-Saharan Africa (Duberg & Gorham, 1983). INSET will need to be provided for these groups, and this study has various useful pointers. In addition, the determining characteristics of the various education systems in Sub-Saharan Africa are also very similar to the Swazi situation: there are often young and inexperienced teachers working in isolation in a centralized education system, often at the "formalist" stage of development; there are an examination-directed curriculum and teacher-centered, under-resourced classroom activities.

However, some aspects specific to the Swazi system might have helped to bring the INSET providers closely in touch with the INSET clients: the conciseness of the geographical unit, Swaziland, with the possibility of frequent informal professional communication through the IMSTIP project, which monitors INSET needs, and progress in addressing these needs (Plomp et al., 1992); the young local teaching staff almost all trained at the same institute providing the INSET support; and the voluntary nature of the INSET activities and its independence from the Inspectorate, which compels attention to the clients' needs.

In such a context, the INSET needs as perceived by the INSET providers and the teachers converge considerably. The practice of identification by the INSET providers of priority INSET activities to address these needs for endorsement by an "educational consortium" proves successful. In countries where INSET providers and non-specialist teachers have less professional contact, their views may diverge further than has been seen in this study. In such situations, a more urgent need exists for regular direct surveys of teachers' needs.

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A Qualitative Study of Elementary Teachers and Students Interactions With Full Option Science System (FOSS)

John Clementson

Introduction

According to James and Hord (1988), the failure of the 1960s and 1970s National Science Foundation (NSF)-supported elementary programs was not their failure to produce appropriate learning outcomes, but their failure to be implemented. This qualitative study conducted in rural school districts in the state of Nebraska suggests that the factors that contributed to the demise of the first generation programs are still operating against the successful implementation of the second generation programs. Specifically, the study focused on the use and implementation of the Full Option Science System (FOSS) program.

Full Option Science System, developed at the Lawrence Hall of Science at the University of California-Berkeley, is the newest of the second generation programs. Together with NSF and Encyclopedia Britannica Education Corporation support, the developers of FOSS have designed a hands-on laboratory science program for grades three through six. The program consists of 16 self-contained modules in 4 major topic areas; scientific reasoning, physical science, earth science, and life science. Although FOSS is a new science resource, the foundation on which it is based has a long history at the Lawrence Hall of Science. The development of the FOSS activities was guided by the compelling evidence that youngsters progress through recognizable stages of cognitive development and that collaborative grouping of students allows the students to develop desired cognitive and affective outcomes of instruction (FOSS, 1989). To that end, the study focused on the implementation and use of the FOSS program by teachers as they grouped students in collaborative learning groups.

Purpose

The purpose of the study was to use a qualitative (naturalistic paradigm) methodology to investigate and understand the nature of the events and perceptions of the teachers, students, administrators, and other key actors involved with the FOSS. The FOSS program was studied as it was used in the natural setting of three rural Nebraska schools. The study was both exploratory and evaluative as it sought to develop questions, insights, descriptions, conclusions, and recommendations for further study.

Reviews of existing literature regarding elementary science curricula effectiveness studies revealed a predominance of quantitative methodologies. The literature reviews also revealed little research regarding the use and effectiveness of the second generation programs. Specifically, qualitative information was lacking about how elementary teachers interact with a prepared hands-on elementary science curriculum. Therefore, this qualitative study serves several significant purposes.

Significance

First, the study creates a comprehensive, albeit context-specific, understanding of the key actors' involvement with the implementation of the FOSS program. Second, the study contributes to a heightened awareness and a basis for judging the efficacy of the general model of national science curriculum reform that gave rise to the program. Third, because of the qualitative nature of the study, it assists teachers, students, and other key actors involved to a greater understanding of themselves and their actions. Fourth, the study contributes to the improvement of teacher education in this country. Information from the study is helpful to teacher educators who seek to expand their understanding of the "cutting edge" curriculum programs of the 1990s. Fifth, the findings are significant for others contemplating the adoption of a hands-on elementary science program. Finally, the study should stimulate other researchers to further investigate the second-generation elementary science programs, specifically FOSS. To that extent, it is this researcher's anticipation that the findings of the study, comprised of multiple interpretations and perspectives, will be an invitation to other researchers who seek to improve elementary science education.

Participants and Data Collection

The participants involved in the study included five elementary teachers, their students, their administrators, and other key actors involved with the implementation of the FOSS curriculum in three elementary schools. The teachers represented a cross-section of teaching experience and professional training. Three of the teachers had less than 4 years of teaching experience, and two had more than 11 years of experience. The three elementary schools varied in size from less than 100 students to more than 700 students.

Multiple data collection techniques were used in multiple sites to provide triangulation for the study. In most instances, documentation was undertaken in the natural setting of the elementary classrooms. The study involved the collection of data from an assortment of sources: teacher journals, formal and informal interviews, conversations, field notes, demographic information sheets, letters, phone calls, the researcher's personal reflective journal, and student artifacts collected in the field. The data were collected over a 5-month period in the spring of 1990. Data collection involved over 40 formal site observations, 10 structured interviews that were recorded and subsequently transcribed, collection of journals every 3 weeks, hundreds of pages of field notes, and other communications with participants through phone calls, artifacts, and final written surveys. Consistent with the constant comparative and analytical induction methodologies of Goetz and LeCompte (1984) and Lincoln and Guba (1985), all phases of the study were continually scrutinized, reevaluated, compared, and questioned until categories and themes began to emerge and the data became saturated.

Data Analysis

The documentation sources were analyzed using five levels of data analysis. Analysis began with an initial framework of working hypotheses that were induced from the literature review, original research questions, and emergent events early in the study. Statements of relationships and categories emerged through a constant comparison of data from varied sources and methodologies. The constant comparative process continued until no new hypotheses or propositions emerged from the data. Glaser and Strauss (1967) refer to this process as data saturation.

Once the data were collected, the task of organizing, focusing, simplifying, and reducing the data was conducted. Several qualitative techniques were useful to accomplish this reduction. First, consistent with Goetz's and LeCompte's (1984) typological analysis techniques, the data were separated into groups to look at the pieces of the whole phenomenon. These separations inductively emerged from the common sense or mundane perceptions of reality as interpreted by the researcher. Qualitative researchers are often faced with the dilemma of figuring out what parts of the observed data fit together with each other. Guba (1978) describes this as the problem of "convergence." Consistent with Guba's techniques, the data were examined for recurring regularities and worked back and forth between the data and the category system until the categories, their properties, and their interrelationships had been fully explored. Enumeration was the second technique used to reduce the data. In this study, enumeration was used to develop categorical frequency matrices during the process of converging the data and during the triangulation of data sources.

A second level of analysis organized the data into five individual case records. The case records included categorized data from eight data sources from three school sites. Each case record was organized around both major and sub-themes established by the first levels of data analysis. Coded data from the case records were organized into nine major categories. To facilitate and ensure triangulation, color codes, source codes, and chronological codes were assigned to each piece of information placed in the case records. The case records were subsequently used to develop five individual narrative case studies.

The narrative case studies represented a third level of data analysis. Themes, perceptions, observations, interpretations, and working hypotheses were cross-checked by comparing the data entries within a category to other data entries from other data sources in the case record. When themes were substantiated by multiple comparisons, they were included. This comparative process enabled a further reduction of the data and allowed for the development of a rich, accurate portrayal of an individual teacher's interactions and experiences with the FOSS program. The case studies were organized around the emergent themes and included verbatim narrative and interpretive description.

A fourth level of data analysis involved the cross-case analysis of the data. In accordance with procedures suggested by Miles and Huberman (1984), the individual case studies were compared. While the five individual case studies represented several levels of data reduction and analysis, the case studies remained large and represented an enormous amount of data. To further reduce the data, a meta-matrix, affectionately referred to by Miles and Huberman as a "monster dog," was developed. This monster dog included the inclusion of summarized data from the single case studies into one very large wall chart. The summarized data included the transformation of narrative text into short quotes, interpretive phrases, and summarizing statements. The monster dog included the individual cases on a vertical axis and the "major" relevant themes on a horizontal axis. The chart served to reduce the data from 100+ pages of narrative text to approximately 30 thematic matrices. Within and across category sorting, clustering, and partitioning produced a summative discussion of themes, experiences, perceptions, and actions that were pervasive in the data of all five individual cases.

A fifth level of data analysis and reduction involved the development of summative matrices. The matrices served to reduce the data to 11 tables that represented the major findings of the study. Additionally, the matrices were used to develop the final conclusions of the study.

Conclusions and Recommendations

Because this qualitative study sought to explore and understand the nature of the interactions of key actors involved with the implementation of the FOSS program, the discussion and recommendations should not be considered as prescriptions for future practice, but as suggestions that emanated from and are consistent with the data. The following themes emerged from the data and are presented as interpretive description and include verbatim narrative from the actors involved in the study.

Collaborative Grouping

For teachers to implement a new science curriculum while trying to also implement a new teaching strategy requires ongoing training and support, or the program will soon become frustrating for both teachers and students. In 1982, a search for exemplary science programs was sponsored by the National Science Teachers Association (NSTA) and the Council of State Science Supervisors (CSSS). Penick and Yager (1983) reported that certain characteristics tended to recur among the identified programs. Generally, the exemplary programs were implemented with the active collaboration of school staff and administration who made a commitment to extensive and continuing in-service. James and Hord (1988) have identified four absolute imperatives for successful implementation of an innovative elementary curriculum: (1) training, (2) arranging for materials and space, (3) monitoring, and (4) follow-up consulting and reinforcing. James and Hord's imperatives were consistent with the work of Joyce, Hersh, and McKibben (1983), which suggested that presentation of theory, modelling, practice, structured feedback, and coaching were critical components of any implementation training process.

The FOSS program is designed to be used in collaborative groups of four students. Developers of the FOSS program have suggested roles and responsibilities for students in groups as they interact with the FOSS materials and activities. The implementation of the FOSS program through the use of collaborative groups presented difficulties that hindered the implementation process in some teachers' classrooms. As teachers struggled with the complexities of collaborative groups, group accountability, group roles, group processing, and group empowerment, the teachers were less able to focus on other aspects of the FOSS curriculum. Moreover, those teachers with less experience and training in the use of the collaborative grouping strategy were less able to foster the positive outcomes of group decision making, lesson processing, student-centered lessons, and the integration of collaborative groups into other subject areas. Although one cannot suggest a correlational relationship from the data, one can suggest that training in the complexities of collaborative groups may be one of the critical components to consider when familiarizing, training, and supporting teachers involved with the FOSS curriculum.

> *I think there should be some inservicing before school even starts. I am having trouble with the cooperative learning groups and I am going to need to show them how to use it effectively.*
>
> *My students seem to have a difficult time working together with one another sometimes. They aren't sharing the work and one does it all.*
>
> I think that anyone that does not know about cooperative grouping may need to have some inservice. Cooperative grouping does work, but you need some training.

Time Allotted for Science Instruction and Preparation

Manning, Esler, and Baird (1982), in their *Science and Children* article "What Research Says . . . How Much Elementary Science is Really Being Taught," suggest that science is a low priority subject for teachers in the elementary school. Manning et al. suggest several factors that contribute to a lack of science instruction in the elementary school. First, elementary teachers are anxious about science and feel unprepared to teach the "content" of science. Second, elementary teachers are concerned about the amount of time required to prepare for hands-on science.

Time was a critical limiting factor to the successful implementation of the FOSS curriculum. First, the observed classrooms devoted an insufficient 30 to 40 minutes two or three times a week to FOSS science. These time limitations hindered the achievement of students by reducing the amount of time for students to successfully explore, experiment, process, and synthesize the FOSS activities. Students, without time to lesson process, may have been left with many unanswered questions and misconceptions about a science lesson. Furthermore, the time between science lessons inhibited teachers' flexibility to continue a lesson during the next science period.

Second, the amount of time allotted for preparation time was also limited in the schools observed. Although the amount of preparation time given elementary teachers has traditionally been limited, several management strategies could be beneficial to teachers. Time required to maintain the FOSS kits could be designated to a paraprofessional, and time could be saved by administrative arrangement of proper storage and instructional space. Additionally, the amount of time required to prepare for a quality hands-on science lesson may be greater than more traditional ways of teaching.

School administrators and other school personnel should consider putting science on a higher priority status by devoting more time for its instruction, preparation, and articulation.

> *Science is time consuming and there were days I couldn't teach science because I hadn't had time to prepare.*
>
> *Time is always a factor and if something has to go it is usually science . . . it is the one that takes the most time to get ready for.*
>
> *I wish I had more time! I am under some very difficult time constraints. I have thirty minutes to get these kids up here and finish the activity and I don't have any time for discussion.*

Teachers' Science Anxiety

The conclusions suggest that the studied teachers were generally anxious about teaching science, but that the FOSS program helped to considerably reduce the teachers' anxieties. Teachers were encouraged by the ease of using the materials and the success of their students. Thus, curriculum developers, curriculum trainers, administrative leaders, and other key actors should be aware of teachers' anxieties when designing and delivering curriculum materials and training sessions. Attention to teachers' needs and concerns throughout the implementation process and follow-up to provide feedback to teachers could be beneficial.

> *I feel that I am more at ease and comfortable teaching with FOSS.*
>
> *Because the children enjoy science much more now, I am much more at ease teaching science with the FOSS materials.*
>
> *Because the plans and materials are provided in the FOSS kits, I don't feel inadequate teaching science.*
>
> *My background in science is very poor. I haven't been real comfortable teaching some of these units.*
>
> *I know a lot of teachers won't touch science with a ten foot pole . . . They put it on the back burner because it is messy and takes extra time. In 90% of the cases in the elementary building, I would guess science doesn't get taught.*

Integration With Other Subjects

To varying degrees, teachers attempted to integrate the FOSS materials with other subject areas in their curriculum. The degree of successful integration ranged from reliance on the FOSS manual, which resulted in little integration, to a thematic curriculum with FOSS as the centerpiece for teaching reading, art, health, and writing. Because teachers attempted to integrate the FOSS materials with other subject areas, careful attention to this process should be given by the curriculum developers, curriculum trainers, educational leaders, and others involved with the implementation of the program. While the FOSS materials offered some suggestions for extension and correlation with other subjects, a greater emphasis on integration possibilities could be beneficial to teachers and students. Particular attention should be given to the integration possibilities with reading and writing. As the whole language approach gains momentum, more science could be taught if integration possibilities are designed and addressed as part of the total implementation process.

> *We have just worked on the skill of predicting outcomes in reading. It went so well because the students were able to transfer ideas from one subject to another.*
>
> *With the whole language approach, I would like my science to be a set of themes with books of various reading levels on the ideas.*
>
> *My outdoor education unit is so much easier to*

teach this year because the kids already have some beginning skills they learned from FOSS.

Changing Paradigms

Because the influence of textbooks and traditional methods of teaching science were a part of the studied teachers' paradigms of instruction, teachers found themselves faced with a dilemma regarding the relative importance of content and process. Previously designed lessons and existing textbooks were used as barometers for teachers to assess the FOSS lessons. Changing the teachers' paradigms of instruction could be a difficult challenge. However, several strategies might be used to address this issue.

First, while philosophically contradictory to the FOSS approach, FOSS developers could develop extensive textbook correlational materials. Second, educational leaders and teachers could abandon their dependence on textbooks and commit themselves to long-term training in alternative instructional strategies. Third, the relative importance of content and process needs to be articulated among all those involved in the use and implementation of the FOSS curriculum. If schools continue to depend on quantitative achievement tests as measures of student achievement, the FOSS developers and others may need to address the match between the FOSS approach and these measures. Alternative student assessment measures may need to be designed and implemented. At the time of this study, preliminary alternative evaluation techniques were under consideration and development by the FOSS developers.

> *The one aspect of the FOSS project that gave me the most satisfaction was watching my students explore their ideas. I was no longer the only source of information.*
>
> *FOSS is very easy to incorporate a lot of things if you want. It has a lot of things you can add to it and it is very open-ended. It gives the students a different type of learning other than just me standing up and just you know.*
>
> *My students are no longer bored by textbooks and discussion.*
>
> *The students felt their science books were very difficult and boring.*
>
> *I've learned to slow down and reflect. I now take a fifteen minute segment and discuss it.*

Lesson Processing

A lack of lesson processing in some teachers' classrooms suggested that the FOSS curriculum may need to stress the importance of allowing time for students to discuss and explore concepts introduced during the lessons. Although factors such as limited time, a perceived need for more information, and teacher-centered behaviors were factors beyond the control of the curriculum developers, the dependence on the FOSS teacher manual provided an opportunity for the developers to emphasize the importance of lesson processing. Although the manual could not be teacher proof or possibly answer all the questions that students might generate, it could stress the importance of processing the lessons. Stressing the importance of processing would be one small step toward changing teachers' existing instructional paradigms and anxieties. Additional changes would need to be the result of long-term training, consultation, and feedback processes.

> *I found that it is very important to discuss the activity after the children have done it. I found that some of the groups did the task differently.*
>
> *I thought the background information in the teacher's manual was well written and I did use and need it.*
>
> *A lot of time I didn't get in the extra time to talk about the lesson. We got them done and things put away and then we were done. That is the sad part, because they need that reinforcement.*

Teachers' Attitudes Toward FOSS

As teachers used the FOSS program, numerous factors influenced how they felt about the program. The most influential factors included the fun and ease of using the program, the students' positive attitudes about the program, and the comparison of previous science programs and materials. Therefore, any training to familiarize teachers with the program should consider these influences. Familiarizing teachers with the physical organization of the materials by having teachers do the lessons as if the teachers were students would be helpful. Additionally, information about how the FOSS program is different from other programs and materials, or how it might be better than what the teachers are already using would be appropriate. Teachers have seen several generations of hands-on science programs before.

> *It is a good program. I like the hands-on and I like that my kids are excited about science. I think you could ask a lot of teachers and that is the main battle.. to make science exciting for them*

> *My students love to do the activities. My students are so excited and they really love science now*

> *It is now more fun to teach science because I have the materials available to teach many more interesting ideas and projects to the students.*

Correlation With Existing Curriculum Materials in Your School

As schools embraced the FOSS program, very little consideration was given to the degree of fit the program had with the existing objectives of the schools. Schools contemplating the adoption of the FOSS program should consider the FOSS program only after carefully considering their existing objectives. Correlation of the FOSS program with existing objectives, textbooks, lessons, and other materials should be strongly considered. Correlation with existing objectives should be considered as a critical component of FOSS training sessions.

Likewise, the articulation of the FOSS program within and between grade levels was poor in the studied schools. Processes should be developed to allow teachers more opportunities to communicate with each other. Educational leaders should consider the lack of time for articulation, philosophical disagreements about content and process, assessment concerns, and geographical isolation as potential threats to the successful implementation of the FOSS program. These issues need to be addressed by schools involved in the implementation of any hands-on science program.

> *Our school's science objectives are taken directly from the text and FOSS doesn't meet those objectives.*

> *I was looking that over and FOSS has Sound, Electricity, and Magnetism units... so in some ways those will fit, but part of the curriculum is still undecided.*

> *The school is planning to implement the FOSS program along with the textbook we are adopting.*

> *Not much extra will need to be done. We already have the book that we use and FOSS goes along with it.*

Institutional Support

Educational leadership and support should be short- and long-term. Addressing the immediate implementation needs of a new program is important, but the leadership and support provided teachers needs to extend beyond the first year of implementation. Schools adopting the FOSS program should make long-term plans for on-going training in the use of the FOSS program, monitoring the implementation process, arranging for space and materials, monitoring the school's changing objectives, and providing feedback for those involved with the implementation process.

> *Believe me this staff will need to be sold on the program. Change doesn't come fast for this group and this school.*
>
> *I feel we will need to provide inservice for the people who need the support on how to go through these types of lessons.*
>
> *Our principal is leaving next year and I am concerned about the support and specifically, she said we were going to get a new science book and with her leaving who knows . . .*

Summary

FOSS and programs like FOSS that have arisen as general models of curriculum improvement need to be continually and critically examined. The general model of elementary science curriculum reform is an appropriate model from a curriculum design perspective, but the design is flawed with regard to the implementation phases of the design. The process of implementation is usually delegated to individual schools and their educational leaders. Unfortunately, this is the same implementation model that was used to implement the first generation programs.

If the "second generation" elementary science programs are to be successful, education leaders will need to pay particular attention to the potential inhibitors to their implementation. Specifically, education leaders need to address those concerns articulated in this article. Like their first generation counterparts, the second generation programs have tremendous potential for effecting the way elementary school science is taught and learned in this country and others. The second generation programs can work if properly implemented and maintained. As James and Hord (1988) conclude, training, monitoring, follow-up, modelling, and practice are all essential for the successful implementation of innovative elementary science programs.

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Models in Physics: A Neglected Topic in the Teaching of the Subject

Jan Jacob Smit and Menachem Finegold

Introduction

Models play an important role in the development, structure, and understanding of physics. Models also play an important role in the communication processes of the discipline. The word *model* can have different meanings when used in different contexts. Thus, it is necessary to outline the concept of a model in physics.

To define a model in physics is difficult because an extended variety of models can be identified. Comprehensive definitions of the concept of model in physics are so wide that they are of little use (Kollard, 1991). A good understanding of the meaning of the term "model in physics" can be acquired if one examines the different types of models used in physics and their functions. In the rest of this presentation we will briefly discuss the following:

1. Two different classification schemes of models in physics;
2. The nature and functions of models in physics; and
3. The perceptions of models held by graduate students enrolled for a teacher's diploma.

Classifications of Models in Physics

Harré (personal communication, 1991) distinguishes among three types of models. Models of type 1 represent a real entity, for example a model of the water molecule or a model of the earth. (All physicists will agree that the earth and water molecules exist.) Models of type 2 represent hypothetical entities. At this stage, the model we have of the Higgs boson is type 2. At certain points in time the eather model, caloric model, and the model for the neutrino were all models of the second type. As physics developed it was established that the eather and the caloric liquid do not exist, but the existence of the neutrino was confirmed experimentally. The neutrino then shifted to type 1. The other two models still exist in the history of physics but are of no use. They are classified as type 3 models. Type 3 models do not represent any real or hypothetical entity. There are, however, models of type 3 that are in use. An example is Franklin's model of electric current, still in use today under the name conventional current. We know that positive charges do not constitute the current in a copper wire, but we model the current in a copper wire as if they did. This model is only instrumenta, used to describe, at the macroscopic level, the transfer of energy in electric circuits. Further insight into the nature of models in physics can be gained by studying Harré's (1970) taxonomy of models. In this taxonomy, models are classified according to the relationship between the model and its source. The source of a model can be the entity of modeling itself (homeomorphs) or it can be something else (paramorphs).

The Nature of Models in Physics

A few characteristics of models are listed below.

1. Leubner (1989) describes a model as an invention of the human mind. Except for the mathematical models in, for example, quantum mechanics (d'Espagnat, 1983), models in physics are mental images, that is, they are pictorial by nature.
2. A model can be a representation of something in reality, but is not reality itself.

3. A model in physics is not a copy, picture, or icon of reality.

4. A model deals with limited aspects of reality and is a simplification.

5. Models must fit into the structure of physics. There must be "harmony" between different models.

6. Physics models are community property. They belong to the community of physicists, and all physicists bear more or less the same mental image of a model.

7. Models usually have tags, like Bohr's model of the atom, the standard model of the universe, the heliocentric model, the lever, and so forth.

8. Models in physics are constructed in such a way that mathematical relationships can be applied to them.

The Functions of Models in Physics

Santema (1978) uses the following representation to illustrate the place and primary function of scientific models:

Figure 1. A Scientific Model

According to Santema, the primary function of models is to give humans knowledge of reality. Humans know reality (nature) through models. (Santema uses the word knowledge models to indicate this class of models.)

This primary function of models can be divided into a number of sub-functions:

1. Models describe phenomena, processes and objects in nature. The description is based on knowledge dealing with an aspect of reality. A model brings order in information that seems to be unrelated. According to Park (1988): "It summarizes a number of observations that may be vast." (Tycho Brahé made observations. Kepler conceived the model that brought order in the data.)

2. Another important function of models is to explain phenomena. (Fraunhofer lines in the solar spectrum require models of the sun and the atom for explanation.) Scientific explanations are always based on a model or models.

3. Models help to predict new entities/phenomena. This point becomes clear if one recalls episodes from history. The planet Neptunus was predicted from model-based calculations and observations. In contemporary physics, models gave rise to the prediction of literally dozens of elementary particles. It is clear that models play an important role in the development of physics.

4. An important cognitive function of a model is that it represents reality. Van Oers (1988) states: "The model constitutes an artificial reality that can be investigated at the mental, visual or material levels." (Author's translation.)

5. Models play an important role in scientific communication. Most models have labels (White, 1988). A physicist associates a mental image with the label. If a physicist hears or sees a label, the mental image associated with the label will be called from the long-term to the short-term memory.

Students Conceptions of Models in Physics

During 1991 an empirical study was conducted at 15 universities in Southern Africa. The aim with this study was to establish the knowledge prospective that physical science teachers have of the nature and functions of models in physics. The population consisted of 196 graduate students enrolled for the teacher's diploma. The majors for the degrees of this group of students included physics, chemistry, mathematics, botany, zoology, and home economics. All the students had at least passed physics at the first-year level.

A questionnaire and personal interviews were used to obtain the data. The questionnaire consisted of two parts. The first part dealt with models in physics in general and the second with models in optics. Statements were given and the students were requested to indicate whether they agreed or disagreed. In addition, they were requested to explain why they agreed or disagreed with a statement. More information on specific responses was obtained through personal interviews with students and/or their lecturers.

Important findings of the empirical study are:

1. A model is a copy/replica/imitation/example/reflection identical or nearly identical to the real thing. There is a one-to-one correspondence between the model and the real object. Fifty-five percent of the respondents held this view.

2. The study revealed that many students holding this view regarded models as unchangeable or fixed. They argued that the underlying reality is fixed, and the model must, therefore, also be fixed.

3. This perception of the nature of models is mainly held by the group of biology students. These students had passed physics only at the first year level. A possible explanation for this perception is that in the biological sciences, carefully produced material representations of the human skeleton, bacteria, insects, and so forth, are referred to as models. These "models" fit the description of copies opr replicas of real objects. One may thus conclude that the concept of a model, as developed in biology, transfers to or interferes with their concept of model in physics. This view of models is not restricted to South African students. Gilbert (1991) reported that undergraduate students, enrolled for a biology course in Michigan, held a similar view. Students who majored in home economics also displayed views of models that differed from those of the rest of the group and from the view held by physicists. The conclusion is that the dominant disciplines in students' study careers have an influence on students' views of models in physics.

4. Only 3% of the students stated that models play a role in research (development of knowledge).

5. A quarter of the group made no distinction between scientists' models and engineers' models (manufactured models).

6. The view that a model helps one to understand "things" in nature (models enhance understanding) was held by 79% of the respondents. This view is clearly related to education. Models are viewed as educational aids. The origin of this view can possibly be explained as follows: most of the students had mainly encountered models intuition, because no research is incorporated in the undergraduate courses.

7. With regard to models in optics, it was established that 44% of the respondents viewed light as consisting of waves and particles. Three different mental images associated with this representation were identified.

   a. Light is seen as wave packets. Some students sketched these packets.

   b. The second representation is that light is a transverse wave motion, propagating in particles (photons).

c. A third representation resembles the motion of the beam on the screen of an oscilloscope when an AC signal is displayed on a long time-setting. According to this model, the trajectory of a photon is not a straight line but takes the form of a transverse wave.

  This "unified" view of light, as revealed by these three mental representations, is in agreement with the finding that a model is seen as a portrayal of the real thing. A student with this view of a model will inevitably try to form "unity" models of entities such as light.

  (Only one student was able to explain the existence and use of the wave and particle models in terms of Bohr's principle of complementarity.)

8. Only 13% of the respondents were able to distinguish between a light ray (model) and a beam of light (the real entity). Ten percent of the respondents portrayed a beam of light as a bundle of rays.

9. In one question, six well-known optical phenomena were given. The respondents were requested to associate a model with each phenomenon, which would be suitable for the explanation or description of the phenomenon. Only 26% of the students were able to associate an applicable model with each of the phenomena.

It was clear from an analysis of the most popular textbooks (Halliday & Resnick, 1988; Kane & Sternham, 1984; Sears, Zemansky, & Young, 1987) currently used at universities in Southern Africa that little general information on models is provided. This fact partially explains the students' lack of knowledge of models.

Conclusion

If it is remembered that models play an important role in the structure of physics and fulfill a key function in human thinking and in the learning of science, it is evident that teachers with a lack of knowledge of models and with misconceptions about models will certainly have trouble teaching an understanding of physics. The constructivist strategy of teaching is to start with the personal model of the child and then teach towards the scientist's model. It is obvious that, to be effective, the teacher must have clarity about the scientist's model himself. This study revealed that it is risky to assume that teachers have this knowledge and insight.

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Pedagogical Knowledge as a Condition to the Adoption and Implementation of Computer-Assisted-Learning Activities

Amos Dreyfus and Benjamin Feinstein

Introduction

During an attempt to introduce a series of Computer Assisted Activities in relation to a secondary-school agro-biological curriculum (Dreyfus & Feinstein, in press), secondary school teachers were trained intensively in the use of a tool that, for them, was completely new—the electronic spreadsheet (Lotus 1-2-3, or a locally developed spreadsheet called Mosaic). At the same time, the potential contribution of the tool to the teaching of the curriculum was explained and demonstrated, as well as its implications concerning teaching strategies and the role of the teacher.

The electronic spreadsheet is an "open tool." Its introduction into the science classroom requires that the students and the teachers learn the technique of its use. Such a requirement is often perceived by science teachers as an additional and unwelcome burden, and regarded as beyond the legitimate obligations and the expected skills of regular science teachers. Teachers who are not "computer addicts" must have good reasons to introduce the spreadsheet into their classroom, especially when, as in the case reported here, no coercion is applied and no extrinsic rewards are offered by the authorities.

The attempt to introduce the activities thus gave an opportunity to observe teachers in the process of deciding whether to adopt or to reject a new method of teaching and to discuss with them their motivations and grounds for their decisions. During 2 years, about 60 experienced teachers remained more or less constantly involved in the various experimenting regional groups, representing about two thirds of the total number of teachers who enrolled in the "beginner" courses. As often found in other places (see for example Baird, Ellis, & Kuerbis, 1989), teachers did not easily adopt the computer, in spite of the fact that they were enthusiastic about the power of the spreadsheet, and that they all participated of their own will in the training course. A questionnaire was developed that dealt with four areas of teachers' concerns (Dreyfus & Feinstein, in press): (a) the pupils (background, difficulties, achievements, and attitudes), (b) the teacher (teaching strategies, attitudes toward the rationale of the curriculum and of the use of the computer, success and failure, time spent on activities), (c) conditions prevailing in the school concerning the introduction of the computer in the biology classes), and (d) the learning materials produced by the project.

The questionnaire served as a basis for structured interviews. It was found that many teachers regarded the use of the spreadsheet to be essentially superfluous, because they felt that they could achieve the objectives of the curriculum without the help, or the interference, of the computer. However, the teachers' answers often appeared to be somewhat contradictory. Most of them, while claiming that they did reasonably achieve some crucial objectives of the curriculum, also claimed that they assigned a low priority to these objectives. They justified their attitude mainly on grounds of technical-organizational constraints (time, size of class, lack of equipment, etc.), but the interviews revealed more than that: Most of these teachers were not irrational in their reactions, because they actually did not recognize the importance of such objectives. Rather, they appeared to not fully possess the scope of pedagogical knowledge necessary for an accurate appreciation of the educational potential of the electronic spreadsheet. By pedagogical knowledge, we mean mainly "curriculum knowledge" (Shulman, 1987), "that particular grasp of the materials and programs that serve as tools of trade for teachers," or "specific subject matter pedagogical knowledge" (Tamir, 1988). This finding was hardly surprising, in view of the necessary width of the relevant knowledge.

Relevant Pedagogical Knowledge

To become convinced that spreadsheet-assisted teaching can be more efficient and rewarding than the conventional methods, teachers must have some well-internalized basic knowledge of (a) the nature of the subject matter (science, discipline) they are teaching; (b) the objectives of the curriculum they are currently teaching, and their relationship to the nature of the subject matter; and (c) the essential features of the spreadsheet that make it specially suitable for the achievement of the objectives of the curriculum.

Without some understanding of several characteristic features of biological science, and of the nature of inquiry in biology, teachers cannot develop a relevant and rational attitude toward the objectives of the biological curriculum they are teaching. Without a sound appreciation of the value of various objectives of the curriculum, the teachers cannot develop a relevant and rational attitude towards the use of the computer in their classes: only the high priority given by the curricula to some objectives gives the spreadsheet its educational importance.

A discussion of the nature of biological sciences or of the objectives of modern biological curricula is obviously beyond the scope of this paper. However, the main relevant ideas can be summed up as follows:

1. Biology is essentially an empirical-quantitative discipline, in which conclusions are drawn, or hypotheses are confirmed, on the basis of quantitative and statistical data and results. Experiments in biology deal with populations and samples. Variables are stochastic, that is, their values can be expressed only in terms of a mean and a measure of the deviations from the mean. In biology-based technologies, such as agriculture, decisions are made and problems are solved on the basis of the same type of data.

2. The intellectual skills concerned with data collecting, processing, manipulating, analyzing, interpreting, and reporting are therefore part and parcel of the meaningful teaching and learning of any biological subject matter.

3. The dialogue with the spreadsheet requires the children to make their implicit reasoning explicit; the data logging and display facilities of the spreadsheet provide rapid numerical or graphic representations of the interrelations among variables; they enable the children to assess the consequences of their reasoning as often as they need (based on Driver and Scanlon's constructivist approach, 1989); the spreadsheet can juxtapose or transform information in one system to another (equation to graph, for instance) (after Kozma, 1991). This transformation is crucial to the construction of links between symbolic domains and the real world (Kozma, 1991).

Did the teachers truly lack such knowledge? Only to a limited extent. They were certainly not ignorant of the objectives of the curriculum and they were, as stated above, quite ready to learn about the educational potential of the computer. But pedagogical knowledge refers to conceptions of teaching and learning. The introduction of the computer in the classroom in a meaningful way implies a change in the role conception of the teacher. Paraphrasing Hewson (1980), we could say that teachers may change their conceptions of teaching if they find their present conception unsatisfactory. As any new concept, the new conception of teaching must, be to the teacher, "intelligible, plausible, fruitful."

Phase 1: Teaching the Teachers

In spite of a most common belief, the main problem is not to train the teachers in the use of the computer, so as to make them overcome the natural anxiety of beginners. To teach them how to use computer-assisted teaching may have been the main goal of the course, but it was not the main problem. The problem was to make them develop the need for such methods, to make them feel that the computer was the partner they needed. To do so, we used constructivist strategies: during group discussions, we analyzed their conceptions of their role as science teachers; we created discrepant events by showing discrepancies between their knowledge and their attitudes, or between their attitudes and their decisions, or between their arguments and their decisions; we were then able to suggest the use of the spreadsheet as a solution to the resulting cognitive conflicts. In view of the very friendly and informal relations between us and the teachers, this method worked quite well: we understood the teachers, we learned about their problems; they "understood" us, in the sense that they understood what we meant. However, their understanding was not systematically translated into changes in their teaching activities (although episodic success was not rare).

Obviously, as is well known about experienced teachers, our teachers would not change their ways of teaching unless they gained new practical personal knowledge (Clandinin, 1985). They apparently possessed such a knowledge, which they tried to convey to us and to their peers, during the group discussions. As well stated by Clandinin, they justified their arguments by relating to "circumstances, actions and undergoings" (Clandinin, 1985) in which they had been involved, and this knowledge appeared to have some "affective content"—a fact that often raised the heat of the discussions. As stressed above, the teachers in the groups were experienced and apparently effective teachers. Their teaching behavior was quite congruent with the beliefs they had developed during their previous experiences. The "cognitive conflicts" we had been able to create did exist, but the behavior of the teachers represented their "knowledge" in the sense that it reflected their compromises between a more or less accepted ideology, and the real world of the classroom, in a real educational system. This point should be clarified: the quantitative nature of biology was never contested by the teachers; they may have been more or less aware of it, but they did not see in this type of argument any ground for discussion. What they said was that this was by and large irrelevant to their teaching, because in the existing conditions in their schools, they never had the time or the facilities to cope effectively with that part of the curriculum. Nevertheless, they had so far "survived"—some of them with flying colors.

The apparent contradictions, the apparent lack of congruence between their knowledge and their attitudes, or of coherence between their decisions and their attitudes, did not really stem from a basic lack of understanding of the nature of biology or of the objectives of the curriculum. It came from the fact that as far as they were concerned, their experience had shown that these parts of their knowledge were hardly meaningful or relevant to their teaching activity (in our words: did not truly belong to their pedagogical knowledge). As all practitioners, teachers learn from practice. For them, theories draw their meanings from practice, at least to the extent to which practice draws its meanings from theories.

Phase 2: Promoting Teachers' Learning

What we needed, in Schon's (1983), or Stenhouse's (1975) words, was to give the teachers an opportunity to approach the problems from within, to "reflect on- and inaction," to develop their own blend of "theories-in-action." By changing the reality, that is, by introducing a new partner into the classes, we had a chance to bring them to better compromises (more congruent with the ideology of the curriculum, and/or with that of the teacher). We had the possibility of introducing new reasonable expectations: objectives that had so far been difficult to reach, might now be achieved.

Our next step was to encourage the teachers to practice the use of the spreadsheet in their classes and to give them all the support we could provide, in terms of practical and theoretical guiding. Then, the meetings took the shape of group discussions, in which teachers raised issues and described their in-class problems, suggested solutions, or examined new ideas. We followed intensively some teachers in their schools so that we could understand, and discuss with them, their own personal and local problems.

After two years of interaction with the groups of *voluntary* teachers, we found that the sample was somewhat depleted. We remained with three main types of participants:

1. Computer addicts, to whom the pedagogical knowledge referred to here may or may not be relevant; their main source of motivation is the pleasure they derive from being involved in computerized activities.

2. Teachers to whom no conceptual change was necessary. Such teachers were convinced from the beginning that the objectives of the curriculum were justified and achievable, and they immediately accepted the computer as a long awaited partner; after learning the technique and principles of the use of the spreadsheet, these teachers are now continuously inventing their own brand of computer- assisted teaching style, thus developing and improving their own pedagogical knowledge.

3. Teachers who have undergone a process of conceptual change. Their pedagogical knowledge has gained new meanings from the experience of teaching computer-assisted activities, and the teachers have accordingly adopted the spreadsheet as a desirable partner. The teaching behavior of these teachers has evolved with the introduction of the computer. Also, they differ from the "computer- addicts" in the sense that they now explicitly express relevant (to the curriculum) reasons for the use of the spreadsheet. The drop-outs were (a) the teachers who lacked self-confidence ("computer-anxious"). These teachers never truly used the computer in their classes; (b) Those who actually never accepted the objectives of the curriculum they were teaching, that is, who never learned the necessary knowledge, because they felt it was irrelevant to their ways of teaching; and (c) Those to whom, for various reasons, the experience of computer-assisted activities did not happen to be meaningful or rewarding. The latter usually started practicing and then, suddenly, withdrew without warning at some stage of their practice. These teachers may have learned something from their experience, but their final behavior did not correspond to our expectations. They may ultimately have adopted the computer if some pressure from an authority had made them prolong their experience until they had reached some meaningful achievements.

Conclusion

The attempt to introduce the spreadsheet in biology classrooms was performed in a situation where autonomous teachers had complete freedom to adopt or to reject the proposed method. Three approaches were used: (a) introduction to the theory of the teaching method; (b) stimulation of teachers' intellectual curiosity by means of constructivist methods of conceptual changes; and then (c) strategies of professional development of the teachers who were given opportunities to reflect on- and in-action. The third approach was found to be essential to the change of the teachers' adoption of a new conception of teaching. The teachers who adopted the curriculum on relevant grounds had been involved in a long process of development of personal practical knowledge, in which they made their own decisions and learned from experience. The complexity of the process may explain why, when no coercion is applied, and when the desirable conditions are not entirely fulfilled, only a minority of teachers adopt new teaching methods.

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Tailoring Science Education Graduate Programs to the Needs of Science Educators in Developing Countries

Vincent Lunetta and Euwe van den Berg

Introduction

Because many developing countries do not have high quality graduate science education programs at this time, students from these developing countries often enroll in science education graduate programs in industrialized countries. Unfortunately, the graduate programs in which they enroll generally have not been designed to meet their unique needs. On occasion, graduate students from a developing country have been admitted to a graduate program en masse as part of a development grant, yet even these programs have been perceived as less than ideally responsive to their special needs. This paper reviews some of the unique needs of science education graduate students from developing countries and suggests ways that graduate programs in industrialized countries can better meet the needs of those students.

This paper comments on student, program, and developing country circumstances, yet it is important to recognize that there are great differences across individual students, across programs, and across countries. There often are large differences from one graduate program to another within specific countries, and there are even larger differences across graduate programs from one country to another.

Goals of Advanced Graduate Programs

Advanced graduate programs in science education prepare students who normally have developed skills and competence in science and in teaching science earlier in their lives. Through admissions policies, instruction, and practical experiences, graduate programs generally seek to prepare science educators to be competent in the domains outlined below. Each domain of competence has both theoretical and practical dimensions modified.

1. Science Discipline(s)
2. Science Teaching
3. Curriculum Design, Implementation, and Evaluation
4. Science Education Research and Scholarship
5. Nature of Science and Its Human and Technological Contexts
6. Teacher Education and Science Education Policy

Graduate Students From Developing Countries: Frequent Circumstances

Cultural Perspectives

The cultural and language differences between the environment of the developing country and the host country may have an important influence on educational practices and outcomes. The roles of questioning, inquiry, and the perceived authority of the teacher and textbook in a developing country may be different from those in the industrial host country.

Discipline Specialization

There are differences from one industrialized country to another in the depth of scientific knowledge that is expected of a science teacher upon completion of the preparation program and in continuing certification requirements. In some industrialized countries, depth of specialization within specific science disciplines such as physics, chemistry, or biology has been increasing in recent years. In other industrialized countries, a movement toward interdisciplinarity in the past 15 years has influenced the depth of preparation of many teachers. In the U.S., for example, the current tendency toward interdisciplinarity results, for many prospective teachers, in greater breadth of discipline preparation but perhaps in less depth than may be the case in other industrialized countries.

School Conditions

The systems of schooling they know may be very different from the systems of schooling in the host country. Decision making in education, cultural influences in schooling, the nature of political authority, financial resources, and facilities are often very different from those in the host country. In addition, the role of external examinations may be very different. In the developing country, the remuneration of teachers may be much more marginal than it is in an industrialized country. Teachers' status in the community may be lower or it may be enhanced beyond that of teachers in the industrialized country. Schools in the developing country may have large classes and serious shortages of textbooks and other materials, and the nature of the school science laboratory may be very different. Faculty-student relationships vary in quality, but often faculty members do not become well informed about the learning of their students. Students may live in a low technology environment with high levels of unemployment or poverty. Often, but not always, there are lower levels of education and expertise in teacher preparation programs in developing countries, and these may have been inhibiting factors in the early preparation of the graduate students.

Entry Competence in Science, Science Teaching, and Related Skills

Students from developing countries enrolling in advanced graduate programs often are lecturers in science and science teacher education, science supervisors, or curriculum officials in ministries of education or universities in their home countries. Sometimes they have been secondary school teachers, and on occasion they are children of affluent officials and have little or no experience as educators. While students from certain developing countries have excellent science preparation, more often their competence in scientific concepts and scientific thinking skills is somewhat weak, resulting in problems with upper level science courses. Sometimes the science they have learned has been taught and assimilated in a rote fashion with little attention to the construction of models and networks of concepts. Often the students have had only marginal preparation and skill in the use of laboratory practical experiences. Their conceptual weaknesses may be more serious than those experienced by students from the host industrialized country, and they may have lower levels of mathematical skill. Limited conceptual development may be complicated by language problems and cultural adjustments. These students may also have been inadequately prepared to write high quality papers and reports. In addition, those who have been teachers may have had little or no experience, instruction, or constructive feedback in the preparation of labs, tests, student assignments, and curriculum materials.

Position Expectations

Upon returning to their home country, many graduates of advanced science education graduate programs will teach science as well as science education in teacher preparation and in-service programs. University teaching loads of 20 hours per week or more are quite common in some countries. Faculty salaries are also very low in many of these countries resulting in the need for faculty members to seek extra income and outside employment. Although time and resources for research are usually limited, sometimes faculty members are asked to evaluate projects, to supervise student projects and theses, and to be involved in the development and production of curriculum materials, in testing, and in-service education.

Reducing Discrepancies Between Student Needs and Program Practices

Communication Skills

Often graduate students do not have well developed writing skills, in part because of less than ideal feedback and support during their earlier education. Writing problems may be perceived by the graduate program advisor as simply a result of working in a second language. However, there may also be more basic problems related to lack of organizational skills. Thus, if students are to be optimally educated, feedback to improve their writing is also an important part of an excellent education. Some of this feedback can now come early in the graduate program by processing students' papers with computer software that provides feedback on grammar and style. In addition, some universities have support systems for international students with second language problems. Support from these writing centers should be used whenever possible. However, excellent writing requires much more than the application of rules of grammar and style. Excellent writing incorporates the ability to synthesize and to organize with a breadth of perspective that connects with the world views of readers. We know of no real short cuts to competent intensive feedback from skilled colleagues or mentors coupled with intensive writing experiences. Developing good writing and thinking skills will probably always be a very labor-intensive activity.

Scientific Knowledge and Skills

A thorough knowledge of school science and first-year university level science in the discipline, including appropriate and important laboratory activities, is essential for the student from a developing country. The science knowledge required very much depends upon the kind of position students are filling when they return to the developing country. If they are returning to educate secondary school teachers and will be teaching a science component of the pre-service program, a master's level competence in science would be highly desirable. The nature of the courses or program emphasis should depend on the entry level competence of the student, but the option to take at least 50 percent of the course work in appropriate science courses should be encouraged. If the student is to return to support the education of teachers at the elementary school level, then course and experience expectations might be very different.

Science Teaching

A principal expectation of university-level science education faculty will be preparing teachers and assisting in their life-long career development. Thus, an important component of a graduate program should be the study and development of appropriate pedagogy for science teaching, for teacher education, and for teacher development. A graduate program should have built-in opportunities to develop and practice important skills in teaching science and in assessing the development of scientific concepts and skills. These concepts and skills can be developed in part through course work and also through special internships and projects that are part of the graduate program. A master's thesis project, for example, might include the development, trial, and assessment of curriculum materials. The graduate program can not assume that students are already experts in science teaching pedagogy. Individual students may have developed some of these skills, but the probability is that many students from both the host and developing countries will not have experienced the models and acquired the understanding that is essential for competence and leadership. Furthermore, although it is important to assure that students are well informed about contemporary innovations in the field, the basic expectations should be given high priority.

Students from developing countries should have multiple experiences with alternative teaching methodologies emphasizing those strategies that will be especially feasible in the unique conditions of the home country. Thus, teaching strategies should be compatible with working with relatively large groups of students and few resources. The students and faculty should discuss the special sensitivities needed to incorporate such methods within the culture and expectations of the home country. Although teaching is a cross cultural activity that promotes understanding and development of thinking, if the methodology is insensitive or inappropriate for the cultural context of the school, it is not likely to be employed for any length of time in the local school environment. Other reasons for poor educational quality include: poor use of teaching time, insufficient attention to developing meaningful student activities and assignments, ineffective monitoring of student achievement and feedback, and lack of simple resources such as textbooks for the students. The lack of laboratory equipment, while a concern, need not be as great a problem as the omission of more basic resources. Assisting students in developing skills in organizing appropriate field activities and working with local materials is an important part of a graduate science education program for students from developing countries.

Science educators and science education students in developing countries sometimes get discouraged about their inability to teach and to learn science because of their distance from the scientific establishment. There is often a perception that to do acceptable science investigation, they must have expensive equipment that is not available in their own countries and schools. Such feelings can be exacerbated when students from developing countries see science education classrooms in their industrialized host countries with well-equipped laboratories and many computers. They may not perceive that sophisticated lab equipment and computers can also be black boxes that inhibit the development of appropriate science concepts. For example, simple demonstrations and activities with batteries and bulbs may be more effective for the development of basic concepts than demonstrations of computer interfaced labs. Even for tertiary-level university courses, simple, clear, low-cost demonstrations and activities can be more effective than complex, high-cost ones. These relationships have not been well researched and may even be subjects for study by students from developing countries.

Developing Research Skills

In most advanced graduate programs in science education, the development of classical research skills is covered, at least in part, by courses in research methodology and statistics. Increasingly in recent years, qualitative research methodologies have been introduced. In addition, one or more courses may introduce the graduate student to scholarly literature related to research in teacher education and science education. Doctoral programs generally include engagement in substantive research projects, but it is important to engage all graduate students in research that is appropriate and sensitive to their special needs and unique circumstances.

Studies that include the diagnosis of students' conceptions may be particularly appropriate for students from developing countries at this time. Such studies provide experiences in developing sensitivity to students as well as in developing research skills. In addition to having important effects on attitudes toward students and on sensitivity to student development, the studies can promote the development of more appropriate teaching methodologies. In many developing-country universities, faculty-student relationships may look respectful and appropriate, yet the faculty member's attention to the nature of the learning and to the conceptual development of the students may be very limited. The kinds of conceptual development studies that are possible include diagnosis of conceptions through paper and pencil tests and through interviews. Such studies can also examine the effectiveness of specific teaching intervention techniques on concept development.

Other relevant research studies include:

1. Description and elaboration of the nature of academic work in classrooms in the country;
2. Curriculum, textbook, and laboratory handbook

analyses using adapted versions of schemes like Lunetta and Tamir (1981) followed by in-class studies of the use of the curriculum resources;

3. Development, implementation, and evaluation of regionally relevant curriculum resources and activities;
4. Development and evaluation of local or regional assessment programs;
5. Assessment of attitudes toward science and technology, attitudes toward school science; attitudes toward the environment, an so forth; and
6. Locus of control studies.

Promoting Appropriate Research and Scholarship in Developing Countries

Even well-prepared doctoral students are unlikely to continue research in their home country because of heavy workloads, lack of inducements in the university or school environments, and lack of appropriate support systems and colleagues. In addition, when the doctoral research is conducted in the culture and environment of the host industrialized country, it is not likely to be perceived as especially relevant to the home country. The most relevant research for science education students from developing countries is research conducted in their own countries. If the doctoral research is conducted in the home country, then the student must address many of the adverse inhibiting factors in completing the study. Only if the graduate program provides that opportunity is the student likely to continue to conduct meaningful research following graduation. In spite of the benefits, however, there are many factors that make conducting research in the home country very difficult to arrange and support. Among other things, students must have financial support for round trip travel to their home countries. Salary support is also essential to enable them to conduct the research without the need to seek extra income for family support during that time. In addition, graduate students need to be especially well prepared in the research methodology to enable them to conduct the research without regular communication with advisors in the industrialized country and without close engagement with the thesis committee. Good preparation and communication with the doctoral advisors in the industrialized country are essential. Yet, in less developed countries, the technology to support easy, low-cost fax, telephone, and/or electronic mail communication between advisor and student may be difficult if not impossible to obtain. Suggestions for supporting the research in the developing country are outlined in a longer paper on this topic.

Cross-Cultural Sensitivity and Development

The presence of graduate students from developing countries can enhance the quality of a graduate program if the students are engaged with local, host-country students in discussing cross-cultural issues. In many ways, teaching itself is a cross-cultural activity. That is, students move through educational interventions toward conceptions and world views that are part of an expert culture that they are to understand and that is external to the culture of the novice. Discussions about cultural differences and their probable effects on education can be productive for students from developing countries as well as for host country students. Graduate education should promote understanding as well as growth in the students' professional behaviors. All graduates of a science education program should be empowered with understanding, sensitivity, and skill that will enable them to engage colleagues in appropriate change and development processes to improve the quality of education, scientific literacy, and scientific capacity. The out-of-culture experience should facilitate change with increased perspective and sensitivity.

Developing countries often have very limited technological resources but may have some other resources not available in developed countries. One such opportunity, for example, is the frequently very large but unskilled labor pool in many communities and local schools. How can this labor pool be organized and empowered to provide more personalized teaching and feedback that can result in better education (teachers' assistants, for example)? How can the human and natural resources that are in abundance in the home surroundings be identified and mobilized to support community development and improved education? Students from developing countries should be helped to think about these opportunities and resources and about how to engage them in improving the quality of education.

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Cross-Country Cooperation in Curriculum Change and Professional Development

Peter Fensham and Richard Gunstone

Introduction

The Secondary Education Development Program in the Republic of the Philippines has involved major curriculum change and consequent whole-country in-service teacher education for all components of the secondary (grades 7-10) curriculum. Within this context, the Philippines-Australia Science and Mathematics Project (PASMEP) has contributed to grades 9 and 10 science and mathematics through equipment provision and "Training the Trainers" programs for those who were to conduct the in-service (ISE) programs.

In this paper we consider one of the two Monash involvements in PASMEP. This focused on the grade 10 subject "Science and Technology," referred to here as S&T4. This is a physics subject. Our brief was to provide a special-purpose, 10-month, full-time program in Australia in 1990 for 34 selected trainers, and to work in four follow-up workshops in the Philippines in 1991 and 1992 for these and 28 additional trainers. These experiences addressed physics content, teaching and learning strategies, nature of ISE, designing ISE, and so forth. We briefly consider some past approaches to teacher development for major curriculum change to give relevant context for the significant processes and outcomes of the PASMEP S&T4 program. The features of the Monash program are considered, the consequences of the program are discussed, and some general issues arising from the work are addressed.

An Outline of some Past Practices in ISE for Major Curriculum Change

When a country embarks on a major reform of its school science curricula it is also faced with the substantial issue of professional development. This ISE of those who are to teach the new curricula, and who have been with varying degrees of success and experience teaching previous curricula, is probably the most critical factor for successful implementation (e.g., Esler, 1969; Fullan, 1982; Zoller & Watson, 1974).

In the 1960s, when the large-scale, centralized production approach to new science curricula was at its peak, there was a sense that the prepared curriculum package was so profoundly different from what had previously been available to teachers that the package would control teacher behavior, rather than teachers controlling the package. In other words, these projects, lavishly funded by any previous measure, were seen to be able to produce a teacher-proof curriculum. Nevertheless, as a form of insurance policy, most of the 1960s' projects in the more industrialized countries did include some form of teacher induction program. These ranged from summer institutes for enthusiastic teachers in U.S. to one-day "talking at" transmissive sessions where teachers were told about the new curricula by members of the project team.

By the early 1970s, evidence was mounting that the new curricula were falling well short of the high hopes held for them. It was becoming clear that teachers were critical to implementation. The further projects of the '70s attempted to give a higher profile to the professional development problem. Greater proportions of initial project budgets were often allocated to this ISE aspect. But there was now an established scale of production of materials from the 1960s and, particularly if serious trials of materials were undertaken, the production of materials insatiably consumed funds. The budgeted minor share of money for teacher education often could not then be sustained.

However affluent or poor the country, however developed or developing, the problems of equipping, informing, and persuading the existing teachers to change in the ways required by the new curricula were and are still similar. Changes required by new curricula include new content emphases, new laboratory intentions, new forms of assessment, new pedagogics, and new teaching roles. Often these are required of teachers who have been accustomed to and, in many cases, successful in teaching science in other ways.

In general, it is true that the richer countries have more resources for tackling these problems than do the poorer countries. However, richer countries can have considerable difficulty in bringing these resources to bear on the problems in an effective and coordinated manner. Because education for development is an international aid and loan priority, it does sometimes occur that a less developed country with the capacity to plan, organize and implement can also have access to substantial resources. Quite remarkable results can then emerge.

Thailand in the 1970s is an example of this phenomenon (Fensham, 1986). Given the ways the above problems and their solutions were conceptualized at that time, and given the dual criteria of extent of coverage of the teaching force and the thoroughness of the induction into the intended curriculum changes, then Thailand achieved professional development of its science and mathematics teaching force that seems to have been without parallel. Wongthonglour (1979) has documented and evaluated this professional development in the specific context of a new Physical Science curriculum.

In the present paper, we describe a similarly remarkable success story from the 1990s, in which professional development occurred in the Philippines on a scale and of quality that far exceeds anything that has been yet possible in the cooperating donor country, Australia. The nature of the approaches contributing to this success reflect current conceptualizations of the problems of curriculum implementation and current approaches to tackling the problems. These differ from conceptualizations and approaches of the 1960s and 1970s, differences that result from research in the intervening years. In brief, the differences of importance in the S&T4 program involved our greater understanding of learning and conceptual change, including the need for time; the recognition of the importance of role models and sustained support; seeing incremental degrees of change; embracing conceptual change in content and pedagogy; accepting the need for networks to support change. We elaborate and justify these after giving an outline of the participants in and structure of the S&T4 PASMEP program.

The S&T4 PASMEP Program

The stated basic purpose of the PASMEP component was to conduct, in 1990, a program for these "trainers" who would perform the whole country ISE for the new S&T4 curriculum in 1992 ("mass training"), and to perform workshops in the Philippines in 1991 as further preparation for mass training. The trainers who came to Monash were selected by region by Philippine authorities. They were current S&T4 school *teachers*, not physics academics or physics teacher educators.

The specific beginnings of the program were late in 1989 when one of us visited the Philippines to see schools, to talk with teachers, and to negotiate the broad structure of the 1990 program with staff from the Bureau of Secondary Education (the relevant National Government bureaucracy), ISMED (The Institute for Science and Mathematics Education Development at University of the Philippines, the body responsible for the ISE for science/mathematics teachers), and those involved with implementation of PASMEP and the new curricula. One issue on which we all had clear agreement was that the major change agent role of the trainers would, in reality, be in contexts other than mass training: in their own schools, in ongoing local ISE, and so forth. This did not diminish the importance of the mass training role. Rather, it placed that role in a broader ISE context.

This issue was of major importance to the S&T4 program approach.

The trainers spent February to November 1990 at Monash. There were 34 in all: 2 teachers from each of the 14 regions in the Philippines, a third teacher from each of the three regions on which PASMEP had a particularly strong focus, one physics educator from Bureau of Secondary Education, and 2 physics educators from ISMED. Subsequent follow-up workshops in the Philippines were held in January 1991 (1 week), May 1991 (4 weeks), October 1991 (2 weeks), and January 1992 (2 weeks). In the May 1991 and subsequent workshops, an additional two S&T4 teachers from each region joined the group to become trainers, and in the last two workshops, teacher educators (who had undertaken a year-long PASMEP program) and selected school administrators were present for part of the workshop. All these personnel made contributions to the 12-day mass training programs in April or May 1992. An intended presence of Monash staff as observers at mass training was canceled because of the concurrency with national elections. A subset of the trainers was also involved in 1991-2 in a series of curriculum-writing and equipment-use workshops. The authors were not involved in these.

In outline, the 1990 program focused on physics content, on issues of learning and teaching, and on the nature and provision of ISE. The culmination of these thrusts was the production of resource material for use in ISE or classroom teaching, and explorations of varieties of use of the material. (Other 1990 program components, such as school visits, other excursions and learning word processing, are not considered here.) The follow-up workshops in 1991-2 were a mix of further planning for mass training, teaching the new trainers, and trials of approaches and considerations of other ISE (both what the teachers had attempted on return to the Philippines and what they might attempt).

The Rationale for the S&T4 Program

In an earlier section we listed some features of the approach to our work with the S&T4 trainers (understanding of learning and change, time, role models, networks, and sustained support). These are described here more fully, our justifications are indicated, and some sense of how the features played out in the program are given. One obvious difficulty in doing this is that although we need to consider the features somewhat separately, the features are interrelated in a complex whole. A further difficulty is another complex interaction, that of teacher, learner, and subject matter, or, in the terms of Hawkins (1973), the interactions in a three-term communications relation-teacher, learner, and subject matter. The importance of this second complexity is embedded in some of the features of the program.

At the heart of the program was a constructivist view of learning (e.g., White, 1988) and a recognition that what was known about conceptual change in school students had appropriate parallels in conceptual change in teachers (Gunstone & Northfield, 1986). Of particular importance in these parallels is the scheme advanced by Posner et al. (1982) for considering conceptual change: there must first be dissatisfaction with the existing concept, and the new concept must be intelligible, plausible, and fruitful. Concern with fruitfulness of new concepts was a pervasive theme throughout the program. Collaborative work with teachers, for example, the Project for Enhancing Effective Learning (Baird and Mitchell, 1986; Baird & Northfield, 1992), has shown clearly the fundamental importance of time and of collaborative, sustained support in fostering teacher change in conceptions of learning and of appropriate pedagogies.

The PEEL and other projects have also pointed to the importance of role models. These are significant not only for the obvious reason of providing an exemplar from which to learn but also for the more profound reason of "learners" seeing that "teachers" value ideas sufficiently to use them themselves. In other words, part of the value of role models is intertwined with the fundamental importance of teachers practicing what they preach (Gunstone et al., in press). One other theme included in this, and described in detail in a number of the associated references, is metacognition. In the context of the S&T4 program, it was necessary for participants to understand and, we intended, eventually accept the approaches we used, particularly in terms of the contributions these approaches could make to the learning of the participants. Time is a major issue here, even just for arriving at a state of dissatisfaction with current conceptions.

The above outline is relevant to our approaches to considering physics *and* learning and teaching. The bulk of the first half of the 1990 program was devoted to physics content, and most of that to fostering a genuine understanding of fundamental concepts through the consistent use of a range of teaching approaches congruent with this goal (e.g., concept maps, predict-observe-explain, interpretive discussion; see White & Gunstone, 1992). The Monash teachers were role models in terms of participants being subsequent users of these strategies with their students for the same goal. Through this time the participants kept diaries about their learning that were used, inter alia, for later considerations of learning and change, and some sessions considered teaching and learning via these physics learning experiences. This dual agenda (i.e., learn physics and at the same time consider learning and teaching) was a common feature of the program. For example, as part of our focus on ISE later in the year, participants had two separate experiences of specifically provided ISE of relevance to the program (one focused on an Australian curriculum development, the other on the PLON project from the Netherlands). As well as being of value as experiences, the two ISEs were also analyzed by participants as examples.

In the second half of the 1990 the program focused on learning, teaching, ISE and professional development. As participants' understanding grew, much of this work was focused by a 4 x 3 matrix which had on one axis "your classroom," "your school," "local schools," "regional/national" and on the other "physics," "learning and teaching," "change." Each cell of the matrix contained questions and issues of relevance.

The materials produced in the latter part of 1990 were generated by groups of five or six trainers and were modules. Each was a structure for up to 1 hour of ISE, and each was required to focus on one concept from the new S&T4 curriculum and one teaching strategy. The concepts were those determined by a simplistic form of Delphi technique to be the likely most difficult ones for the teachers who would be involved in mass training. The teaching strategies were selected from the experiences of the program. A total of 103 modules ("components") were produced, and 53 different teaching strategies were used. In the last few weeks of the Monash program we focused on seeing the components as a resource to be selected from. We used a building metaphor to emphasize the need to include linking between selected components ("cementing"), which would vary by purpose. A wide variety of purposes was used by taking cells from the 4 x 3 matrix (e.g., use the components to generate a teaching sequence for your S&T4 class, generate a ___ day ISE about different teaching strategies for local physics teachers). "Selecting and cementing" for mass training was largely left for the 1991-2 follow up workshops.

The same broad approaches were used in the follow ups in the Philippines. Clearly time was much shorter with the 28 who joined in May 1992. However the power of role models was evident here. In the 1990 program, acceptance of our purposes and approaches by the trainers was a long and demanding process. For some it took months. In May 1991, some of the new trainers had embraced much of our approach before the end of the first week. They informed us that this was because of the presence of the group that had been at Monash, and the ease with which the new trainers could check with peers the likely value of what Monash staff were doing and asking them to do.

Some Outcomes and Reflections

Given that we did not run a concurrent formal evaluation of the program, our statements of outcomes from and assessment of the program rest on data and anecdotes not collected for program evaluation. Evidence of change in the 1990 participants was strong—change in physics conceptions and in conceptions of pedagogy and the conditions appropriate for fostering change. This evidence is in their diaries, their assignments, and in more general issues such as the organizational structure of the 1990 program. When the trainers arrived at Monash they found we had no formal, year-long timetable of activities to hand them. This distressed them. Later, most of them had changed to the point where they could argue why such a year-long timetable would have been inappropriate.

Of more interest are the consequences of the program in the Philippines. At the first follow-up in January 1991, we asked the 31 high school teacher members of the group to describe what they had attempted to do since returning from Monash 2 months before. All but one gave convincing accounts of the trials and successes of their use of alternative teaching strategies in their own S&T4 classrooms. Some had already run ISE sessions for local physics teachers. One had initiated lunch-time seminars on alternative teaching strategies for pre-service students on teaching practice in his school, with the student teachers being from all school subject areas. This activity in areas other than mass training has continued to grow throughout 1991-2, with the whole gamut of likely practices being evident (from individual classroom work to ongoing ISE). We were unable to be present at the mass training. But PASMEP staff then based in the Philippines were present, and we have their reports, feedback from the trainers, and an occasional evaluation from a teacher being trained. These data point to a consistent features that separates this mass training from the usual approach to this form of ISE in the Philippines: concern with pedagogy in the approaches used in mass training. Put another way, the trainers were aware of the need for them to be role models for the trainees, and of the fundamental importance of this to the trainees at least considering the adoption of the new teaching strategies included in mass training.

The whole program can be characterized, in an aquatic metaphor, as a long soak followed by repeats of intensive swims. Between the swims (the follow-up workshops), there were other significant aspects with which Monash was not directly involved. These aspects, which all contributed to the support and network issues already addressed, included curriculum and equipment workshops conducted by PASMEP staff in the Philippines, trainers collaborating in the provision of regional and local ISE programs, and, most importantly, the strong support for PASMEP and the trainers given by staff at ISMED and by the director of the Bureau of Secondary Education. The active support of these significant local educational bodies has encouraged trainers to pursue their ISE work beyond mass training and has led to the formation of a PASMEP alumni. This body provides a structure for maintaining the network in the absence of PASMEP, which has now formally concluded.

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Induction Program for Beginning Teachers

Poul Klindt

The Problem

The first year is probably the most eventful and by far the most difficult in most teaching careers. The beginning teacher, just out of university or college, and most likely with little or no previous teaching experience, faces a host of tasks, all unfamiliar and difficult to handle, and more often than not with too little support during the first crucial months.

It is during the first year that teachers forms their attitudes toward the teaching profession in general. Ways of handling problems relating to classroom management, choice and administration of teaching methods and teaching aids, and administration of curriculum and staff room procedures have to be developed. One has to find a way of adjusting to the administration and management of the school and the whole educational system, not to mention dealing with parents, extra curricular activities, and so forth. The list is endless.

To safely pass through the obstacles mentioned above is, even when conditions are optimal, difficult. The gap between theory and practice is realized, and the teacher training institutions attempt to prepare their students for this situation. Some are more successful in their endeavors than others, but no matter how well the pre-service instruction is geared toward helping teachers get started, there will always be that reality shock when the new teacher faces the classroom situation for the first time.

The Induction Program at the Science Education Department of the National University of Lesotho came into existence some 4 years ago to try to help the beginning teacher deal with this situation.

The Start of the Induction Program

The idea of the starting an Induction Program to help new science and mathematics teachers get a better start in their profession was developed at the Center for In-Service Education of Mathematics and Science Teachers (CIEMST), which forms part of the Science Education Department at the National University of Lesotho. Approval was obtained from the Ministry of Education, and the Program started with a pilot program during the academic year 1988-89. Funding came from the European Community (EC) and the Netherlands Government (NUFFIC, later DGIS) for the running of the Induction Program for a period of 4 years.

Development of the Induction Program

In the pilot year (1988-89), seven beginning teachers, all graduating science or mathematics teachers, participated in the program. The following year, (1989-90) 19 completed the program. A rapid growth was experienced in the following 2 years, and the program has now stabilized with a participation of between 70 and 80 beginning teachers every year. The target group of science and mathematics teachers was expanded with a smaller group of home economics teachers from 1990-91, and this year a group of 10 teachers of business studies graduating from the National University are participating as well. In the last couple of years, after the program became known and accepted, the enrollment percentage has been between 85 and 90, participation being voluntary.

Approach of the Induction Program

One important principle in the program is that participation is voluntary. However, a binding agreement is made that beginning teachers participate in all the activities of the program once they have joined. No credits are awarded for participation, but there is no cost to the participants.

Also important is that the beginning teachers' principal agrees to the participation. The activities of the program are partly school based and partly centered around workshops and seminars, for which the beginning teacher has to travel. However, these almost always take place during holidays and weekends. The Induction Program thus does not generally affect the daily routines of the teacher.

Aims and Objectives

The Induction Program, in its present form, operates with the following aims and objectives. The Aims of IP are to help the beginning teachers taking part in the Program to:

1. Develop confidence in themselves as teachers and to acquire a positive attitude towards the teaching profession;
2. Learn to care for their pupils and to appreciate their individual strengths and weaknesses;
3. Become able to realize their own potential as teachers and to improve their teaching;
4. Fit into the school environment as members of staff and departments; and, thus,
5. As a result of the above to gain job satisfaction, expressed as a wish to remain in the teaching profession.

The Objectives are seen as the following:

1. To devise and administer a package of in-school support to be used by the beginning teachers during their first teaching year.
2. To identify and appoint suitable mentors in the schools and to provide the necessary training for them.
3. To arrange regularly scheduled seminars and workshops, linked with the school-based activities and providing necessary and useful input for the participants.
4. To facilitate visits to the schools of the beginning teachers to introduce and set up the Program activities and later to monitor the progress of the individual participants as well as to offer any assistance needed.
5. To provide a natural link between the learning institution and the schools receiving the beginning teachers.

The Induction Package

The activities and methodologies of the Induction Program in its present shape appear below:

1. Participation in the Program is offered to all graduating secondary and high school teachers from the institutions aforementioned.
2. Participation is voluntary.
3. Participation is subject to the approval of the principal of the school where the beginning teacher is employed.
4. A mentor is found at the school to assist the beginning teacher.
5. An agreement, specifying the roles of the beginning teacher, mentor, principal and CIEMST, is written and signed by the four parties.
6. During the induction year, seminars and workshops are held to keep mentors and beginning teachers informed about the program activities;

school principals are welcome to participate in these activities.

7. In the school the beginning teacher is expected to enjoy continual and sympathetic support from the mentor.

8. Regional peer meetings between the beginning teachers in a particular geographical area are arranged twice per term. During these meetings they will, in a non-threatening atmosphere, share problems and ideas with their peers.

9. A system of logbooks kept by the beginning teachers, pupils' questionnaires, lesson observations, and informal consultations between teacher and mentor form a structure of in-school support.

10. Regular visits from the Induction Program take place to ensure the smooth running of the Program in the schools.

11. Staff members from the learning institutions may, on request, visit their ex-students, the beginning teachers, in their schools to discuss content related problems with them. Likewise, the beginning teachers get the opportunity to meet their former lecturers during workshops and seminars.

12. A handbook is issued to the beginning teachers, containing relevant materials developed to support them in their work.

The Methodologies of the Induction Program

The Mentor

When the beginning teacher has found employment and the principal has agreed to participation, a mentor is identified. The mentor is preferably a teacher at the same school with some years experience, if possible in the teaching subjects of the beginning teacher or at least in related subjects. The mentors receive instruction in their role in helping the beginning teacher and is, in consequence, considered a participant in the Induction Program. It is anticipated that the mentor will be of assistance for the beginning teacher in a variety of ways. Most important is that mentors are available for the beginning teachers whenever they feel the need to discuss problems arising.

School Visits

The Induction Program Coordinators visit the beginning teachers regularly in their schools. During these visits, problems that the beginning teacher and the mentor have failed to solve, or just want to discuss, are discussed. If the beginning teacher faces problems of a nature that calls for expertise from other members of the staff of the Science Education Department, the Coordinator will assist in approaching the person in question for a visit to the school and teacher concerned.

Peer Meeting

Once quarterly, the beginning teachers meet at regional centers. These meetings are informal, and the purpose is to give them a possibility to exchange experiences in a non-threatening atmosphere. No other people are present during the meeting, but a mentor is normally asked to be available so that the beginning teachers can call upon the mentor's expertise in particular cases arising from their discussions.

Seminars and Workshops

All beginning teachers and mentors are invited to participate in seminars and workshops, which last for 2 or 3 days and are held during holidays or weekends. Principals are also invited, but rarely attend. An Introductory Seminar, in which the Induction Program is explained, is held in July. In October and January two follow-up workshops are held in which the experiences of the teachers and the mentors during the Induction Year are discussed. Selected topics of interest for beginning teachers are presented as well. These can be content related in nature, dealing with general educational issues or the kind that helps the new teacher get acquainted with the overall educational setup in the country. In May or June, the last seminar, which includes an evaluation of the Induction Year for the beginning teachers, is held. Around this time, the Induction Program is introduced to the next graduates of the Science Education Department.

Teacher Evaluation Methodologies

A variety of methodologies has been developed to help the beginning teachers get a picture of their own performances as perceived by the beginning teachers themselves and others, as well as to be able to measure the progress made. Those that have been formalized are available for inspection.

The Logbook

This self-evaluation instrument is designed to use during 2 teaching weeks at 3-4 monthly intervals. In the logbook, the beginning teachers record what activities were planned for the lesson, the deviations from the plan observed and positive and negative experiences gained from the lesson. These entries in the logbook are then analyzed in a categorized system that enables the teachers to identify strong and weak areas as well as registering any changes during the Induction Year.

Even though all beginning teachers appreciate the value of the logbooks, some fail to put them into full use because of the amount of time it takes them to work with this evaluation tool. Some adjustments have been made to the original logbook format, but the same problem prevails. A new teacher self-evaluation instrument is being tried at the moment. If it proves successful, it will either replace or supplement the Logbooks.

The Pupils' Questionnaire

The beginning teacher administers this questionnaire with 10 students selected at random who are asked to respond to 17 statements about the teacher, all dealing with teacher behavior in the classroom. The responses, which are given on a 5-point scale, are consequently analyzed and categorized. Thus, teachers can get an indication of how their teaching performance is perceived by the learners. Both students and teachers are in general appreciative of this evaluation tool, and the use often spreads to other teachers in the school, when they hear about it.

Lesson Observations

The third way in which beginning teachers get useful feedback on teaching is by using lesson observations. In most cases, it is the mentor who performs these observations. During workshops and seminars, mentors and beginning teachers are given training in the way these observations can be planned and conducted to serve their purpose. Models of clinical supervision are introduced, and the non-threatening, result-oriented approach is always emphasized.

Conclusion

Ongoing evaluations more than indicate that beginning teachers taking part in the Induction Program have an easier and, therefore, more successful first year of teaching than they would otherwise have had. There is less possibility of disenchantment resulting in a negative attitude to teaching or in resignation. It seems to be a fact that the retention rate among the science and mathematics teachers has grown during the life span of the Induction Program. Thus, the aim of getting better and longer-serving science and mathematics teachers to the benefit of the secondary and high school learners in the schools of Lesotho is seen to be achieved.

After 4 years of operation, the Induction Program has become fully accepted in the schools all over the country. It is in regular contact with the Ministry of Education and often calls upon its civil servants to assist in presenting topics of interest to the participants. The

Association of Headmaster and Headmistresses follows the development of the Program with interest and appreciation. Of Late, CIEMST has been encouraged to draw up a proposal for extending the Induction Program to cater for all graduating teachers in the secondary sector in Lesotho, regardless of teaching subject.

Improving Science and Mathematics Instruction: A Project for Fostering Teacher Development

David Ben-Chaim, Miriam Carmeli, and Barbara Fresko

Introduction

This paper describes an on-site project for the improvement of science and mathematics instruction in six comprehensive secondary schools (Grades 7-12) in the Northern Negev region of Israel. All schools are located in development towns characterized by severe social and economic problems and in relative isolation from major urban centers. In the schools, there tends to be a shortage of fully-qualified teachers, high teacher and administrative turn-over, overall low pupil achievement, and a tendency for the brightest children in the area to transfer out of the system when they reach the secondary level. All schools offer both academic and vocational tracks. Relative to other Israeli secondary schools, these schools are small, with an average of 20 classes per school and a student body ranging from 300 to 570. Few students earn a matriculation certificate upon completion of Grade 12, necessary in Israel for study at the university level.

In November 1989, the Science Teaching Department at the Weizmann Institute of Science was asked by the Jewish Agency and local town officials to do a diagnostic survey of science and mathematics instruction in the six schools. Results indicated that improvement was sorely needed in mathematics at all levels, in general science in the junior high school, and in physics and chemistry instruction in those senior high schools where the subjects were offered. Biology studies at the senior-high level were considered satisfactory in so far as sufficient numbers of students were taking and passing this matriculation examination (Ben-Chaim & Carmeli, 1990). Following this report, a project was undertaken to ameliorate the situation.

The project adopted a holistic approach out of a belief that all science and mathematics teachers in a school must be involved in the change effort for it to succeed. Although teachers should be helped with their individual problems, the real focus, in the long run, must be the school. Moreover, the high level of teacher turnover in these schools made a school-wide approach almost imperative. (For other examples of similar approaches and discussion of their merits, see Bashi et al., 1990; Fresko et al., 1990; Joyce et al., 1989, and Reynolds et al., 1989). In the present project, the following goals were defined.

Improved School-Wide Organization of Science and Mathematics Instruction

This goal included up-dating of textbooks, curricular topics and laboratory equipment, creating a general instructional plan as well as specific plans for each grade level, ensuring that pupils receive at least the minimal number of weekly hours of subject-matter instruction required by the Ministry of Education (which, among other things, includes studying chemistry in Grade 10 and physics in Grades 9-10), and arranging learning groups according to ability.

Improved Instruction in the Classroom

The emphasis here is on better and more varied teaching methods specifically; greater lesson planning; a better use of tests and instructional materials to facilitate learning; suitable pacing of instruction; and, in the case of science, a more efficient integration of laboratory work, demonstrations, and regular classroom instruction.

Improved Pupil Achievements

The aim is to increase achievement at all grade levels, culminating in a greater number of Grade 12 pupils who take and pass the matriculation examinations. Moreover, it is hoped that more pupils will take and pass these tests at higher levels.

Improved Functioning of the Teachers as a Team, With the Subject-Matter Coordinator as Team Leader

Encouragement of teamwork and nurturance of the subject-matter coordinator to take on leadership roles in the school are crucial for the continued maintenance of any changes achieved through the project.

From the outset, the Weizmann staff requested that the project be of long duration. Experience has shown that acquiring new habits takes time and that several years of practice are required to alter time-worn routine (Ben-Chaim et al., 1988; Donovan et al., 1987; Mumme & Weissglass, 1988; Mandeville & Rivers, 1988/89). The project was planned for a period of 3-5 years. Intervention during the initial few years was to be intensive at all levels, after which there would be a lessening of this intensity as the teaching staff in each school became self-sufficient. At present, the project is in the middle of its third year.

Project Operation

Three modes of intervention are being operated to help teachers with average and above-average pupils. (Approximately 70 teachers have participated each year). Consultants engaged in performing project activities are all part-time project workers (and most are also teachers in other schools). Once a week they visit project schools, and once a week they meet at the Weizmann Institute where they are organized into "module" teams and coordinated by a team leader.

Module 1

This mode of operation is directed toward teachers in the junior high school classes (Grades 7-9). One day per week is devoted in each school to project activities. On this day a project consultant visits the school and conducts a 2-hour workshop for all junior high school teachers (of either general science or mathematics), holds a 1-hour meeting with the subject-matter coordinator, and provides assistance to individual teachers. The workshops are aimed at exposing the teachers to new instructional approaches and at creating a teaching staff that works as a team. Topics treated in the workshop sessions have included updating the curriculum taught in the school; selection of appropriate text books; jointly planned instruction, placement, and test construction; joint preparation of instructional aids; discussion of learning difficulties; observation and discussion of lessons; and the use of different instructional strategies and methods in the classroom. In addition, achievement tests prepared by project consultants are administered to monitor pupil progress. Great importance is attributed to Module 1, through which the foundations for learning, essential for successful continuation at the more advanced senior high level, are expected to be laid.

Module 2

A consultant visits the school once a week to provide individual assistance to teachers, observe classes, and give feedback, consult with teachers about the pace and topics of instruction, and occasionally take active involvement in classroom teaching of new curricular units or laboratory work. This latter activity benefits both students and teachers, particularly with mathematics. By studying topics that are usually not taught in these schools but are nevertheless part of the curriculum, students are given a greater range of topics from which to choose when taking the matriculation examinations. Teachers are given the opportunity to observe how these new topics are handled in the classroom as preparation for teaching them in the future.

Periodic examinations prepared by the Weizmann staff are given to these classes for the purpose of stimulating the teachers to work more efficiently and to move on to new topics at a reasonable pace. These tests are also planned along the lines of the matriculation examination, enabling the pupils to become accustomed to the type of problems and questions generally asked, and enabling teachers to better assess pupil progress. This mode of activity was performed in Grades 10-12 mathematics and chemistry classes and Grades 9-12 physics classes, which were not involved in Module 3.

Module 3

The intent of this mode is to provide teachers who teach matriculation material (Grades 10-12) with an intensive and active in-service experience designed to assist them in better preparing their pupils for future matriculation examinations. This module does not involve all teachers of these grades, but only those who are new to teaching this grade level or who have particular problems teaching it. Accordingly, 1 day per week a consultant comes to teach the class. The teacher observes the lesson and often assists the consultant. The topics taught in these lessons are an integral part of the regular instructional curriculum and require careful coordination between teacher and consultant. Lesson content and pacing must be planned so that the consultant's lesson is a natural continuation of the material taught by the teacher during the week. By teaching actual classes, consultants are able to directly demonstrate new methods of instruction and to show how to integrate materials. They also get to know the needs of the pupils better, which enables them to give better advice to the teacher concerning appropriate materials, level of instruction, and pacing.

The learning of the pupils in these classes is monitored through periodic examinations, some of which are prepared by the teacher and consultant together, and some of which are prepared by the Weizmann staff for all participating schools. Dates for the latter tests are set in advance, which is intended as an external stimulus to the teachers in their preparation of the pupils.

Operational Difficulties

A project of this size and complexity inevitably encounters numerous organizational problems along the way. One of the major difficulties has been the problem of adjusting teachers' schedules so that they can participate in such project activities. This means that junior high school teachers all have to have a common 2-hour slot on the day of consultation to enable the workshops to take place. With respect to Module 2, it means that all relevant teachers have to be teaching project classes on the day the consultant regularly visits. Moreover, it means that all teachers participating in Module 3 have to be present in school on the day consultants comes to teach and to have at least one free period to meet with them. In addition, all relevant classes have to be scheduled on that same day. In some situations, all of these requirements could not be met. Consequently, a few teachers were excluded from the central project activities and maintained contact with the consultant only by telephone or hastily held meetings in school. In some cases, teachers were expected to participate in more than one module. This created further scheduling difficulties and also became very demanding for those teachers involved.

Another difficulty encountered is that in several schools there was not always a subject-matter coordinator. Other impediments to smooth operation have included high teacher turnover (even in mid-year), faulty maintenance of laboratory equipment, lack of suitable and operable computers for activities involving software, and difficulties concerning the purchase of updated textbooks for the pupils.

There have also been difficulties whose source is not organizational but attitudinal. As noted by Fullan (1982), Sarason (1982), and others concerned with educational change, resistance to change efforts is to be expected and perfectly natural in the transition to new modes of behavior. In the present project teachers, new to the profession or new to the particular schools, have tended to welcome the help they receive from consultants. However, some of the more veteran teachers have resisted the project efforts in their schools. As time passes, positive changes are gradually occurring in veteran teachers' attitudes toward the project, although one or two teachers still maintain some resistance.

Interim Results

Evaluation activities accompany the project and include testing of pupils; interviews and questionnaires for teachers, subject matter coordinators, principals, and consultants; regularly submitted reports by consultants of their activities; and data collected from school records. Two years of project activity are summarized below.

Organization of Instruction

Textbooks and curricular topics have been updated at all levels, the number of weekly hours of science and mathematics instruction has increased, chemistry and physics are being taught at all required grades levels, and a core curriculum has been established for the junior high schools. Homogeneous, and often smaller, study groups have been created, which enables more efficient learning in general and makes laboratory work possible. Teachers have begun to cover more topics than in the past; however ,the gap that was previously created as a result of not progressing has not yet been closed for most classes.

The Teachers

It was found that most teachers had positive to very positive opinions of the assistance they were receiving from consultants and were satisfied with the consultants' involvement in classroom teaching. This was particularly true for those in Module 3. Teamwork has greatly increased, particularly among general science teachers—a change noted by teachers and principals alike. Teachers noted that, in the classroom, there was some change regarding the teaching of new topics, better pacing of instruction, better lesson plans, and improved test construction, science demonstrations, and laboratory work. Little change was noted in such areas as remedial instruction, use of new methods, integrating computer software with regular instruction, and questioning pupils' learning difficulties. Finally, it should be noted that most teachers hired since the project began are fully qualified, raising the proportion of qualified teachers in all schools from 28% to 42%. (63% are university graduates but do not necessarily have a teaching certificate).

Testing

Achievement tests given by the Weizmann staff indicated that pupils in most classes and in most schools were making strides in their learning. In addition, results of the matriculation test in mathematics revealed that whereas only 25% to 31% of the Grade 12 pupils took the test in the past, 40% were tested at the end of Year 1 and 49% at the end of Year 2. Previously, only about half of these tested actually passed the test. Since the project started, more than two-thirds have passed each year. In addition, more pupils took higher level tests, and passed them, than before. In physics and chemistry, there has been a slight increase in the number of pupils studying for matriculation, and these subjects are being offered at matriculation level in more schools than in the past.

Science Coordinators

Whereas there was a science coordinator in three schools at the start of the project, there are now coordinators in five schools, all of whom are performing their jobs adequately. In two schools, improved functioning of the mathematics coordinator was noted, in two schools no change has occurred, and in two schools coordinators were appointed only towards the end of the second year.

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To Master the Knowledge, Acquire the Methods, Lead the Pupils

Moshe Barak

Introduction

One of the main problems concerning the advancement of science and technology studies in Israel is the ongoing lack of highly qualified teaching staff. This problem is especially acute with schools in less populated areas that are also remote from the big cities, the universities, and the science and technology centers.

The Department for Education in Technology and Science at the Technion is in the fourth year of a program that aims to advance the studies of mathematics, physics, electronics, and mechanics in 17 schools in the Galilee, in the north of Israel. Preliminary research conducted in 10 schools in the area (Evyatar, 1989) showed that the number of pupils learning science and technology at a high level was significantly lower than in equivalent schools in the metropolitan areas. The main objective of the Technion project is to bring about fundamental and lasting changes in the educational environment of the schools and to increase the number of students who successfully study science and technology at a high level. The efforts are focused on the advancement of low achievers in science and technology studies and the preparation of this group for Bagrut (matriculation) examinations.

The project is aimed at improving most of the factors influencing science and technology studies, such as updating teachers knowledge in the subject-matter, improving of laboratory activities, providing learning materials, and applying special programs for the advancement of unique groups of pupils. However, the core of the program is the advancement of the teachers. This paper presents the 6-year project program and describes two main activities: in-service courses and school supervision. Interim findings concerning project effectiveness are also included.

Teachers' Backgrounds

The problem with teachers' backgrounds can be illustrated by examining the level of education of the teachers at the 17 schools that participate in the Galilee projects, as shown in Table 1. Approximately 21% of the mathematics teachers, 7% of the physics teachers and 71-72% of the electronics and mechanics teachers do not have academic degrees. The majority of them hold lower diplomas, such as technicians.

It was found that a substantial number of teachers with a formal education lack pedagogic training or teach subjects different from those for which the teachers were prepared during their academic studies. For instance, there are teachers who teach physics although their academic training was mathematics or engineering. The question is whether a teacher who has no academic degree can prepare pupils for academic studies, arouse in them curiosity and challenge, and be a model for them. It would be a mistake to think that a substantial number of these teachers could be replaced within a short period. Most of them live in the area and have been teaching there for many years. Despite the efforts to introduce highly educated teachers to the schools, it is evident that the present teachers are the keystone for any educational innovation (Mitter, 1991).

The 6-Year Program of Assistance to Schools

The planners of the project were faced with the question of when to begin the activities and how to extend the assistance to schools over a long period. Should the program begin in the 7th grade and gradually advance to the 12th grade, or should the assistance be

Table 1: Education of Teachers in Galilee Schools

	ACADEMIC DEGREE			
SUBJECT	NON	B.A.-B.Sc	M.A-M.Sc/Ph.D-D.Sc	TOTAL
Mathematics	17 (21%)	38 (46%)	27 (33%)	82
Physics	2 (7%)	14 (45%)	15 (48%)	31
Electronics	35 (71%)	9 (19%)	5 (10%)	49
Mechanics	31 (72%)	6 (14%)	6 (14%)	43
				205

given to the junior and senior high schools in parallel? In view of the project limitations, and the immediate needs of the schools, the following plan was established: during the first 3 years, the efforts were focused on the training of teachers and the development of the curricula for secondary schools. Teachers' training courses during the first year concentrated on the curriculum for the 10th grade and gradually proceeded to the curricula for the 11th grade during the second year and 12th grade in the third year. Personal guidance was given to all teachers (grade 10-12), according to the special needs of each school.

The program for junior high schools is also a 3-year plan. In-service courses start with the curriculum for the 7th grade and gradually continue to the curricula of the 8th and 9th grades, as well as giving personal guidance to all teachers. One of the reasons for starting the program in the high schools was that the project was put into operation simultaneously with the reforms enacted by the Ministry of Education and Culture regarding the curricula of technological studies in high schools. The new curricula include far-reaching changes in the syllabus, reflecting technological developments. At the same time, study requirements have been increased and greater emphasis has been placed on the mathematical and physical aspects of the technological systems. Schools in the north of the country are faced with many difficulties, and there was a concern that substantial damage would be caused to a large population of pupils. The Technion, as a unique institute that comprises both technology and sciences under one roof, was expected to face the challenge and help the high schools cope with the new curriculum. Also, the preliminary research showed that there were a significant number of pupils who could be advanced toward higher levels of study in science or technology. Because a 6-year plan is extensive, it became important to introduce objectives that could be achieved within a shorter period of time and create the dynamics of success.

In-Service Course

The aim of the in-service courses is to impart to the teachers basic knowledge and specific pedagogical training on subject matter. This is regarded as the best way to produce clear-cut benefits (Walberg, 1991). The courses, which take place during the entire school year, are located in the area. The teachers arrive in the morning by special transportation from a radius of 90 km, and study 4-6 hours. During 1992/1993 there were eight groups: three for mathematics, two for physics and three for technology. During the courses the teachers not only acquired a more thorough knowledge of the content, but the teachers also solve problems, prepare tests, perform laboratory experiments, and use computers, just as they will have to in the school. Many new learning materials are provided. The number of teachers participating in the in-service courses in the last 3 years have increased each year, as shown in Figure 1. The percentage of drop-outs during each year is negligible, and the attendance in lessons reaches about 80%. Although the topics of the courses change every year, Figure 1 shows that many of the teachers took the courses during 2 or 3 consecutive years. It should be mentioned that the teachers attend the courses by their own choice and on their own free time (there is a minor compensation from the Ministry of Education and Culture according to standard criteria). From the level of participation and continued presence in the courses, it can be concluded that the training courses meet the teachers' needs, and they are most probably rewarded for their investment in class.

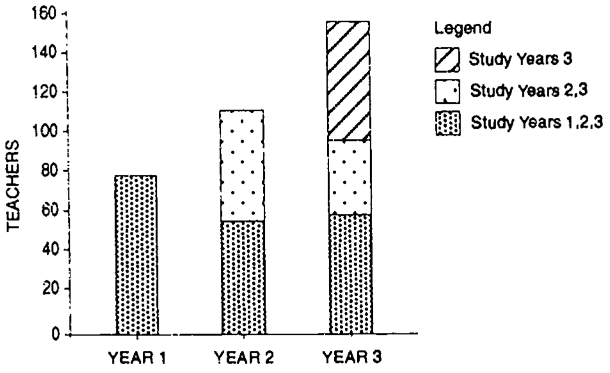

Figure 1. Participation of Teachers in In-service Courses

Tutoring and Supervision

Personal assistance to teachers in schools is given by a team of about 20 tutors who visit the schools once every 2 or 3 weeks. The supervision is instruction-related as well as pupil-related. The tutors are qualified teachers in mathematics, physics, electronics, and mechanics, and are experienced in preparing pupils for the Bagrut examinations. The tutors are not inspectors, and it is not their duty to evaluate the teacher. Tutors must not divulge information regarding their work with the teachers to anyone, including school head-teacher. There is cooperation between the tutor and the teacher in locating problems and establishment of goals (Goldhammer, 1980). The supervision is also provided to teachers who do not participate in the training courses. In addition to the individual assistance to teachers, the tutors also deal with a wide range of subjects, such as fostering teachers' teamwork and guidance in planning the yearly curriculum of certain subjects. The tutors have the important duty of locating low achievers who could advance toward the Bagrut level and planning, together with the school staff, special programs for these students.

After 3 years of experience in running the supervision program, it can be concluded that in most schools tutoring was accepted positively. The trust of the teachers in the tutors has increased gradually, and in some schools the tutors, together with the teaching staff, implemented extreme changes in the teaching of a certain subject. At the beginning many schools requested the increase of tutoring to one visit per week. However, after 2 or 3 years, the rate of visits was reduced in most of the schools to one visit per month. It can be concluded that the activities of the tutors complement the training courses and offer solutions to the specific problems in each school.

Examples for Advancing Low Achievers

Improving the teachers' work is only the first step in the efforts to increase the number of pupils studying high-level science and technology in a high school. Special steps are implemented at schools to "push" low achievers toward higher levels and to prepare them for the Bagrut examinations. For example,

1. The mathematics teams have given special tests to the 9th graders, for the third year, to identify pupils who have a chance of advancement. During 1 year about 1200 pupils were tested, out of which 170 were found capable of studying at a level that meets the minimum requirements toward Bagrut examinations. Such groups follow a special curriculum, get additional study hours, and are subject to a close follow-up.

2. In the past, the mechanics classes in high

schools accepted many low achievers, and only a few of them were presented for the Bagrut examinations and passed them.

After 3 years of the Technion project, there are the first signs that the educational climate in three schools has been changed, and the number of pupils learning toward the Bagrut diploma have increased. For instance, in 1989 only 30 pupils took the Bagrut examinations in mechanics, out of which only 9 (30%) passed successfully. In 1992 the number of pupils taking the examinations increased to 95, and 85 of them (89%) passed them successfully. About 150 pupils are expected to take the next year's Bagrut examinations.

Summary and Conclusions

Although substantial results of a project of this kind can be measured only years later, the interim findings indicate the beginning of the desired change. In addition to the in-service courses and school supervision described in this paper, there are other activities, such as the development of learning materials and performing tests in the schools, which represent an important contribution toward achieving the objectives of the project. Nevertheless, our experience shows that a change was achieved only in those cases where an atmosphere of cooperation and trust between school teachers and Technion staff was established. In the course of the program for the next 3 years, the support of high schools will gradually decrease, and the efforts will be directed towards junior high schools.

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Teachers as a Source of Erroneous Ideas: Implications for Biology Teachers' Educators

Martie Sanders

Background to Study

A number of erroneous ideas about respiration are held by matric biology pupils in South Africa (Cramer, 1988; Sanders & Cramer, 1992). Anderson et al. (1986) point out that respiration is a key life process, the understanding of which is fundamental to a complete comprehension of the way in which living organisms function. For example, the breathing systems, digestive systems, and circulatory systems of many animals function as they do largely because of the need for body tissues to engage in respiration. Erroneous ideas held by pupils about the process of respiration could thus result in errors about work in other parts of the curriculum.

Purpose of the Study

Before remedial strategies can be developed to address erroneous ideas held by South African pupils about respiration, a sound understanding of possible causes of such errors, based on empirical educational research in this country, is required. The purpose of this study was to investigate one possible source, the teachers.

Research Questions

1. Is there evidence to suggest that South African biology teachers might have erroneous ideas about respiration and related concepts?

2. Are there indications that the methods of assessment used by the teachers could influence the development of erroneous ideas in their pupils?

Methods

The Research Instrument

The instrument used in this study was based on a strategy used by Nussbaum (1981), who analyzed the work marked by his student-teachers to see whether they could identify pupils' misconceptions. The instrument consisted of the supposed answer of one Standard Grade Matriculated Biology pupil to a class test that required the pupils to write a brief essay on respiration. The answer provided contained 13 scientifically incorrect statements obtained from pupils who had answered open-ended probes in previous studies in Australia (Haslam & Treagust, 1987) and South Africa (Cramer, 1988). Teachers were asked to mark each correct statement in the essay with a tick, to mark each incorrect statement with a cross, and to allocate a mark out of 20.

Reliability and Validity of the Study

The face validity of the erroneous statements was established by three university physiologists. The face validity of the instrument as a means of ascertaining whether there was evidence to suggest that biology teachers might hold erroneous ideas about respiration was determined by two biology teacher educators. Gronlund (1976) reports that traditional estimates of reliability are inappropriate for criterion-referenced tests, and that, as yet, no viable alternatives are available. Sanders (in press) discusses this further.

The Subjects

The subjects included four groups of biology teachers

Table 1: Teachers Responses to 13 Inaccurate Statements About Respiration (n = 136)

Error no.	Erroneous idea	% teachers marking wrong answers correct
1	The purpose of respiration is to provide oxygen and to remove carbon-dioxide.	77.2
2	Respiration is a gaseous exchange process during which oxygen is taken in and carbon-dioxide given off.	42.6
3	Animals respire through tracheae and lungs.	44.1
4	Plants respire through stomata on the leaves.	43.4
5	Respiration occurs in the lungs and cellular respiration in the tissues.	69.8
6	Respiration in plants occurs only at night.	14.0
7	Respiration in plants occurs only at night as during the day plants take up carbon-dioxide. and use it for photosynthesis.	35.3
8	The oxygen given off during the day by plants is used up during respiration at night.	22.8
9	Photosynthesis is the process which provides plants with the energy they need for life processes.	41.9
10	Digestion is the process which provides animals with energy for growth, movement etc.	52.9
11	The energy for the life processes of living organisms comes directly from the sun.	27.2
12	The formula for respiration is O_2 + glucose = CO_2 + H_2O	40.4
13	Oxygen is essential for the life proceses of all living things.	53.0

(n= 72, n=8, n=11, n=45) present at talks given by the author on erroneous ideas about respiration identified during a study by Cramer (1988), who was a co-presenter at one of the talks. The group of 45 formed the sample that was questioned for corroborative evidence. Sixteen teachers attending a further talk answered a short questionnaire on their assessment practices when marking essays.

Results and Discussion

The results suggest two areas for concern.

Many Teachers Appear to Have Erroneous Ideas About Respiration and Related Concepts

Although the instrument used was an indirect one, the results suggest that a number of the teachers could have erroneous ideas about respiration. This assumption is based on the number of teachers who marked correct answers as wrong or incorrect answers as right (see Table 1 and Figure 2).

The Methods of Assessment Used by Teachers May Influence the Erroneous Ideas of Pupils

Two disturbing features were identified.

The first is the range of marks allocated by a group of experienced teachers for the same essay. Allowing for the fact that essay marking is subjective [see Sanders (in press) for a discussion of problems], the range of marks allocated is perturbing. The essay used in this study contained *13* scientifically incorrect statements (virtually one in every sentence), indicating that the student had severe problems in terms of his knowledge of the process of respiration. Yet a "fail" mark was allocated by only 19.1% of the teachers. A "pass" was awarded by 80.9% and 9.9% awarded a "distinction" mark. Thus, depending on the marker, pupils could receive conflicting messages about the quality and scientific accuracy of their work (Figure 1).

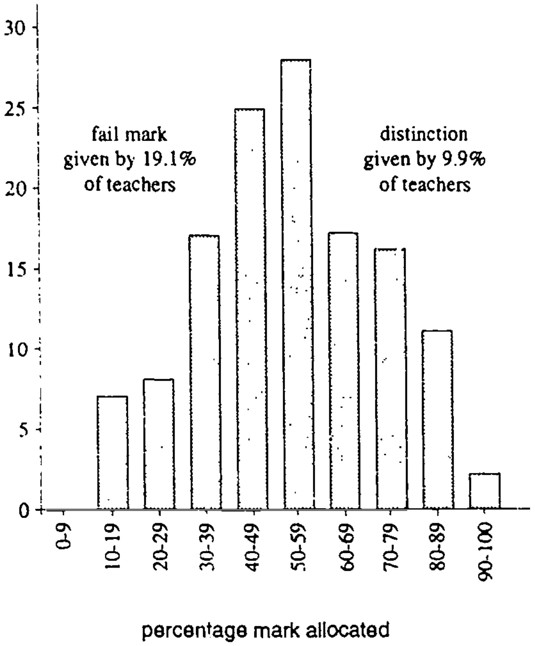

Figure 1. Marks Allocated by Teachers for the Essay (n=136)

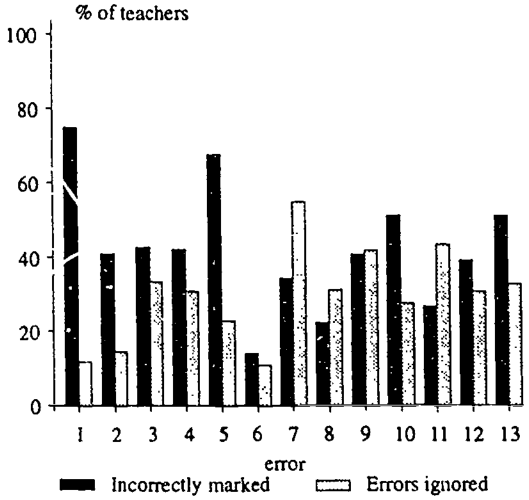

Figure 2. Percentage of Teachers Marking Incorrectly or Ignoring Errors (n=136)

The second problem is the marking itself. Two aspects seem likely to influence students' errors. First, a number of answers were incorrectly marked (correct statements marked wrong, or incorrect answers marked right). Second, a number of incorrect answers were ignored by many of the teachers. These teachers appear to forget one vital function of testing—the feedback after the test that will make it a learning experience for the writers. It is important that pupils be given feedback about whether their ideas are correct or incorrect, with special emphasis on erroneous statements. It seems logical to assume that if errors are not indicated, pupils may not realize that a problem exists, and because nothing is done to correct the information, the erroneous ideas persist.

Corroborative Evidence

Forty-five teachers were questioned about the likelihood that their pupils have erroneous ideas about respiration and possible factors that could have caused the errors. The purpose of this survey was to obtain corroborative evidence from the teachers about the two conclusions arising from the first section of this research. All teachers said that they thought their pupils would have erroneous ideas about respiration. Over three-quarters of those who answered the relevant questions said that *what they taught* and *how they assessed* could have affected their students' erroneous ideas, and almost all the teachers felt that textbooks were a source of erroneous ideas.

The assessment practices of South African biology teachers, if judged by the responses of the 16 teachers questioned on this matter, suggest that the way teachers assess *is* likely to influence pupils' misconceptions. Fifteen of the teachers indicated that they did not tick every correct fact when marking an essay (only relevant facts, or only up to the maximum number of points allocated for the question). Thus, pupils do not always get feedback on all of their *correct answers*. More serious is that 14 of the teachers said that they did not indicate every *incorrect fact* when they marked, and 13 ignored facts seen as irrelevant to the essay. The essay used as an instrument in this test suggests that this practice of teachers is cause for concern. In this case, the teachers considered any comments on photosynthesis as irrelevant to the essay, which they saw to be on respiration. However, several of the "pupil's" sentences *were relevant* in that they addressed the essay question (which asked about the source of energy for living things). The essay was designed to elicit misconceptions linked to which process provides energy for metabolic processes in plants and animals.

Fifteen of the teachers stated that their usual reason for giving a test was "to get marks" (for their mark books, or for pupils records or reports). The same number stated it was "to help pupils learn." While all 16 teachers provided verbal feedback to pupils on their tests, the quality of this feedback suggests that no effort is made to address misconceptions, as the feedback centered around the correct answers on their marking memoranda. These teachers do not appear to realize that assessment of pupils' answers can provide the teacher with insights about pupils' misconceptions and misunderstandings, and that the type of feedback teachers provide is vital in identifying and addressing or preventing such misconceptions.

Implications of the Study

The fact that teachers could be a factor influencing the development and perpetuation of erroneous ideas in their pupils has particular implications for teacher educators.

Scientific misconceptions need to become a focal point for academic content courses for potential teachers. A number of steps need to be taken in methodology courses, both pre-service and in-service.

(Student-)teachers need to be informed about what science education researchers have discovered about "misconceptions." Knowing that such phenomena exist is a vital first step without which errors cannot be corrected. Teachers also need to know what erroneous ideas their pupils hold about various biological concepts and what factors cause and exacerbate misconceptions and errors, with specific emphasis on assessment practices.

Teachers need to acknowledge the possible role they might play in both causing and remediating errors and misconceptions and be willing to make the effort to do what is necessary to address the problem. In adtion, the teachers need to know how they can effectively eliminate misconceptions and errors and how to prevent new ones arising. Two areas need to be considered here:

1. Teaching and learning methods. Suggestions regarding respiration are discussed by Sanders and Cramer (1992). Teaching methods that take into account the constructivist theory of learning are vitally important.

2. Methods of assessment. Assessment needs to be viewed in a totally different light. Teachers should not only assess to get marks for the pupils and should not "mark with blinkers on." Pupils' answers can be extremely revealing about what pupils understand and how they think. If teachers "listened" to what their pupils were telling them, it could have an immense influence on what the teachers then teach and how they do it.

Conclusion

This preliminary study suggests that teachers could be a factor contributing to the formation of errors and/or misconceptions in their pupils.

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Science Teachers Collaborative Action Research: Cost Effective Professional Development for Developing Countries

Allan Feldman

Introduction

During the 1991-92 school year I performed an in-depth study of the ways that the process of collaborative action research has changed the practices and understandings of science teachers. The purpose of this study was to better understand the ways that teachers use their own experiences and those of their colleagues to become better teachers. That is, in general, "Where does their knowledge originate?" and, more specifically, "What are the ways in which teachers' knowledge about teaching and their educational situations grow when they are engaged in collaborative inquiry about their own practice with other teachers?" Although there are investigations of the types of knowledge both novice and experienced teachers possess, little research has examined the origin of that knowledge (Grossman, 1988; Hashweh, 1987). In addition, when the lens of research has been focused on how teachers accumulate or generate knowledge about teaching, little attention has been paid to the ways in which teachers learn from each other and from their own experience. My field research and experience suggest that much of teachers' knowledge of teaching, of their students, and of the micropolitics of their educational situations arises through exchanges with other teachers.

For the past 2 1/2 years, I have acted as facilitator for a group of eight physics teachers engaged in *collaborative action research.* Although this label can be applied to a variety of different activities, I am using Stenhouse's (1975) definition of *research*: systematic, critical inquiry made public. In addition, although others have labeled research arrangements between university researchers and school teachers as *collaborative* (Feldman, in press), I am using it to refer to a relationship among teachers. By *action,* I mean that the teachers are investigating their own practice by acting within their settings to improve their teaching and come to a better understanding of their educational situations.

The design and methodology of the study consisted of a set of parallel and contrasting longitudinal case studies of the *Physics Teachers Action Research Group* (PTARG), a group of U.S. physics teachers engaged in a year-long inquiry into their own teaching. The sample of teachers was distributed with a mix of public and private schools, grade levels, and genders. They vary in their own level of schooling and whether or not they had been students in teacher education programs (Table 1). The data collected includes interviews of the teachers and their students, audio tapes of PTARG meetings, and teachers' writing.

This research supports my hypothesis of the origins of teachers' knowledge. This paper demonstrates the importance of these activities as a source, among others, of teachers' knowledge as they attempt to improve their practice. The implications of this for both pre- and in-service education of science teachers are significant. The implications are of even greater significance to developing countries because this suggests that more teacher development can be done through collaboration among teachers in the field rather than relying heavily on outsider expertise.

The Sharing of Knowledge

Through their participation in collaborative action research, the teachers became more knowledgeable about and gained a better understanding of their practice. This occurred through several different mecha-

Table 1: The Teacher Sample

Teacher	Gender	Undergrad major	Teaching experience	Teacher education	Type of school
Janet Moore	F	physics	>15	MAT	public HS
Anne Apple	F	physics	>15	none Ph.D. in physics)	community college
Jack Holland	M	physics	>15	MA	private HS
Louis Hill	M	physics	>15	undergrad	public HS
Laurie West	F	forestry	>5	MA	public HS
Barry Stein	M	physics	>15	MA	public HS
Scott Foreman	M	science, technology, and society	>5	MA	private HS
Robert White	M	physics	>15	MA	private HS

nisms. These were first, sharing professional knowledge through story telling; second, trying their own and others' ideas in their classrooms; and third, engaging in critical and systematic inquiry processes. Each of these mechanisms resulted in the increase of individual teachers' knowledge about teaching and how to teach, and of their knowledge of physics. In addition, by engaging in a research process, they generated new knowledge and shared that knowledge with other teachers. They also came to new understanding of the nature of research as they learned the best ways to inquire into their own teaching.

Storytelling

The teachers in PTARG have had nearly 150 years of combined teaching experience. This does not include the 20 or so years that each has spent in an "apprenticeship of observation" (Lortie, 1975). During this time they have amassed knowledge and know-how about teaching. When these teachers gathered for their more-than-monthly meetings they shared that experience and expertise through story telling. Although it has been documented that story telling is an important component of teaching (Egan, 1988; ; Jackson, 1987; Shrigley & Koballa, 1989) its function in the exchange of knowledge among teachers is not well established. In this paper I show that it is also an important part of the way that teachers share their knowledge of teaching with other teachers.

It is important to clarify what I mean by *knowledge*. Following the precedent set by Shulman (1986; 1987), I reject the philosopher's definition—validated true belief—and will use a more operational one. Knowledge is what people have when they "know that" or "know how." Again in following the seminal work of Shulman and his colleagues I refer to several categories of teacher knowledge, specifically those laid out by Wilson, Shulman, and Richert (1987) and reexamined by Grossman (1988). These authors have identified the following seven categories: knowledge of pedagogy; knowledge of curriculum; knowledge of learners; knowledge of the context of schooling; pedagogical content knowledge; knowledge of content; and the knowledge of educational philosophies, goals, and objectives. Although the PTARG teachers told stories that relate their knowledge in each of these categories, three in particular were emphasized: content or subject matter knowledge, pedagogical content knowledge, and general pedagogical knowledge.

Trying Ideas

Receiving knowledge through the stories of others is only one way that these physics teachers learned more about teaching. Their knowledge also increased by trying for themselves what had been suggested by others. Many of these suggestions came from the other teachers in the group, but there was also much that came from the wider educational community, including that of educational research. It is important to make clear that although I was a link to that world of educational research, I did not make suggestions as to how the teachers might change their practice based on my knowledge of that research. The teachers' knowledge of new ways of teaching were from sources external to PTARG, such as professional journals and meetings and various in-service programs.

It must be remembered that because there was communication among the teachers, they told each other of those externally generated innovations, their successes and failures with them, and asked for suggestions from the others about ways that they could improve the implementation of those innovations.

Systematic Inquiry

During the academic year, the teachers engaged in one collaborative piece of research that involved the entire group. This was an investigation into the teaching of the concept of electric charge. The origin of this inquiry was an agreement made between PTARG and Lee Shulman of Stanford University. At that time, Shulman was involved in a Spencer Foundation funded project entitled "Toward a Pedagogy of Substance," which looked at teachers use of representations:

> *Simply put, neither teachers nor students make sense of the world directly. Instead they construct representations of that world in the form of visual images, analogies, metaphors, stories, and key cases as examples.*
>
> (Shulman, undated)

As part of that research, I proposed to Shulman that it would be worthwhile to have a group of teachers look at their own use of representations. He agreed, and I invited these physics teachers to begin this inquiry. Although the organization of the inquiry and the sorting of conflicting research agendas was problematic, an investigation into the uses of representations in the teaching of the concept of electric charge was begun. This inquiry had three main components: discussions of the ways that the teachers introduced the notion of charge, the development of methods to investigate their own teaching, and an analysis of the data collected. A fourth component would be making the results of this systematic inquiry public. Although most of the meeting time of the last third of 1991-92 academic year was spent discussing how to do this, when given the opportunity at research and professional meetings the teachers chose to report on their experimentation with various forms of pedagogy.

Conclusion

Teachers shared and generated knowledge about teaching, primarily through three mechanisms: the sharing of knowledge through storytelling; trying. in their own classes. ideas that have come from others, both from inside and external to the group; and through systematic inquiry into their own teaching. These three mechanisms are all different aspects of collaborative action research.

The key to the argument is that teachers' knowledge is never divorced from teachers' intentions or actions. That is, what teachers know affects both their goals and how they decide to act in an effort to reach those goals. Although there is not a one-to-one relationship between conscious thought and actions (Searle, 1992), it should be obvious that what people know affects the way that they think and reason about their practice. What this suggests is that when teachers in PTARG listened to another teacher tell a teaching story, the knowledge, or new understanding, gained by the listeners affected their intentions and/or actions. As a result, they might then try something in their classes based, on what they learned from that other teacher in the group. This is what happened with Foreman when he began to have his students write approaches to numerical problem-solving after hearing Moore tell a story of how she does the same. Similarly, Apple began using the file cards to check on student understanding after she heard White tell a story that reminded her of a workshop that she attended in which this technique was presented. She tried it in her classes and reported on in to the group through storytelling. Her tales of success with the technique prompted others to do the same. In addition, it became the principal probe in the group systematic inquiry.

What this suggests is that a process is occurring that is more complex than simple story swapping. It is true that a story told by one teacher often received another story in response, but through this, a complex mélange of knowledge exchange, testing though action, and knowledge generation was created. This mélange is collaborative action research—a way that teachers can improve their practice while coming to a better understanding of that practice.

There is a subtle distinction here. Many would claim that only the systematic inquiry that the PTARG teachers engaged in was action research. That is, action research would be seen as a form of academic research, using the same methods and based on the same methodology as that used by university researchers but done by teachers. Others might make this definition more specific by claiming that what makes it action research is that the subject of the inquiry is the researcher's practice. Action research, and particularly collaborative action research, is a process that originates in the practice of teachers and in the culture of schooling, and thus, is significantly different from either of those two formulations. When teachers engage in collaborative action research they tell stories, they try ideas in their classrooms, and then tell stories about that to other teachers. The result is an *enhanced normal practice*: a way of providing the time, space, and opportunity for teachers to comment, critique, and share the understandings that they have gained from and with others.

Implications

The prevailing models of staff development that pervade schooling are derived from a process-product perspective of educational research (Sparks & Loucks-Horsley, 1990). That is, some treatment is developed, teachers are trained to implement it, and then students are tested for the results of that treatment. When applied to the in-service education of teachers, this model appears as the training of teachers to implement curricula and pedagogy to increase student learning (Joyce & Showers, 1983; 1988). When put into practice, this model is most often realized as outsider experts coming to schools to either train teachers in some new form of pedagogy or to instill them with knowledge derived from educational research. What this current research suggests is that for most teachers, other teachers are an important source of the knowledge that they have about teaching and schooling. In addition, it suggests that an important factor in helping teachers to gain new understandings of their educational situations is a combination of their sharing of knowledge and understanding, and then trying those ideas in their own classrooms. But what is most salient is that much of what has been identified here already occurs as enhanced normal practice.

The implications of this for pre- and in-service teacher education are significant. It suggests that if there is to be lasting effects of teacher education, it should be organized so that there is a combination of the sharing of knowledge about teaching through storytelling and other mechanisms, a trial of ideas from that knowledge, and the sharing of new stories or other forms of narrative about how it progressed. In addition, some sort of systematic inquiry could be a part of this process but only if the questions that are investigated arise from the dilemmas and dissonances of practice.

For science teacher education in developing countries, results of this study suggest that more effort be put into helping teachers to see one another as important resources for self-development. To accomplish this, there might be a need for some to be trained as facilitators. In addition, if outsider knowledge is to enter the discourse and practice of teaching, some mechanism must be developed to make that available to at least some teachers. A model similar to that of the Physics Teachers Action Research Group might be appropriate—teachers meeting on a regular basis to share stories, try out new ideas, and to attempt systematic inquiry into their practice, in an atmosphere that supports critical and dialogical conversations resulting in enhanced normal practice.

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Assessing Prior Knowledge and Its Effect on Learning

Ruth Amir and Pinchas Tamir

Introduction

One of the most often quoted statements in the science education literature is by Ausubel (1968):

> *If I had to reduce all of educational psychology to just one principle, I would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly.*
>
> (p. 6)

This statement has since guided numerous studies, and the importance of Prior Knowledge (PK) to subsequent learning of science is widely recognized. Despite conflicting results obtained in several studies, it seems reasonable to hypothesize that PK affects subsequent learning. The present study describes instruments for assessing PK and offers additional insights into its effect on learning.

Purpose

In the study we address the following questions:

1. What is the level of understanding of several prerequisite concepts prior to studying photosynthesis?
2. What is the relationship between PK and achievement in the pre-test?
3. What is the relationship between PK and achievement in the post-test?
4. What is the prevalence of misconceptions among students with different levels of PK?

Overview of the Study

The study was performed as part of a broader study in which we evaluated the effectiveness of special remedial materials in overcoming problems and misconceptions about photosynthesis among high school students (Amir & Tamir, 1992). The learning materials included a teacher's guide and worksheet for the students. The following topics were included in the learning materials: (a) basic concepts (e.g., energy, food, and autotrophy), (b) photosynthesis and transpiration, (c) photosynthesis and respiration and (d) limiting factors.

Method

Prior to the study of photosynthesis, students responded to a Prior Knowledge Inventory (PKI) comprising 14 concepts. The use of PKI has several advantages: it is easy to construct, does not require a lot of class time to respond and is simple to score and to analyze. At the same time the students were also given a specially designed pre-test aimed at establishing their prior knowledge of several concepts and principles about photosynthesis and its function in the biosphere. The pre-test did not include items dealing with advanced topics such as the biochemistry of photosynthesis. A post-test was given at the completion of the study of photosynthesis, which lasted for about 6 weeks.

Two unique features characterize the whole study and bear directly on the issues discussed in this paper:

1. The participating teachers and students received a detailed report of the results of the PKI and pre-test shortly after they were finished. In this

report, deficiencies in PK, misconceptions, and mastery of certain concepts were indicated for the teachers.

2. The teachers were given a "free hand" to choose whatever worksheets to use with their students. We assumed that the pre-test report would serve as a guide in selecting appropriate worksheets.

Sample

Twenty-three 11th or 12th grade classes (516 students) participated in the study. All of them were specializing in biology. In 18 (out of 23 classes), ecology was studied prior to the study of photosynthesis.

Results and Discussion

Prior Knowledge and Achievement

A stronger relationship was found between PK and achievement on the pre-test than on the post-test. Among the 14 concepts in the PKI the concepts, autotrophy, transpiration, and limiting factor were least understood by the students. The PKI enabled us to group students according to their PK level and compare these groups with one another. This was done through an analysis of variance with the PK levels of each concept (autotrophy, transpiration, and limiting factor) as the independent variable and several achievement scores as dependent variables.

Autotrophy

The achievement, in both pre- and post-test, of students with higher levels of PK of the concept autotrophy is higher than the achievement of those who report that they do not understand or are not sure whether they understand the concept. The amount of remedial teaching was about the same for all levels. Considerable improvement in understanding the concept autotrophy was found after instruction, especially among those who understood it less well when taking the pre-test.

Transpiration

The results for the concept transpiration are somewhat different. At the time of the pre-test there were significant differences among the students according to their PK of the concept transpiration. The post-test results show no such differences. This finding can attest to the effectiveness of the remedial materials in "wiping out" differences in prior knowledge which existed prior to instruction.

Limiting Factor

The results for the limiting factor concept are similar to those obtained for transpiration.

Prevalence of Misconceptions

Another aspect of PK is the existence of misconceptions. From the results we can see that misconceptions were less frequent among the students who had reported that they understood the concepts well at the time they took the pre-test. These results lend further support to the validity of the PKI.

Conclusion

The results of the present study support the validity of the PKI as a measure of PK. The effect of PK on learning is somewhat more difficult to elucidate. According to the findings of the present study, this relationship has two unique characteristics: (a) It is highly concept (content) specific, and (b) deficiencies in PK can be ameliorated by special instruction such as that received by our students in a learning environment that took account of students PK and misconceptions.

Both of these characteristics are congruent with Ausubel's directive "teach them accordingly" and lend support to his theory of meaningful learning.

Two important implications arise from this study. First, students should not be regarded as Tabula Rasa. What they know can be validly assessed and is valuable to subsequent learning. Second, teachers who are informed about their students' PK are better equipped to sequence instruction and deal with specific deficiencies and misconceptions.

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Chapter 4

The Classroom

Introduction to Strand C: A Focus on the Classroom

Reuven Lazarowitz

Symposium C1: New Models for Teaching Learning Settings in Science Classrooms for a Heterogeneous Student Population

The first symposium in this strand presented several issues. The need for considering the heterogeneity of the science classrooms was brought to our attention by Lazarowitz and Huppert, who suggested that one of the ways of relating to the heterogeneity is by more use of the instructional methods of cooperative learning in small investigative groups. This method of instruction, in which students are required to participate in peer-tutoring, enables teachers to prepare learning material at different levels of difficulty and sophistication, so that every student will be able to learn, prepare, teach, and contribute to the learning activities of the group members. This method enhances students' on-task behavior and their academic achievement and improves the classroom learning environment.

Goldberg demonstrated how the use of computers may help the students to establish a correlation between abstract models to phenomena of the real world, as well as enabling students to interact, in a meaningful way, among themselves and with the instructors. New roles for teachers and learners from a critical constructivist viewpoint and social-cultural perspectives on learning science were presented by Tobin. He mentioned that if we expect changes to occur in the classroom, we have to provide teachers with the autonomy to review, for themselves, what happens in their classrooms and the reasons why it happens. Only through these activities of descriptions and interpretations will teachers be able to decide upon the needs and procedures to sustain these changes in teaching practices.

According to Howe, classroom life organization is a factor in the process of constructing knowledge. Student interaction is an effective strategy for increasing student learning and conceptual changes. One may assume that learning that occurs through students' interactions facilitates exchange of ideas and thoughts. Students can verify their knowledge and increase their security by mastering the learning material.

In this symposium, we realized that time has come for science teachers to make use of a variety of teaching strategies to satisfy students' different styles of learning, the demands of different topics, and the personalities of teachers, as well as the heterogeneity of students. These trends raise the issue of disseminating the research findings in science education and their application in classroom instruction. Currently, there seems to be a wide gap between what has been achieved in research and classroom practice. Science curriculum and textbooks are mainly content-oriented only and still do not make use of the available research findings. Science content should be integrated into pedagogical content knowledge (Shulman, 1986). This approach could then be used later, in pre-service and in-service training courses.

Symposium C2: Language and Communication in Science Classroom

Sutton mentioned the fact that, if teachers want to represent the nature of science to learners, they have to indicate in simple words how imagination works and emphasize that the "most objective knowledge has a personal human voice behind it." There are two languages, an exploratory, tentative, interpretive and persuasive one, and the language that is actually more a matter of facts and less exploratory. Students should be encouraged to use words that express their thoughts rather than just "report information." Students have to listen to scientists' use of words to interpret and make sense of things. Bosman raised the issue of quantitative communication skills to be developed by children through the use of sketches and graphs, symbols and codes. Kulkarni presented the problem of the third world countries where, in his opinion, language behavior and lack of language development are affected by the socio-economic situation and result in perpetuating this deprivation. He thinks that language is a social tool before it is used as a language of instruction. The problem of home language versus the language of discourse necessary to conceive and communicate concepts should be of concern for teachers.

Students tend to answer in one word, and teachers should insist on answers in full sentences that derive from the nature of the questions. On the one hand, the voices of the scientists and their ways of using words to express their thoughts and imagination should be brought to students' attention. On the other hand, students' language should be taken into consideration to help students communicate clearly, master science concepts, and express their thoughts in full sentences. Thus, students can overcome background deprivation.

Symposium C3: The Learning Environment in Science Classrooms and Its Effects on Learning

Fraser, Giddings and McRobbie brought to our attention the idea that classroom learning environment has an effect on students' achievements, and that there are relationships among the classroom learning environment and new curricula, teachers' strategies of teaching, and classroom environment. Classroom learning environment is perceived differently by teachers and students. Many studies in different countries have shown that students found that their actual and preferred learning environment differ, which may indicate differences on the teaching methods used in their classrooms.

The instruments used to assess science laboratory environment were found to be valid for high schools and university laboratories, sensitive to gender differences in perception of the laboratory and classroom environments.

Other results indicated that students achieved better results when there was greater congruence between their actual and preferred environment.

Symposium C4: The Effectiveness of Particular Instructional Strategies

In this symposium, the issues of lack of resources, variable training of teachers, and large classes in developing countries were raised by Hofstein and Giddings, who suggested that innovative science teaching strategies may be used to overcome these problems. In their opinion, meaningful learning can occur only in classes where strategies that maximize student involvement in the learning process are used. They contrasted the teacher-centered instructional activities (lectures, discussions, demonstrations) with the student-centered learning activities (inquiry laboratories activities, individualized learning, small group work, computer simulations).

Cohen and Ben-Zvi agreed with Hofstein and Giddings with regard to the teaching of chemistry in high schools, where students improved their performance, and inquiry skills when instructed in a student-centered learning mode. Camino and Calgano raised the issue of the structured activity and role play in the classrooms, when students participate in discussions regarding decision making on controversial aspects of problems.

Finally, the issue of students' size group and laboratory work was addressed by Za'rour, who found that these may be the factors that inhibit proper use of the facilities and active participation of students in the learning process.

Impediments to the Improvement of Teaching and Learning Practices in Science Classrooms in Developing Countries

Kenneth Tobin

Introduction

The students clustered excitedly around a table of fruit. Five students, blindfolded, were tasting fruit and inferring what the fruits were from the flavor. The lesson was a standard activity that had gained popularity in programs like Science 5/13 developed in Britain in the early 1970s. As the students returned to their desks the fruit was left on a table. My eyes glanced over toward the watermelon. It was black, covered with what appeared to be a shimmering cover of watermelon seeds. I walked to the table for a closer look. Flies! More flies per square inch than I had ever seen.

Students began to mill around the table, some of them excitedly tugging at my sleeve. I followed one child past an overflowing garbage can, and beyond that, over the school fence, to a stream polluted with trash from nearby houses. In just a few moments two ideal habitats for flies had been identified by these students. How to control the flies? This, I thought, was a problem that needed to be solved, and one from which students could learn. Understandably the teacher appeared agitated by our departure. He spoke sharply to the students, and they obediently returned to the classroom. My lesson from these alert young learners was over.

The above scenario happened several years ago during one of my visits to a developing country. At the time I was incredulous at the use of curricula resources from countries such as the United States and Great Britain. With science-related problems abounding, the activities taught in the schools I visited were not unlike those taught in any of the "developed" nations. This impression was reinforced in visits to several other developing countries. The science curriculum assumed a form that reflected a culture-free view of science. If an education in science was to somehow connect with the present lives of students and their future lives as citizens, it seemed that the needs of students in developing countries would differ significantly from those of students in developed countries.

Although my experiences in developing countries are limited, several images from four countries frame my point of view. First, in the rural part of one country, I observed irrigation channels used by families for washing dishes and clothes; further along, farm animals drank from the same channel. Second, in the mountains of another country insecticide was sprayed on each side of the road. Some 50 meters behind the person spraying the roadside weeds, and following him up the hill, cows grazed on the freshly sprayed weeds. Third, I saw the deeply scarred face of a range of mountains, caused by open cut mining. Fourth, students enjoyed a swim at a beach that was closed because of pollution caused by the dumping of human sewage into the sea. Would science education lead to different practices in each of these scenarios? Can science education have a role in developing countries so that some of the problems that have already arisen in developed countries can be avoided? Can science education connect with the health, welfare, and aesthetics of the citizenry of a developing country? Can science education connect with the economic, social, and political problems that these countries face in their developing phases?

Questions such as these ought to be addressed by those who shape the educational policies of developing countries. From my perspective, on that day when students were tasting food, they ought to have been learning about flies, where and how they breed, their life cycles, their habitats, and how they fit into the ecosystem. They ought to have been examining the ways in which flies can spread disease, asking questions about possible ways of controlling the numbers of flies, and formulating ways to control the spread of disease via flies. Through a project that is local in its extent, students could extend their understandings to regional, national, and global issues associated with flies and the spread of disease. In this case, the sources for learning would have been numerous and would have spanned a range of diverse social and technological issues.

Activities for students should be potentially meaningful. That is, science activities ought to intersect with the world of the student. This requirement is subtle in many ways. First, and I think foremost, activities ought to be amenable to the extant knowledge of students. What students have to do is given meaning in terms of what they already know. Unless students have the knowledge to make sense of an activity and pursue goals that relate to learning science, the curriculum will be of little benefit to them. Second, if students are interested in the science content to be learned, there is a greater likelihood they will have the commitment to learn and apply what they have learned to meet personal goals. Accordingly, activities should have relevance to the present and future interests of students and their potential roles in the world outside of school.

The notion of curriculum transfer often has been applied in the past. It has been assumed that a curriculum resource developed in the United States or the United Kingdom, for example, could be applied in developing countries. This assumption has problems because it ignores the needs of learners and the culture in which the curriculum, as implemented, is embedded. That is, the beliefs and actions of the participants in a culture are an important dimension to any curriculum. What does a community expect to achieve from science education? What do learners know that will support a curriculum in terms of building science-related understandings? What local resources are available, around which to build a curriculum that is perceived as relevant and that will maximize the usefulness of science as a way of thinking? Transported curriculum materials have been designed to be relevant in particular contexts and draw on examples that assume particular prior knowledge and goals. To the extent that these assumptions apply to a given setting, it is conceivable that teachers and students might benefit from curricular resources developed elsewhere. Accordingly, some of the speakers at the meeting who were advocating curriculum transfer, no matter how well intentioned, miss an important point. A curriculum that is appropriate for students in Memphis, Tennessee, for example, might have little relevance to a student in Eastern Africa. Furthermore, adapting a curriculum from the United States to meet the needs of learners in Eastern Africa is a complex task that will necessitate collaborative efforts of people who have not only a good understanding of a particular science discipline, but also a good knowledge of teaching and learning, and the culture of the intended learners.

The use of advanced technology, such as computers and interactive media affords opportunities and cautions for teachers. The goal for using technology ought to be to enhance learning. Just as curriculum transfer has potential problems, so, too, does technology transfer. It is not just the hardware that is being transferred, but also the cultural dimensions that are incorporated into the courseware that are the substance of advanced technologies. It seems wise to closely examine the assumptions and ideologies that underpin courseware prior to making a commitment to use particular technology to enhance learning. With that caveat, research undertaken in developed countries suggests that computer hardware can promote interactions among students, focus learner attention on important ideas, and assist student in the development and application of powerful ideas. Also, it seems that interactive media can present tasks that students find motivating and challenging. In some instances, the media can be used to fit the capabilities of students to the difficulty of the tasks. Furthermore, the use of interactive media that incorporate computers can facilitate explanations of phenomena in terms of diagrammatic representations of models and can assist students in connecting abstract models and real world phenomena. One interesting dimension involving computers is that they provided a context for meaningful conversations between pairs of students and between students and a teacher.

To what extent are teaching strategies generic and independent of culture? This is an important question to ask in terms of this conference because so many of the papers presented in relation to teaching were based on studies conducted in "developed" countries or were undertaken by researchers from such countries. Indeed, this has been the source of some criticism about the conference and its applicability to science education in developing countries. The ability to generalize is a challenging concept. From an objectivist point of view, the generalization of the findings of a study is claimed by a researcher if certain design conditions are met. If the external validity of a study is high, then the ability to generalize to a population from which a sample has been drawn is considered legitimate. The significant components of the ability to generalize externally are sample size and characteristics of the sample (e.g., culture). From this standpoint, research undertaken in Australia, for example, often is considered transferrable to schools in the United States of America, despite cultural differences in the two countries. However, the same research is usually not claimed as possible to generalize with respect to countries that might be considered developing (e.g., Indonesia), because the conditions that prevail in the schools are manifestly different (e.g., socio-economic conditions are different, and a language other than English is used for instruction).

Interpretive researchers consider the ability to generalize as problematic and leave to readers of the research the issue of whether or not a study is applicable to other contexts. Findings of a study are reported in a context that is "thick" with description to allow a reader to build an understanding of what has been learned in a way that is anchored in context. Efforts are made to ensure that findings are not idiosyncratic of one or two visits to a site but are representative of general patterns that apply to a setting described in rich detail, thereby providing a context in which to embed the findings of a study. Findings must be supported by data from a variety of sources, be convincing in terms of the evidence provided in support of assertions, and be authentic and credible with respect to the perspectives of participants.

The grounded theory that emerges from a program of interpretive research is inextricably linked to the culture that pertained to those studies, and details of the culture are a necessary part of the findings. Accordingly, readers and potential users of grounded theory can make an assessment of the extent to which findings are potentially applicable, and in the settings of practice, site-based users can ascertain whether or not particular findings are applicable. The implication of this perspective with respect to the ability to generalize is that in all stages of the implementation of a curriculum, it is imperative that practitioners reflect on their actions, and thereby ascertain what happens and reasons for what has happened. This requirement goes beyond what is usually meant by action research. What is required here is deliberative reflection on action and interactions among participants to ensure that their own experiences become sources for their learning, in addition to potentially relevant research undertaken elsewhere. The quality of reflection for participants at an implementation site becomes a critical issue for staff development. Teachers, students, parents, administrators, and policy makers are among the groups that need to be considered when plans are made for participants in a curriculum implementation process to be reflective in and on their actions.

Method

Adopting the perspectives outlined above, a synthesis is provided on the papers presented in the teaching strand. I attended plenary and concurrent paper sessions and poster sessions and, on the basis of my involvement in those sessions, I considered the implications for teaching science in developing countries. In addition, at one of the plenary sessions I asked participants to write down what they considered to be the main implications (for teaching science in developing countries) of what had been presented and discussed at the conference. From this list I developed a set of headers that were used as an organizer for a summary presentation at the meeting. These headers also became organizers for developing this paper. However, in writing the paper there were several tensions. First, I had some holistic perspectives that were not represented in the list that I had used in my presentation. These holistic issues related to: teaching "white man's lies," the pejorative character of the terms used in developing and developed countries, and the relatively low participation in the conference of professionals from developing countries. Second, my understanding of curriculum is that it is a concept that is inclusive of the setting in which implementation occurs. From my perspective, curriculum is embedded in culture, and it makes no sense to think of the elements of a curriculum as being separate from one another. Accordingly, to have one strand on the classroom and another on curriculum was something that presented a challenge for me.

Throughout the conference, and as I wrote this paper, I found myself thinking about the notion of developing country. What is a developing country? First, I recognize "developing" in a metaphorical sense. The meaning I give to the term is that, in an educational context, the system is less well developed than systems associated with other contexts that are regarded as developed. A country might be regarded as developing in an educational context and developed in other contexts. Developing countries might be in the initial stages of building their educational systems, or limited economic resources might have restricted development to such an extent that resources available to support learning throughout the country, when compared to the resources available in other countries, are limited. Shortage of resources is likely to be seen in domains such as the education of science teachers, the availability of suitable accommodation for schools, the availability of equipment and supplies, and the availability of suitably qualified consultants. This last example is seen as particularly problematic because the needs of a country with respect to science education depend on the extent to which there are people available who know enough about what might be done and how a science education might contribute solutions to the problems of a nation. If developing countries are to define their own needs, it is imperative that people from those countries are educated in science education so that they can participate as consultants in the process of building a viable program.

Science as "White Man's Lies"?

"Why should we teach white man's lies?" One year after the Conference on Science Education in Developing Countries these words ring in my ears. These words, or words very similar to them, were spoken at one of the plenary sessions at the meeting and represented a point of view of a significant minority of participants. This person was focusing on the contention that science is not a culturally neutral enterprise. For example, what we regard as science in western culture can be regarded in some developing countries as contradictory to customary ways of making sense of everyday phenomena.

Knowledge of science allows an individual to solve problems, give meaning to everyday experiences in an informed way, and participate in the decision-making processes of society as an informed and scientifically literate person. What might be meant when science is described as white man's lies? First, the statement seems to imply cultural disenfranchisement. The speaker does not identify as universal the value of what westerners regard as science. The reference to "white man" draws attention to the fact that science, as we usually represent it in schools, is essentially the creation of white men. Both words (i.e., white and men) are foci for attention. Skin color plays a part because it is rare that we speak of school science in terms of the accomplishments of non-western scientists. Second, the use of the pejorative term "lies" suggests that, in some cultures, scientific knowledge may not be viable as a way of thinking. In other words, scientific knowledge does not allow individuals to pursue their goals and may conflict with other socially negotiated truths of a cultural group.

The question, "Why teach white man's lies?" raises additional questions. Is this a question that ought to be considered when we think of science in developing countries? Is the cultural dimension of science considered when curricula are planned and implemented? How is the extant knowledge of participants in a cultural group considered in relation to the scientific truths that are to supplant the untutored knowledge of students, or is it that scientific truths also will replace some of the tutored knowledge of a cultural group? It is entirely possible that the taught knowledge of a cultural group is as at odds with science as it is socially accepted by scientists. Indeed, superstitions and folk knowledge of people in developing countries are frequently a target for science education. Often, science is seen as a more powerful way of knowing, one that ought to take precedence over other ways of knowing. On such occasions, an individual's ways of knowing and making sense of experience are placed in a position of less power than science as a way of knowing. What makes sense to an individual is to be set aside in favor of scientific ways of giving meaning to experience. If learners do not understand the warrants for scientific knowledge, it is possible that they could regard attempts to teach science as akin to indoctrination or to learning principles of faith.

Whether an individual experiences science, and in the process becomes disempowered, or whether knowledge of science is an empowering experience depends entirely on the manner in which the subject is taught and learned. Science usually is presented as a body of knowledge, facts, principles, and laws that stand as separate from people and as objectified truths about the way things are. Science often is presented as a superior way of knowing, a way of viewing the universe that is not subjective. The uncertainty and tentative character of science that permeate the lives of those who practice scientific research usually are missing from textbook portrayals of the products of science. This approach toward school science is, in many ways, elitist and disempowering to other ways of knowing (e.g., spiritual). Furthermore, the tacit knowledge gained from the experience of living a life in a given cultural context frequently comes into conflict with science as a way of knowing. In such cases, tacit knowledge is classified as incorrect, a misconception, an alternative framework, or a misunderstanding and is targeted for change, even though that knowledge might be viable in the life contexts of individuals.

In developing countries, knowledge of the way things are will be rooted in a history that probably does not resemble the emergence of scientific thinking in western society. When "western-oriented" science programs are introduced, it is probable that there will be a high incidence tacit knowledge of the culture being at odds with official "canonical" science. To what extent should policy makers take these differences into account? From my perspective, the extant knowledge of any learner is of paramount importance when the issue of designing a curriculum is considered. The principal question to be asked is, "How can science education benefit learners?" The goals of science education ought to reflect the culture in which science is to be learned. Accordingly, learners should have opportunities to experience science as a process, learn how to engage in science, frame questions, design investigations, implement investigations, and pursue follow-up problems as they arise. In addition, some involvement with case studies is advocated, in which learners explore the development of science in a specific area, taking the time to study the social context associated with the development of ideas over time. The context would include the people who practice science, the social organization of science at the time specific science knowledge evolved, other social forces in effect at that time (e.g., the church), the political influences on policy and funding of science, and so forth. The scientists who do science should be an integral part of the study of science and so, too, should the voices of the scientists. Instead of teaching and learning science in an objectified and decontextualized form, care should be taken to present science as a human-made enterprise that is influenced by socio-political forces. In a study of science, some insights should be given into the changing nature of knowledge, the necessity of negotiating official canonical knowledge, and the process of building consensus about what is considered within a community to be scientific. It is felt that bringing back the voice of scientists will do much to humanize science and to ensure that science always is seen as a way of thinking of specific individuals, subject to change, and always potentially fallible.

Teaching and Learning Science

The status of teachers with respect to learners is something that cannot be mandated in a culture-free way. For example, although I might advocate a preference for teaching styles that allows students significant amounts of autonomy in particular situations, beliefs about authority in given cultures might be such that students might learn better in highly teacher-controlled environments. In addition, the size of classes and the availability of resources to support learning might be such that teacher-centered and teacher-controlled learning environments are preferred in many situations.

A challenge for teachers is to ascertain how power and control can be distributed between the teacher and students and among students. Research in classrooms in developed countries suggests that there is merit in providing students with some autonomy with respect to the pace of content coverage; the selection of content; priorities among given, often competing, goals; and when, how, and what, with respect to assessment tasks. An optimal learning environment is probably one in which the teacher empowers students to assume control in given situations and the teacher retains control in other situations The type of control envisioned is to allow students to make decisions with respect to their own learning and the assessment of their learning. This is not an unconditional control. If, as a result of monitoring student actions, a teacher decides that the learning environment is dysfunctional, or in danger of becoming so, the teacher can take actions to facilitate the learning of all students.

Traditional approaches to teaching and learning have been consistent with a transmission metaphor, whereby knowledge is seen as a commodity to be transferred from a source to a receiver. Such approaches are usually concerned with transferring specified amounts of content from a source to multiple receivers. The curriculum is planned to cover content and examinations are set to ascertain the extent to which the learner has been able to learn what has been covered. Rigor is conceptualized in terms of the discipline. Certain topics must be covered, and students need to accomplish particular types of problems.

The way science is taught very much determines how science can be learned. For example, if a teacher views knowledge as a commodity to be transferred from sources such as a teacher or a textbook to students who are empty vessels, teaching strategies are likely to be consistent with a traditional transmission style, whereby science is told to students. Such a scenario hardly seems consistent with the metaphor of science as argument.

Imagine how learners would have to be arranged if the goal were for students to learn science as a form of argument. Seats would be arranged so that students could argue, and the teacher's role might be to referee arguments. Students might be arranged in groups to argue the merits of different explanations for phenomena. If this were to happen in an orderly way, there would be a need for students to see one another's faces and to hear one another's point of view. Furthermore, students would have to possess a vocabulary that bridged the language of the home and the language of science.

Another level of science as argument would be the individual. One scenario is that the learner would always be asking for evidence for assertions. Relating evidence to knowledge claims would characterize the study of science. At a whole class level, one can imagine very different discourse patterns to those that traditionally have shaped science classrooms. Students asking questions would be automatic, and the teacher's role might not be to answer them so much as to steer the questioner to sources of evidence for and against the knowledge claim. Such sources could span historical and cultural contexts.

A constructivist view places the needs of learners as the highest priority. Accordingly, efforts are made to take into account the learner's extant understandings in the process of coming to know in a scientific way. Coverage of content becomes less of a priority and is subsumed by the greater concern to ensure that learners understand what is to be learned and can see how it relates to what they know and understand already. The creation of linkages is important in many ways. For example, students need to link at least two linguistic registers. First, the language they have used to make sense of their experiences from soon after birth to the present time needs to be linked to the linguistic register of science. Interconnecting terms from these two registers is seen as an important activity so that students can build semantic networks that will allow them to use language to reflect on their experiences and build scientific knowledge as they live their lives and make a transition to adulthood. It is important that activities are organized to encourage students to engage in explaining, questioning, elaborating, justifying, and evaluating.

Negotiation is an important dimension of a successful curriculum. To what extent do the goals of a curriculum intersect with the goals of a teacher and the goals of students? In my research, I have frequently noted a good fit between the goals of the teacher and the goals of the students. For example, in recent studies we conducted in Australia, it is clear that teachers and students both had the goal of getting through the course with a satisfactory grade. The goal of learning science and making sense of phenomena in terms of science was not a goal that either the teachers or the students seemed to have as a high priority. That is not to argue that teachers would say, for example, that learning with understanding was not a priority for them. If they were asked they would, more than likely, strongly assert that it was a major goal. However, their actions in the classroom were more consistent with a "getting the work done" metaphor. Completion of products and content coverage seemed to be valued goals that were, generally speaking, equated with learning. For the most part, the goals of students were not ascertained, and if they were, it was assumed that students' goals were less important than those of the teacher, who knew better what the goals ought to be. My assertion, which underlines a problem with this belief about goals, is that students will learn in a way that is in accord with their own goals. No matter what the goals of the teacher might be, students learn in ways that are shaped by their own goals. For this reason, it is important to ascertain the goals of students and negotiate those goals, not just on the first day of a course, but throughout the course, as teaching and learning occur.

One dimension of negotiation is for teachers to become aware of what students perceive the classroom to be like and what the students would prefer it to be like. To assist in this purpose, there is a large volume of survey forms available to ascertain what students experience and prefer in terms of a classroom environment. Although these instruments need to be adapted for use in different cultures, the instruments do survey students over many possible dimensions and provide information to teachers that can be the basis for rich conversations that lead to negotiated goals for a science curriculum.

Teaching and learning of science seem to be most effective when teachers allow students to use their everyday language to connect experience and science learning. This is particularly important when the language of instruction is different from the native language of the learners. Students are likely to need particular assistance to make links among the language of home, the classroom, and the science textbook. It is important for teachers to be aware of the significant role of language in relation to learning and to the process of making sense of science. By fostering these links, science can be a vehicle for developing the linguistic capabilities of learners.

The main benefits of arranging students to interact verbally is that each student can be a learning resource for others. Because the language of peers has much in common, it is possible that clarification, explanation, and justification, for example, are more effective when students interact together instead of the teacher interacting with students. In this regard, there is an impressive body of research to support the use of cooperative learning strategies among learners. Typically, these involve small groups of learners interacting with one another and collaborating to build meaning and to share the work, so that tasks are completed expeditiously. Care should be taken to ensure that all students within a group understand what each of their peers is doing toward accomplishing a given task.

One example given at the conference reinforced a problem that might be applicable to certain native languages. For example, some languages, such as Samoan, are not ideal for learning science because precise scientific terms often do not exist in the Samoan language. There are likely to be predictable problems in teaching science in a native language such as Samoan and, in such instances, another language such as English is used for science instruction. When science is learned in a language, such as English, that is not the native tongue, teachers ought to make provision for students to develop understandings through the use of both their native language and English.

It is often stated that a picture saves a thousand words. Although it is acknowledged that the use of diagrams can be of considerable benefit to learners of science, it is important to remember that making sense of diagrams and symbols requires cultural knowledge that cannot be taken for granted. A representation that has meaning in one culture might have quite another meaning in a different cultural setting. Accordingly, textbooks developed in other countries should be carefully examined from the perspective of whether or not students will be hampered in their efforts to construct the meanings intended by the authors of the text.

It has been shown repeatedly that assessment strategies drive the curriculum. That is, students and teachers shape the curriculum to make it possible for students to do well on assessment tasks. Of course, there is no problem with this trend so long as the assessment tasks are authentic. What this means is that assessment tasks should allow students to show what they know about science. Given assessment tasks should permit students to reconstruct what they know in all of its richness. Traditional paper and pencil tasks are inadequate for this purpose, and performance tasks are difficult to design, are culture dependent, and costly to administer. Accordingly, teachers in developing countries have a challenge to develop authentic assessment tools. Use of portfolios and performance-based tasks appeal as just two approaches that will comprise a multidimensional approach to an authentic assessment that is cognizant of the need for each community to develop an approach that meets the needs of the students in that community. Not only do different approaches to assessment change the format of an assessment task, but in some cases, such as when portfolios are used, there is an opportunity to provide students with choices about what artifacts to include in the portfolio, to indicate what learning an artifact represents, and to decide what to put in and what to take out of a portfolio.

The physical milieu also is an important restraint on the way teaching and learning of science can proceed. How much space is available for science activities? Is there room for movement in the classroom? Are there sinks, running water, and a source of power? Are materials and textbooks available to support the curriculum? Is the temperature of the room conducive to concentration and learning? Questions such as these will influence the learning of science just as much as psychosocial dimensions of a learning environment. In circumstances where resources available to support learning are in short supply, careful thought ought to be directed to the task of identifying the components of that which constitutes an appropriate physical milieu that can facilitate learning.

Conclusion

Teaching and learning science are not culture free. Indeed, the meanings of life in classrooms can only be understood in the context of the actions of the participants, and these are inextricably linked with culture. Accordingly, the resources available to guide the development of science education in developing countries are limited. However, that is not to say the situation is bleak. Resources, such as curriculum materials, consultants, and computer software might be appropriate to the needs of a given country, or they might not. In our haste to improve science education in developing countries, it is imperative that we think carefully of the culture of those countries in relation to potentially viable science education programs. Consideration should be given to the possible hazards of employing resources designed for learners in other countries and the use of consultants who (a) may not understand the nuances of the culture of the developing country, and who (b) base recommendations on fallible notions of what is valued and appears to work in other countries. Such resources as curricular materials, consultants, and computer courseware ought to be closely scrutinized and evaluated to ascertain whether or not the resources will facilitate science teaching and learning that are consistent with the needs of the developing country. Curriculum transfer is a misnomer and ought be considered only after careful analyses. A cruel irony is that approaches that are perceived as requiring radical reform and restructuring in countries such as the United States are frequently advocated by consultants as suitable for the educational needs of developing countries.

A similar scenario applies to the applicability of research undertaken in one context to the situations that prevail in developing countries. It is not the prerogative of researchers to make claims about applicability of research in various contexts. Rather, it is for potential users to consider the research and determine whether or not particular findings are potentially applicable. Needless to say, it is a priority for developing countries to establish a research agenda to facilitate the teaching and learning of science. The role of research in improving the quality of science education is at the center of a possible solution to persistent world-wide problems that have characterized the learning of science.

Teaching and Learning Science in New Settings

Reuven Lazarowitz and Jehuda Huppert

Introduction

The teaching and learning of science in high schools today are in a transitory period. Before the 1960s, high-school science curricula were characterized by the emphasis put on the content as a body of knowledge that should be transferred from textbooks and teachers to students. After the 1960s, new curricula emphasized the teaching and learning of science concepts and principles through facilitating students to seek the knowledge by using and mastering science or process skills. But in no science curricula were students' needs considered. With the democratization of secondary education, large numbers of students started to attend high schools, and the learners represented a very highly heterogeneous population. This heterogeneity of students is characterized by different cognitive stages and preferences, learning styles, social background, interests, and needs. Therefore, there is a natural need to address this heterogeneity. The learning theories and modes of teaching and learning of the 1980s and 1990s are characterized by an attempt to meet students' needs.

The science, technology, and society approach (STS) (Hofstein & Yager, 1982), the constructivism and general theories (Driver & Bell, 1986; Osborne & Wittrock, 1983), the individualized approach (Huppert & Lazarowitz, 1990), and cooperative small group instruction (Lazarowitz & Karsenty, 1990) are some of the answers offered to students. In this paper we present how STS and the generic and constructivism theories, on one hand, and new learning settings such as computer-assisted learning, as well as individualized and co-operative small group instruction, on the other hand, may be a partial answer to the learning process of the heterogeneous student population.

Science Curricula and Students

According to Tyler (1950), curriculum goals should reflect the needs of students and society and the subject matter structure. If we accept the definition that curriculum includes the content knowledge and pedagogical knowledge of the subject matter to be taught, then in retrospect, we can argue that although the subject matter content, suggested methods of instruction, and society's needs were taken into consideration in the curricula of the last decades, students' needs were almost ignored.

The definition of the curriculum has different meanings for different people. This paper refers to the curriculum as an entity that has two facets.

1. The curriculum has to include the substantive content and syntax of the subject matter according to:

    a. The knowledge in a specific subject matter, up-dated with the scientific research and society needs; and

    b. The curriculum should include recommended methods of instruction and learning settings, based on learning theories and directed to students' needs. Therefore, this is the point at which curriculum, classroom instruction, the learning process, learning settings, and students' needs should meet.

2. Two important events happened in the last decades:

    (a) High schools were democratized. Almost all young people of school age attend different types of high schools; and

(b) Students seek relevant knowledge and literacy, which are the only vehicles for social movement and the fulfillment of the students' need to improve their life conditions.

But at school, students meet academic curricula aimed to prepare them for academic careers only. Does the high school science curricula meet the requirements raised earlier in this paper? We assume that in spite of the democratization of the society and schools, science curricula writers consider their roles as (a) including science-substantive knowledge and syntax as viewed by scientists, (b) including society's needs, and (c) seeing science curricula as a means of preparing students for academic careers

Science Curricula Before the 1960s and 1970s

Science curricula in the 1960s were content oriented and represented the scientific knowledge as was known to scientists. Instruction was mostly expository.

Science Curricula of the 1960s and 1970s

These years were characterized by the following features, which drove the developers: (a) the need to update the scientific content, (b) teaching science by emphasis on the learning concepts and principles, and (c) teaching science by inquiry

The goals were to help students master inquiry or science-process skills—skills that were aimed at (a) learning science in a way similar to that by which science is made by scientists; (b) affecting learners' attitudes toward the understanding of the process of science; and (c) hoping that those skills would serve students, in their daily lives, in relating to society, life, family, and events with an objective approach. Those curricula were and are academic oriented and are not relevant to most of our schools' student population.

Science and Technology

We live today in a society which is characterized by:

1. An enormous "explosion" of knowledges in science;
2. The development of technology that includes new types of industries, automatization, computers and information;
3. Developments in medical sciences, including the transplantation of human organs;
4. Biotechnology and genetic engineering in agriculture, animals, and human life, factors that may bring an abundance of food and health care to people; and
5. Nuclear energy that, when used properly, may solve the problem of lack of energy.

All these features, when used and applied properly, may improve the living conditions of people in undeveloped countries, as well as in undeveloped areas of developed countries (Project 2061). But these achievements are not available to most of the world's population. Starvation; disease (such as AIDS); lack of energy for people in winter; wars; and insufficient and inadequate training for new types of jobs that will be needed in the 21st century, resulting in high unemployment, are most of society's problems.

These problems require changes in the organization of society, reorganization and proper reallocation of national resources and revenues. Students are aware of these problems, and it may be that one of the reasons for students' lack of motivation for learning science is that in schools, students see the irrelevancy of the academic science curricula to students' own lives and needs. In this paper we address changes in science curricula that educate people toward meeting their needs in the next century.

Problem-Oriented Curricula

We define the new curricula as the third generation curricula aimed toward the 21st century. We characterize these curricula as problem oriented. Science curricula should be related to science and technology as serving the members of the society. The emphasis should be put on the members' needs first and society's needs second.

One of the first instances of this new trend is the STS approach, which, in our opinion, is best represented by Hofstein and Yager (1982), with their stated goals for science education for the future. Science curricula for the next century should relate to:

1. Preparing students for academic careers;
2. Meeting students' pragmatic needs;
3. Bringing to students' attention that by learning science they can have other than academic careers;
4. Educating people as literate citizens, who will be able to function and make decisions in a highly scientific and technological society; and
5. Providing information about available jobs in a society that is changing technologically.

We need to find models of teaching and learning settings based on learning theories. These models will be used to educate learners to absorb new knowledge, to cope with new technologies, and to be able to adjust to societal changes. These curricula should be individually oriented to meet students' different abilities and needs, as well as group-learning based to enable students to master social skills that will be needed by the students to equip them to as part of workers' teams in high-tech industries, hospitals, and other professions.

In science curriculum development two components must be considered, if we want to be relevant to both students and society: learning theories that are available and learning environments or settings.

Learning Theories

New science curricula must consider the constructivist theory. In contrast to the transmission view of teaching, the constructivist approach focuses on learners constructing their own understanding and on the social interactions that take place in the classroom during the learning process. The understanding and mastery of knowledge are obtained by the learners who are actively engaged in constructing meaning by bringing their prior knowledge and development to bear on new situations (Driver & Bell, 1986; Driver & Oldsham, 1986).

Social interactions in the classroom occur when students negotiate their understanding by engaging in class discussion and exchanging ideas (Prawat, 1989; Tobin, Brisove, & Holman, 1990) in small group settings. In the small group settings, students discuss their tasks, learn together, exchange ideas, and experience peer tutoring (Lazarowitz & Karsenty 1990; Lazarowitz, 1991).

Driver & Bell (1986) outlined six main issues that are emphasized by a constructivist view of the process of learning:

1. Learning outcomes depend on the knowledge, purposes, and motivation that students bring to the learning situation;
2. Learning involves personal construction of meanings;
3. The construction of meaning is a continuous and active process of mental activity;

4. Learners evaluate constructed meanings and consequently reject or accept them;

5. Learners have the final responsibility for their own learning; and

6. There are patterns in the types of meanings that students construct because of shared experiences with the physical world and through natural language.

In our opinion, the learning settings in which the constructivist approach can be implemented and in which students can construct their knowledge through social interaction is the cooperative small group approach to learning and instruction.

Science-Technology-Society (STS)

The STS approach provides a philosophical framework that will redefine school science curricula. According to the position paper *Science Education for the 80s*, the NSTA Board of Directors stated that "the goal of science education during the 80s is to develop scientifically literate individuals who understand how science, technology and society influence one another." The main points raised were: (a) how special content and process of technology can be combined with the general purposes of science education; and (b) how one can integrate relevant social, moral, and ethical problems into the science curriculum.

Holman (1987) suggested two approaches: (a) integrating technology applications into the science curriculum, which represents the main core course; or (b) emphasizing the technology applications or issues as the main core course beside the science topics, which are derived from them and are added at relevant points. This way, the course is built of everyday experiences in a social, environmental, and technological context from which scientific ideas were drawn. The Salters Chemistry course (Smith, 1988) is an example of the application-first approach. This chemistry course is constructed around relevant chemistry topics integrated in everyday experiences familiar to school students and does not begin with chemical facts and principles.

In biology, Huppert, Simchoni and Lazarowitz (1992) developed a course, Human Health and Science, based upon the application and issues first approach. The course contains five modules, and each module includes topics from different sciences and technology topics, demonstrated in Table 1.

STS topics	Description
Biology	Digestion and absorption; Sugar metabolism
Chemistry	Structure of sugars and fats; Cholesterols
Physics	Heat and temperature; Energy in food
Technology	Recording metabolic rates; Modern agriculture technology; Society Obesity; Anorexia Nervosa; Dietary habits; Malnutrition

Table 1. Module 1—Human Energy Expenditure

Individualized Instruction

The individualized audio-tutorial method of instruction was developed primarily for college use (Postlethwaite, Novak. & Murray, 1972). This method consists of a set of structured learning activities that are based on discrete modules. Students pursue the learning process individually and at their own pace. The learning activities require students to read parts of texts, teacher-written learning materials, workbooklets, and journal articles. The learning materials are presented in a fashion that replaces teacher-student verbal interactions. Students have to manipulate and examine models, view slides and films, listen to and follow directions from tape recorders, and perform laboratory experiments. Teachers are available to guide students and to encourage students who encounter difficulties. In an individualized method, the learning process is student-centered, and students are expected to be responsible for their own learning.

The advantages that this method may have for students, teachers, and science classrooms were described by Smiley, Bush, and McGraw (1970) and Novak (1970), who mentioned that this method allows students to progress at their own pace and makes it suitable for teaching heterogeneous groups. The individualized approach to learning involves the use of various kinds of educational technology as well as the individualized performance of the different learning tasks.

Lazarowitz and Huppert (1982) reported that the individualized audio-visual method was effective in increasing the achievement and motivation of kibbutz junior high school science students in Israel. This study showed that the introduction of instructional methods, focusing on students' individual styles and rates of learning, would change the "normal" bell-shaped curve of the distribution of grades. Tamir & Amir (1975) also found that the motivation and the learning achievement among primary school pupils increased when studied in an individualized method.

The individualized approach had positive effects on the academic achievements of girls. More details about the method and study's results of implementing this mode of instruction can be found in Huppert and Lazarowitz (1990). There are some doubts about the effectiveness of individualized instruction in a mixed-ability environment, especially for the able students (Hacker & Rowde, 1993; Sands & Hull, 1985).

Computer-Assisted Learning

Using the computer for content instruction is known as Computer-Assisted Learning (CAL) or Computer-Assisted Instruction (CAI). The use of the computer affords the learner the opportunity to be actively involved in the learning process, because the computer can be used either in groups of two or three people or on an individual basis. The computers allow students to progress at their own pace, thus having an important implication for the gifted learner as well as for the slower one. Computers can be used to simulate real objects or events when there is a shortage of time or equipment, or where there is an opportunity to raise the level of instruction to a higher cognitive level.

The use of computers enables remedial education and may help students develop creative abilities; as a result, changes are to be expected in students' cognitive and affective domains. The research outcomes indicate that the use of CAL improved the academic learning by below-average and average students at the middle school level (Becker, 1983) and encouraged gifted primary school students toward further learning (Adams & Batcheller, 1993). Improvement in achievement associated with the introduction of CAL has been reported by Burns & Bozeman (1988).

The use of CAL on an individual basis increased the teacher-learner interaction, and students' learning motivation was enhanced (Erickson, & Shore, 1993; Schofield, 1991). Computer simulations were found to enhance students' active involvement in the learning process and may also raise the cognitive level of instruction (Hounshell & Hill, 1989, 1984; Rivers & Vockel, 1987). It was also reported that problem solving can be enhanced by using computers (Cognitive and Technology Group at Vanderbilt, 1993; Simmons & Lunetta, 1993). Intelligent Computer Assisted Instruction programs in biology (Dori et al., 1992) can be used successfully at the high-school and university level.

Cooperative Learning

The cooperative learning movement dates back to the desegregation process in junior-high schools. Initially, the main goals of cooperative methods, such as the jigsaw (Aronson et al., 1978); group investigation (Sharan & Hertz-Lazarowitz, 1980); learning together (Johnson & Johnson, 1975); Student Teams Achievement Division (STAD); and Teams-Games-Tournaments (TGT) (De Vries & Slavin 1978; Slavin 1978) were to facilitate positive ethnic relationships and to increase academic achievement in heterogeneous classrooms. These co-operative methods were widely adapted in elementary schools.

In the last decade, cooperative methods have reached high-school science classes world wide. The common feature of the cooperative method is that students learn and prepare for examinations together. Studies using different methods of cooperative learning in small groups in junior- and senior-high school science have shown that students' academic achievement was significantly higher in earth science (Humphreys, Johnson, & Johnson, 1982) in chemistry, biology and physics, (Okebukola & Ogunniyi, 1984; Okebukola, 1985), in biology, (Lazarowitz, Baird, Hertz-Lazarowitz, & Jenkins, 1985; Lazarowitz & Karsenty, 1990; Lazarowitz, 1991; Watson, 1991), and in physics, (Scott & Heller, 1991).

Working in groups in junior-high school biology laboratory and classrooms enhanced learning and research skills; students developed reporting skills and displayed enjoyment and greater understanding (Walters, 1988). Group learning induced the creation of a supportive climate in learning, organization, responsibility, and division of work (Tingle & Good, 1990).

Other studies reported that "on-task behavior" of students instructed in cooperative modes in biology was significantly higher (Lazarowitz, Hertz-Lazarowitz, Baird, & Bowlden, 1988; Rogg & Kahle, 1992), and students gained in mastery of inquiry skills, improvement of the classroom learning environment, and self-esteem (Lazarowitz & Karsenty, 1990). Two more studies reported that students with a prior preference for cooperative learning who were instructed in a cooperative mode achieved significantly higher than students who preferred the cooperative learning but were taught in a competitive mode (Okebukola, 1988); students who learned in cooperative small groups achieved significantly higher in principles, questioning, and recall tasks but not in application (Okebukola, 1985).

In the cognitive domain, the cooperative mode of learning helped to reduce students' work, to understand better and to master skills of teaching, listening, and standing in front of a class. In the effective domain, students made more friends and practiced more helping behavior and social skills.

It is our intention in this paper to raise the issue of matching curriculum to students' needs. Science curricula and textbooks for the twenty-first century should present the content in a didactic mode, making use of learning theories and instructional methods. Science curricula should present students with concepts and principles from a historical perspective and show students the wide range of career opportunities that are available for literate citizens.

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The Use of Computers to Promote Learning in the Domains of Geometrical Optics and Electric Circuits

Fred Goldberg

Introduction

We developed a classroom environment consisting of an integrated set of activities centered around group discussions, computer programs, and laboratory experiments, all aimed at promoting the learning of physics ideas. These activities are incorporated into a physics course for prospective elementary teachers. The course has two major teaching and learning goals. The content goal is to help students understand and apply conceptual models to explain a wide range of observable phenomena in the domains of light, color, electric circuit, and magnetism. The metacognitive goal is to help students become more aware of, and to take more responsibility for, their own learning (Gunstone, 1992).

We have initiated a number of classroom activities to achieve the content goal. In one type of activity, pairs of students work interactively with computer programs. The programs focus on phenomena, challenge current thinking, and promote development of target ideas (which we refer to as "powerful ideas"). In a second type of activity, small groups collaboratively design actual set-ups to accomplish assigned tasks. These tasks are interesting to the students and provide opportunities to discuss and apply the powerful ideas to novel situations. Finally, in a third type of activity, we require our students to write several lengthy explanations for homework. These assignments provide the opportunity for students to apply the powerful ideas and to communicate these ideas to peers.

There are a number of classroom activities aimed at achieving the metacognitive goal. The computer programs mentioned above consistently prompt students to ponder various questions and, therefore, promote active participation. The explanation assignments mentioned are evaluated in class by a small group of peers. This mechanism provides the opportunity for students to discuss ideas and to become aware of others' thinking. Each day, students write and submit a journal entry in which they are asked to reflect on their learning of that day. These are read by the instructor, who makes comments and returns them to the students the following period. Finally, we have students do a research project that requires them to reflect on their own learning about a topic, and to investigate, through administration of interviews designed by themselves, others' thinking about that same topic. In this paper we focus on both the content and metacognitive roles of the computer programs.

In trying to design this course around constructivist and conceptual change strategies (Scott, Asoko, & Driver, 1992), we were confronted with a tension between letting students use and develop their own ideas, and promoting a set of ideas that are consistent with those accepted and used in the scientific community. We describe below how we have tried to reach a compromise that draws heavily on the use of the computer to help students develop a set of powerful ideas that are meaningful to them. Each conceptual model promoted in the class consists of a set of defining terms and verbal and diagrammatic ideas. Although the models are more qualitative and less rigorous than the models currently accepted by the scientific community, they are constructed to make sense to the students, to emerge out of discussion, and to enable the students to account for a wide range of phenomena.

General Characteristics of Computer Programs

We have developed a set of computer-videodisc programs in the domain of geometrical optics (Goldberg & Bendall, 1992) and a set of graphics-oriented computer programs in the domains of electric circuits and magnetism. Pairs of students work on these programs in a special computer room that is adjacent to a wet laboratory room. We have 15 full computer-videodisc systems. The students use the table space next to their systems to perform experimental observations that use simple apparatus and that are keyed to the programs.

We summarize here five important features that are common to all the computer programs.

Elicit and Challenge Students' Existing Knowledge

Each program consists of a set of tasks in which the student is asked to predict what happens if a change is made in a physical system. For example, in the optics program, the student might be shown a video picture of a set-up with a light bulb, converging lens and screen, and also a view of what is seen on the screen, which in this case is a sharp inverted image of the bulb. The student might then be asked to predict what might happen on the screen if part of the lens were covered with an opaque card. In the electric circuits program, the student might be shown a pictorial representation of a circuit with several batteries and bulbs and be asked to predict how the brightness of each bulb might change if one of the bulbs were unscrewed from its socket. In each case, the two students working on the program discuss the question and explain their thinking to each other, often drawing on their prior (or current) knowledge to guide their thinking. The tasks are carefully sequenced to build on the students' evolving knowledge. Later tasks present new challenges to the students, requiring them to modify or extend their existing knowledge.

Promote Development of Powerful Ideas

Many of the computer task questions are designed to challenge the students' own ideas. The outcomes are often a surprise to the students and provide some motivation for them to consider changing their ideas. To promote a change to the target ideas, the feedback provided for each task question asks students to compare their predictions and reasoning to that provided in the feedback. At appropriate times we introduce a powerful idea (usually containing both verbal and diagrammatic information) that can be used to explain the phenomenon of interest. A list of powerful ideas is available to the student as a pull down menu, but specific ideas only become accessible at appropriate places in the program. To help students recognize that the powerful ideas are fruitful, when pondering a new task the computer often suggests that previous powerful ideas could be used to guide thinking in the new situation. In this way, we promote the development of a limited number of ideas that collectively can account for a wide range of new phenomena.

Facilitate Making Explicit Connections Between Conceptual Models (Diagrammatic Representations) and Real World Phenomena

Scientists often use diagramatic representations to help guide their thinking about phenomena. To help students develop this skill, the computer program enables them to draw diagrams right on top of, or along side of, video or graphic pictures of apparatus. For example, in the optics program on shadows, the student is shown video pictures of both a top view and front view of two light sources, an opaque card, and a screen. Both darker (umbra) and lighter (penumbra) shadow regions can be observed on the screen. The students are asked to predict what will happen if the two sources are moved further apart sideways. They are also asked to draw a diagram to help guide their thinking. One of the students then uses the mouse cursor to draw light rays from the assumed new positions of the sources past the object to the screen, delineating the predicted new shadow regions. Upon command, the computer then actually shows the sources moving and the students can observe how the actual change in the shadow region matches their diagrammatic predictions.

In the electric circuits program, the students construct a diagram of a circuit in which arrows are drawn to represent current, and lines of varying thickness are drawn to represent voltage (actually pressure in our conceptual model). Students use their diagrammatic representation of the electric circuit conceptual model to guide their predictions. They then compare their diagrams and predictions with those provided for feedback and with what they observe when they make the corresponding changes in their own apparatus, which is along side the computer.

Promote Meaningful Conversations Between Student Pairs

The computer allows students to represent their ideas diagramatically, using drawing tools on the computer screen. The symbols so constructed provide a common meaning for abstract terms. For example, in the electric circuits program, the students construct explicit representations for current and voltage (electric pressure). This helps them differentiate these two concepts. In the optics program, the students construct light rays to represent the behavior of light. In both cases, once the students have drawn the representations they often point to the symbols on the computer screen and gesture with their hands when discussing their ideas with each other. Explicitly representing their ideas on the screen also helps reduce demands on the students' working memory as they try to use the ideas to reason about particular task questions.

Facilitate Effective Interaction Between Students and Instructor

The diagrammatic representations drawn by the students on the computer display provide a window into their thinking. This not only facilitates meaningful conversations between the students themselves, as suggested above, but it also facilitates effective interaction between the instructor and the students. When the students call the instructor for help on a particular task, the instructor can look at what the students have drawn on the computer screen and infer the probable difficulties that need to be addressed.

Conclusion

In this short paper we have summarized some of the common features of a series of computer programs that we have developed to facilitate learning of certain topical areas in physics. These programs are an integral part of a learning environment in which students also work on experimental design tasks, write extensive explanations and collaborate on their evaluation, participate in large group discussions, and have numerous opportunities to reflect on their learning.

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Critical Perspectives on Constructivism, Power and the Mediation of Science Learning

Kenneth Tobin

Introduction

During the past decade, practitioners in a variety of fields have embraced constructivism as a theoretical framework on which to base some of their activities. Not surprisingly, different parts of the theory appeal to different practitioners. For example, many science educators throughout the world have studied alternative frameworks in science and conceptual change. These practitioners focused on the importance of prior knowledge in learning. The trend for so many practitioners to describe their theoretical rationale in terms of constructivism led to the emergence of a number of adjectives to characterize the particular brand of constructivism that was utilized in particular situations. von Glasersfeld (1992) uses the term radical constructivism to emphasize that knowledge could not be separated from knowing. The term radical is used as a counterfoil to those who see constructivism mainly or only in terms of learning being built on prior knowledge. In this weak form, constructivism is referred to as trivial constructivism.

An examination of the views of those who have used constructivism (e.g., Bauersfeld, 1992; Saxe, 1992; von Glasersfeld, 1992; Wood, Cobb, & Yackel, 1992) leads me to a synthesis position that knowledge is personally constructed but socially mediated. That is, knowledge only exists in the minds of cognizant beings, but cognizant beings only exist in a socio-cultural sense. From the outset, an organism constructs knowledge in the presence of others who are able to perturb the environment in such a way that a learner's experiences are constrained by the presence of others. The newborn infant learns, with the assistance of others, to make sense of the signs of the culture, which would not exist without the existence of the culture. Accordingly, the constructions of the individual are constrained by the perturbations that become a part of that individual's experience. A concrete example of this process is the use of language, which is a tool to facilitate communication among participants in a society. When a learner thinks in terms of language, the thinking is a social process even though it is occurring within the mind of a single individual.

All individuals construct their own environment, which includes those with whom they interacts. Thus, individuals construct speakers and listeners and assign roles to those with whom they interact. When we think of knowledge, it is convenient to think in terms of both the individual and the social components. Just as it is sometimes useful to think of an electron as a particle and at other times a wave, so it is sometimes useful to think of knowledge as an individual construct and at other times as a social construct. But at all times, knowledge is both social and individual, a dialectical relationship existing between the individual's contribution to knowledge and the social contribution. To those who want to give greater emphasis to one than the other, this may seem a paradox. However, to those who are comfortable with multiple ways of representing reality, it is acceptable for knowledge to be considered in complementary ways. The recognition that knowledge has both individual and social components that cannot be meaningfully separated enables us to construct science learning environments where multiple ways of knowing (i.e., women's ways of knowing, indigenous people's ways of knowing) are sought and valued.

Evidence of scholars emphasizing the social aspects of constructivism is clearly evident in the work of Cobb and Saxe (e.g., Saxe, 1992; Cobb, 1990). As Cobb and his colleagues pointed out, it is not helpful to think of the personal and social emphases as an either/or dichotomy. Rather, both have important roles in thinking about knowledge, knowing, and teacher and learner roles in classrooms.

> *... it is useful to see mathematics as both a cognitive activity constrained by social and cultural processes, and as a social and cultural phenomenon that is constituted by a community of actively cognizing individuals.*
> (Wood, Cobb, & Yackel, 1992, p. 3)

Saxe (1992) noted that for Piaget, the socio-cultural processes were largely not analyzed. His preference was to build a theoretical framework for knowledge that emphasized the social and cognitive components. Saxe makes a compelling case for a problem-solving approach to the learning of mathematics, in which students are involved in structuring their own problem. In his two case studies, the emphasis was on finding a coherent solution to a problem rather than remembering how to apply a recipe to obtain a solution. Indeed, in Saxe's studies, more interest was focused on learning mathematics to be "street wise" and to negotiate effective deals in the commercial sense. In Saxe's subsequent classroom studies, he used a game format to enable students to construct goals that are not directly related to mathematics. To achieve these goals it is first necessary to learn and apply mathematical knowledge. Saxe concentrated his framework on the notion of goals. Cognitive goals emerge through an individual's daily participation in cultural practices. In attempting to accomplish these emergent goals, children generate new knowledge linked to social and cultural life. According to Saxe, individuals construct novel understandings as they attempt to accomplish goals rooted in both their prior understandings and their socially organized activities.

Constructivism: Method or Referent?

Some authors (*e.g.*, Fosnot, 1992) use constructivism to represent a method of teaching whereby the teacher bases what happens on beliefs that are consistent with constructivism. What they mean by this is that constructivism has been used as a referent to build a classroom that maximizes student learning. Typically, the teacher takes account of what students know, maximizes social interaction between learners such that they can negotiate meaning, and provides a variety of sensory experiences from which learning is built. Another example of this practice is seen in Russell (in press) where some teaching practices, such as lecturing, are regarded as having little value compared to alternatives such as small group learning or interactive discussions that are "constructivist" in nature. This position, although understandable, reduces constructivism to a set of methods and diminishes its power as a set of intellectual referents for making decisions in relation to actions. Just as constructivism can be used to explain how students make sense of experience in interactive discussions or in small group problem-solving activities, so too can constructivism be used to explain why learning occurs in lectures and how lectures can be adapted to improve the quality of learning.

Wheatley (1991) described approaches to curriculum that have been carefully built with constructivism as a referent. Known as problem-centered learning, students work together in small groups making meaning of tasks and setting out to solve problems that are perplexing. The teacher in such classes has an important mediating role, ascertaining what students know and structuring tasks such that they can build knowledge structures that are commensurate with knowledge of the discipline. Wheatley described how students negotiate meaning in small group situations, and then negotiate consensus in whole class settings. The teacher's role is to monitor student understandings and guide discussions so that all students have opportunities to put language to their understandings and to engage in activities such as clarifying, elaborating, justifying and evaluating alternative points of view. Such visions of classroom learning environments are exciting and appeal as viable alternatives to those so often reported in studies of learning in traditional classrooms (e.g., Tobin and Gallagher, 1987). However, as appealing as these alternative visions of classroom learning might be, to label them as constructivist tends to mask an important application of constructivism.

Constructivism, as a set of beliefs about knowing and knowledge, can be used as a referent to analyze the learning potential of any situation. For example, constructivism can be used to explain why certain students have been successful in learning science in contexts where teachers lecture day after day and students listen and copy notes until their hands ache. To be a viable theory of knowing, constructivism must have explanatory power in all situations where knowledge is constructed or cognizant beings are deemed to know. Similarly, constructivism ought to be useful in predicting how any given set of circumstances might be changed to improve the opportunities of people who wish to learn in such situations. For example, if a biology department has a policy that all classes contain at least 200 students, it is probably not feasible to think in terms of Wheatley's problem-centered learning. However, from a constructivist perspective, learning can be thought of as a social process of making sense of experience in terms of what is known.

To improve learning, therefore, a teacher might consider how to improve the quality of each of the four components (i.e., social process, making sense, experience, extant knowledge) given the constraint of 200 or more learners. Similarly, in countries such as Taiwan, where class sizes of more than 50 or 60 students are common, teachers can think in terms of improving the quality of social interactions, providing a range of meaningful experiences to each learner, and making it possible for all students to become aware of their relevant prior knowledge and to apply that knowledge to the process of learning. Constructivism, as a reflective tool, empowers teachers and enables them to fashion learning activities to the circumstances in which they find themselves. Thus, teachers can focus planning and implementation strategies on the needs of learners as they understand them from a constructivist perspective.

In contrast to the use of constructivism as a method is the notion of constructivism as a tool for critical reflection. As such, constructivism can act as a referent for deciding which teacher and learner roles are likely to be more productive in given circumstances. Such use makes it possible to plan and implement activities that are postulated to enhance learning. Constructivism tends to provide different angles on thinking about educational problems. For example, in teacher education, the question of how prospective and practicing teachers can learn to teach science and mathematics needs to be answered. Traditionally, the question has been addressed in terms of what we know about teaching and learning, as if the knowledge exists as a body to be discovered or learned by teachers. Research findings are regarded as contributors to this body of knowledge. Accordingly, solutions to the problem are framed within a set of assumptions that a body of knowledge exists, and learners (in this case practicing and/or prospective teachers) can come to know this body of knowledge by interacting with it. The focus is on the interaction between disciplinary knowledge and the learner.

In contrast, two questions are of significance from a constructivist point of view. What does the learner already know about teaching and learning, and how can this knowledge be represented? The associated set of questions relates to the process of making sense of experience. What experiences should teachers have to enable them to build an understanding of teaching and learning? Finally, it seems as if teachers need time to make sense of their experiences. That is, they need time to process things themselves and then have time for such cognitive activities as clarification, elaboration, justification, and consideration of the merits of alternatives. From a constructivist point of view, the emphasis is on the teacher as a learner, a person who will experience teaching and learning situations and give personal meaning to those experiences through reflection. At that point, extant knowledge is connected to new understandings as they are built from experience and social interaction with peers and teacher educators.

Constructivism and the Curriculum

Thinking of science from a constructivist perspective helps science educators decide what might comprise a science curriculum. Because all knowledge must be individually constructed, it makes no sense to begin by thinking solely about the disciplines of science in the absence of learners. A learner has to make sense of science through an existing conceptual structure. Whatever science knowledge is constructed will be an interpretation of experience in terms of extant knowledge. Accordingly, two questions are fundamental: first, what experiences should be provided to the learner to facilitate learning; and second, how can the learner represent what is already known to give meaning to these experiences? The familiar debate in science education over whether to emphasize concepts or processes has little meaning from a constructivist point of view. Making sense of science is a dialectical process involving both content and process. The two can never be meaningfully separated. The process skills can be considered thinking processes, such as using the senses to experience; representing knowledge through language, diagrams, mathematics and other symbolic modes; clarification; elaboration; comparison; justification; generation of alternatives; and selection of viable solutions to problems.

A curriculum is conceptualized as a set of all learning experiences. Although broad, this definition is consistent with constructivism, because it does not regard knowledge as separate from the knower and the culture in which learning is to occur. In the past, objectivist ways of thinking about an existing body of knowledge to be learned resulted in curricula that were thought to be transferable to sites in greatly differing contexts. When teachers and learners adapted the resources to fit local needs, the designers of the materials viewed this as "implementation infidelity." From a constructivist way of thinking, a curriculum is embedded in culture and cannot be separated from culture, which includes other learners, the shared "taken-for-granted" knowledge of the culture, myths, customs, taboos, and history. Also to be considered are the social-political-economical milieu and the influence of others such as parents, administrators, and teachers.

The teacher's role is to mediate the learning of students. This assertion should have an important influence on the way teachers think about teaching. To begin with, the focus ought to be on the learners rather than the discipline. This is in contrast to what Tobin and Gallagher found when they did a case study of a group of Australian teachers to find out what happened when they implemented the science curriculum (Tobin & Gallagher, 1987). Teachers in this study focused on content coverage as one of their highest priorities. They planned with this in mind and stuck to the plan to the best of their abilities. They changed topics at the scheduled time, without respect to the extent to which students had learned what had been covered. If teachers see themselves as mediating the learning of students, two critical components of their role are to monitor learning and to provide constraints so that student thinking will be channeled in productive directions. To undertake such a role, teachers must interact with students to a greater extent than in traditional classrooms to ascertain what they know and what they are thinking. The interactions can begin with the goals of the curriculum, which ought to take account of the goals of the students. Too often there is a wide discrepancy between the teacher's goals and the students' goals. Many studies have revealed a less than optimal level of student engagement in science classes. In very few classrooms has the majority of students been motivated to learn science for most of the time. With few exceptions the students do not appear to be in class to learn science. Perhaps this problem can be overcome, to a degree at least, if teachers begin to negotiate the goals of the curriculum with students.

As a mediator, the teacher needs to ensure that students are provided opportunities for quality learning experiences that provide a solid base for learning with understanding. A constructivist perspective suggests that teachers can enhance learning in the ways mentioned above, and by constraining experiences, to provide students with a scaffold to build knowledge in directions that would not be possible without the influence of a teacher. (It needs to be clarified that the teacher mentioned throughout this section might be a student/learner who already knows about particular content.) In any classroom, there will be the potential of using peers as tutors to enhance the learning of those who do not yet understand specific content. The process benefits those students who can learn through the constraining assistance of peers; it also benefits the tutors, because they have an opportunity to clarify and elaborate their knowledge and to represent it in a variety of ways, including the assignment of language to specific science knowledge.

Other metaphors, such as the teacher as provocateur, can bring into focus the variety of productive roles available to teachers. The provocateur may be seen as a master fencer engaged in a struggle with students, thrusting at times, defending at other times, but always making visible the skills that make the provocateur a master fencer. Thrust, defend, defend, thrust; the master and student engage in earnest struggle intent on the goal of becoming a more expert fencer. The teacher contributes a great deal and is exhausted by the effort, and in like manner the student is stretched to the limit in a process in which no one is hurt, mutual satisfaction is attained, and the gap between the current skill level and what is needed to be successful is always managed in such a way that it is elusively beyond the student.

What are the essential requisites for student learning? Constructivism suggests that learning is a social process of making sense of experience in terms of what is already known. In that process learners create perturbations that arise from attempts to give meaning to particular experiences through the imaginative use of existing knowledge. The resolution of these perturbations leads to an equilibrium state whereby new knowledge has been constructed to cohere with a particular experience and prior knowledge. Because of the importance of students testing the viability of knowledge claims, teachers must consider how to provide opportunities for such testing through negotiations with students and by providing opportunities for problem-solving.

There are other things a teacher can do to promote the learning of students. Planning and implementing tasks is an important role, and teachers should remember that they can only constrain the thinking of students. For example, if the teacher decides to assign activities related to electrochemical processes, then students will spend some time at least thinking about electrochemical processes. To be more specific, if the teacher asks students to discuss the definition of oxidation in small groups, then students will think about oxidation and begin the process of making sense of that concept. The teacher is not transferring knowledge to anyone, but by assigning a particular activity the teacher is allowing students to construct certain experiences rather than others. If students do as the teacher wishes, their thinking will be constrained by engaging in the activity, and the chances that they will learn about oxidation are increased.

In the classroom, teachers should provide opportunities for students to represent their knowledge in a variety of ways throughout the lesson by writing, drawing, using symbols and assigning language to what is known. Student thinking needs to be stimulated by providing time to think: students need time to engage in the processes required to evaluate the adequacy of specific knowledge, make connections, clarify, elaborate, build alternatives, and speculate. Accordingly, teachers should use an average wait time of more than three seconds during explanations and interactions with students (Tobin, 1987); during lectures, at least 2 minutes of every 10 should be provided for interaction with peers (Rowe, 1983). For example, after 8 minutes of lecture and whole class interaction, the teacher might ask students to discuss linear motion with the person sitting at the next desk, with the purpose of writing three questions for which they do not have answers. This example highlights the time students need to clarify lesson elements and make connections with what they know already; it also shows that an important part of learning is identifying questions that need to be resolved to better understand given science content.

In my experience, it is most unusual to find teachers who require students to generate questions and seek answers to them. Constructing questions might be one way for students to build conceptual conflict, and seeking answers to them might begin the process of resolving the conflict. The use of groups has been discussed extensively elsewhere (e.g., Linn & Burbules, in press); accordingly, I will not provide a full rationale for group work here. However, group discussions can play a significant role in the learning of students by providing time for interaction with peers to answer student-generated questions, clarify understandings of specific science content, identify and resolve differences in understanding, raise new questions, design investigations, and solve problems. Group interactions also provide a milieu in which students can negotiate differences of opinion and seek consensus.

A most significant role of the teacher, from a constructivist perspective, is to evaluate student learning. In a study of exemplary teachers, Tobin and Fraser found that these teachers routinely monitored students in three distinctive ways: they scanned the class for signs of imminent off-task behavior, closely examined the nature of the engagement of students, and investigated the extent to which students understood what they were learning (Tobin and Fraser, 1987). If teachers are to mediate the learning process, it is imperative that they develop ways of assessing what students know and how they can represent what they know.

A social perspective on learning draws attention to the fact that all learning occurs in contexts that are inherently political and historical. The hegemony of society is represented in curricula and in the knowledge constructed by participants. Accordingly, as teachers mediate in the learning of students, it is imperative that thought be given to the relative power between participants in the culture. Who should have power and associated control in specific situations? If we are to have schools there will always be situations in which power must rest with teachers and administrators. Social order requires such to be the case. However, from a learning perspective it is clear that power and control must also be with learners, in many situations. Of course, it is not that teachers must have power or students must have power. Both teachers and students must have the power to maintain environments that are conducive to learning. What is at issue is the dialectical relationships between the control exercised by students and the teacher, and the extent to which emancipatory and technical interests are represented in the curriculum. These are areas that need to be carefully considered from a constructivist perspective (Tobin & Tippins, in press a,b).

Reform of Science Curricula

In traditional classrooms it made sense for teachers to have control over students in most cases. The common sense underlying control being with the teacher is grounded in objectivist beliefs about the nature of knowledge. If teachers have the knowledge to be transmitted to students, who do not have that knowledge, then classrooms need to be set up to enable the transmission process to be efficient. Students need to listen, think, and absorb the knowledge. Quietness is the essence of the traditional classroom, allowing these important processes to occur. However, as a teacher I can well remember the great importance of attaining control of students in the first several weeks (minutes) of the year and then relaxing control so that students had areas of autonomy, but that law and order were maintained in the classroom. In Grundy's terms, technical interests based on rules predominated in the initial part of the year, as teachers asserted their right to be in control. However, as students became knowledgeable of the rule structure and learned to adhere to it, teachers allowed emancipatory interests to surface in defined areas. At times it was even permissible for students to speak to those near to them. A good class was characterized by a "working hum." If the teacher left the room for a short period, it was expected that the classroom atmosphere would not change appreciably. The working hum was recognition that students needed to do some things that involved talk, so long as the talk did not disrupt the work and learning of others. There was a place for group work, individual activities, and whole class activities. Attaining a balance between control with the teacher and control with the students was a critical factor in classrooms. The best classes were characterized by a respect for rules and were not disruptive. Other classes were characterized by constant challenges to the authority of the teacher and disruption to the learning process.

A part of the folk lore of teaching is that one can judge the teaching effectiveness of another by walking down the hallway. What is implied in this myth is that the amount of noise emanating from a room is a direct measure of the position of the equilibrium between teacher and student as far as control is concerned. Indeed, many teachers still judge the effectiveness of themselves and colleagues as teachers in terms of the extent to which they can control students. The relative balance between technical and emancipatory interests defines an equilibrium that is of critical importance as far as learning in the sociocultural context of a classroom is concerned. The position of that equilibrium is probably not the same for each class; will depend on characteristics of the community, school, class, teacher and students.

Accordingly, in any attempt to describe what is happening in a classroom, or to prescribe how the learning environment might be improved, it is imperative to describe the relative emphases on technical and emancipatory interests. Such descriptions ought to recognize that technical interests have a place in the curriculum and will always be present. Similarly, there will be areas in which students need autonomy to learn with understanding. Furthermore, if a classroom is to evolve from its present form to a more optimal balance between technical and emancipatory interests, the starting point for the change is the prevailing conditions. If those conditions are to change, there will need to be a commitment to personal change from all participants involved in the relevant culture, a negotiated vision of what the class should look like in terms of technical and emancipatory interests, and regular reflection on the progress the class is making towards attaining its goal of changing the learning environment. Because the position of the equilibrium will differ for each class, it is inappropriate for an outsider to decide, *a priori*, on the ideal state.

The vision of the ideal state, and the state that is attained at any time, will reflect the beliefs and actions of the participants in the culture. There will always be a dialectical relationship between the new practices and the old (Tobin, Tippins & Hook, in review). The old will always be a lure to participants in a culture because these former beliefs and practices allowed them to attain particular goals that are still attractive. For this reason, it is imperative that participants in a culture continue to discuss their goals and the progress they are making toward the attainment of those goals.

Discussions with teachers on how to improve learning might begin with learning, as has been my contention for many years. However, the social organization of teachers and students is of critical significance. In any social organization it is import to examine power and control. It is my contention that issues of learning cannot be meaningfully separated from issues of power and control. This is because learning is inherently social. The reform of science education will necessitate re-examination of the dynamic interrelationships between teachers, students, and other "participants" in schools and classrooms. Of particular significance in these examinations will be dialectical relationships between beliefs about power and control and beliefs about knowledge and knowing (i.e., the power-knowledge dialectic). Identification of salient roles of teachers and students; associated beliefs that take the form of metaphors, images and metonymies; and subsequent deconstruction of them in terms of the power-knowledge dialectic are expected to be essential ingredients in the process of reforming science curricula.

Conclusions

Readers ought not gain the impression that I am advocating a universal truth to replace objectivism, a now invalidated truth. On the contrary, constructivism is conceptualized as a set of beliefs about knowing that has the potential to facilitate different ways of thinking about education, of framing problems, and of formulating answers that extend into areas not considered when objectivism was used as a referent. As I have thought about constructivism, I have come to realize that it is not a unitary construct. Daily, I learn something new about constructivism. Like the bird in flight, constructivism has an elusive elegance that remains just beyond my grasp. However, I have learned to think of constructivism as a referent, not the only referent for our professional actions, but nonetheless important. Over time I have noticed how constructivism has become relevant to one situation after another; however, it is not universally and automatically used as a referent. So many of our actions are based on other referents, not all coherent with constructivism. Sometimes the epistemology of action is inconsistent with constructivism, usually because the conscious referents being used are belief sets related to control or constraints.

As our professional goals change, so, too, do the aspects of constructivism that seem most applicable to the problems that confront us. And as multiple referents become applicable to given problems, additional beliefs are included with constructivism as referents. Accordingly, beliefs about control have become so intertwined with constructivism that I began to use the term "critical constructivism" to include the self-regulation that reveals the psychological, ethical, moral, and political intertwined with the construction of knowledge (Tobin & Tippins, in press a,b). Providing learners control over their own learning and knowledge began to be more important as I used constructivism as a referent to think about teachers using their knowledge to think about curriculum reform. Rather than having two separate theoretical frameworks, it was clear that there was only one, no longer radical constructivism, but nonetheless a coherent derivative. Similarly, the social component of constructivism has been so important to me that I gave greater emphasis to it, the individual and social components being parts of a dialectical relationship, where knowing is seen dualistically as both individual and social—never one alone, but always both.

By way of conclusion, it is my contention that constructivism is an intellectual tool that is useful in many educational contexts. Using constructivism as a referent has led to many changes in our roles as teacher educators and researchers, and as we have watched the evolution of science teaching during the past 5 years, I have observed that teachers who learn to use constructivism as a referent begin a journey of educational improvement that is comprehensive and on-going (Tobin, Tippins, & Hook, 1992). I do not claim that use of constructivism as a referent is the only way to initiate changes of such a comprehensive and significant scope, but from our experience I can assert that constructivism can assume a dialectical relationship with almost every other referent in a process that culminates in a coherent world view consisting of compatible referents for action.

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New Models and Settings for Learning Science: Teaching for Conceptual Change in Chemistry

Ann Howe

Introduction

Chemistry is perceived by large numbers of students as difficult, arbitrary, and of little use in everyday life. Although thousands of students are enrolled in chemistry classes at large universities, only a handful major in chemistry; it has been suggested that introductory chemistry courses have the effect of turning students away from further work in science (Rickard, 1992). In universities in the United States, chemistry is typically taught in large classes, often classes of several hundred students, with no opportunity for interaction between instructor and students or among students themselves. Students sit passively taking notes as the instructor lectures and works problems on the blackboard or overhead projector. Weekly recitation or study sections, each with a small number of students, were intended to provide an opportunity for questions and discussion, but in common practice, a teaching assistant works problems while students take notes, and no meaningful interaction occurs. The lack of interaction, the competition for grades, a student's class notes that look like "an early Greek inscription" are memorably described by Tobias (1990).

Another problem that has caused concern is the evidence from a large body of research that misconceptions in all areas of science persist in spite of instruction. One student gave expression to what many believe when she said, "You can take a [science] course and never really understand it and still do OK. That happened to me in chemistry" (Tobias, 1990, p. 78). These problems have not gone unnoticed by chemists or science educators, many of whom have recognized the need for change (Bodner, 1992; Marek, 1986) and have sought to find ways to improve the teaching and learning of chemistry (Basili & Sanford, 1991; Gabel & Sherwood, 1983; Gabel, Sherwood, & Enochs, 1984), focusing both on concepts and problem solving.

Classroom structures that promote interaction and cooperation among students seem to hold some promise for addressing both the affective and cognitive problems that have been noted. This is a model of classroom instruction that is by no means new.

Vygotsky, among others, can be cited as stating theoretical bases for using interactive strategies. Cognitive conflict is central to Piaget's view of knowledge construction, and social transmission of ideas is central to Vygotsky's view of learning. During the past two decades, cooperative learning has been used and studied extensively in primary and elementary school classrooms (Slavin, 1989), but studies of its use in secondary or tertiary level science teaching have only occasionally been reported.

This paper describes some work in which teacher-structured student-student interaction was used as a classroom strategy with the aim of promoting conceptual change in chemistry. For the purposes of this presentation, conceptual change will refer to a process in which the learner restructures knowledge related to specific concepts in chemistry, giving up incomplete concepts or misconceptions and forming new or revised concepts. Presumably, but not necessarily, the new or revised concept will be closer to the concept currently held by scientists.

The first time we explored the use of a planned interactive strategy in a chemistry classroom was in a secondary school classroom some years ago (Howe & Durr, 1982). The strategy was peer interaction, and its use in this context was an exploratory extension of an earlier study with young children. Because the theoretical framework was Piagetian, the aim was to determine whether the interaction between two peers of different cognitive levels would stimulate conceptual change. In language that seems dated today, we said that cognitive conflict occurs when new information conflicts with the learner's "previously held notions or assumptions" and that "learning occurs if the old, less adequate notion is changed to a more general, more adequate form to accommodate new information" (Howe & Durr, 1982, p. 226). Today we would probably use the current vocabulary of misconceptions or alternative conceptions in place of "less adequate notions" and conceptual change in place of "change to a more general and adequate form."

The experiment had several parts, but what is of interest here is the procedure for structuring peer interaction and the outcome. Peer interaction was used after an instructional unit had been taught and a concept-based unit test had been given. The teacher explained that another test would be given 3 days later and that the higher of the two scores would be recorded. In the experimental group, low scoring students were paired on an individual basis with high scoring students; each pair was assigned problems covering points missed by the low-scoring students on the test. The assigned work was designed to induce cognitive conflict and to engage students' attention for a significant period of time. Each pair had different assignments and were required to agree on and submit one answer for each problem. Several days were allowed for the peers to work together. In the control group the teacher made the same announcement about a subsequent test and used the class time to go over all questions and to assign problems for individual work. The sample was very small (only six high-low pairs in the experimental group), but the results were interesting. On a 15-item test, the mean score of low-scoring students in the experimental group went from 9.8 on the first test to 10.8 on the second; the comparable change in the control group was from 8.4 on the first test to 6.9 on the second. This study had the incidental result that many of the students liked working together and continued to study together after the experiment was over.

A more persuasive study using an interactive strategy was conducted with students in a university introductory chemistry course. It was designed to test the hypothesis that students working in cooperative problem-solving groups would show greater conceptual change than those working individually. All students attended a lecture delivered to a large audience; the experiment took place in four weekly study sections of 21 students each (N=84). Sections were randomly assigned to experimental or control groups. Students' initial concepts, or misconceptions, were determined by administering the Mole Concept Test, an instrument developed for the study and found to have a reliability of 0.81. In the experimental groups, pre-test scores were used to form cooperative working groups of four students each, such that the average pre-test score was similar for all groups. Students in both groups received instruction in procedures and expectations for cooperative group work or for individual work. The experimental treatment consisted of four recitation class periods, one week apart, during the period in which students were attending weekly lectures on the mole and related concepts. Student groups in the experimental classes solved assigned problems cooperatively and submitted one set of solutions at the end of each session; those in the control group worked on the same problems individually and submitted individual solutions. In all classes, an instructor was available to answer procedural problems and encourage students but not to provide answers or significant cues. The sessions were observed by outside observers and audiotaped to ensure that the instructor and students performed the procedures as intended. At the end of the four sessions the Mole Concept Test was administered again.

Scores were analyzed by means of a 2 x 2 repeated measures ANOVA followed by Tukey t-tests. The results can be summarized as follows, using $p \leq 0.01$ as the decision rule:

1. Experimental and control groups had statistically similar scores on the pre-test.

2. Scores of students in the control group did not improve significantly in spite of four weeks of instruction.

3. Post-test scores of students in the experimental group were significantly higher than their pre-test scores and were significantly higher than post-test scores of the control group.

When the pre-test and post-test scores of the small cooperative groups were examined more carefully, the data showed that three of the groups did not accomplish conceptual change. Verbal interaction patterns of the groups, available on the audiotapes, were then analyzed using a system devised by Basili and Sanford (1991). Chi square analysis showed that successful groups engaged in significantly more behavior characterized as "promoting change" and less behavior characterized as "impeding change" than the unsuccessful groups.

A third study, which has only recently been completed and for which data have not been completely analyzed, also used students in an introductory university chemistry course. It took place over a 6-week period in the recitation sections of a chemistry course that enrolled several hundred students. The instruction in lectures and in all recitation sections was on learning to solve stoichiometry problems, a major focus of instruction in introductory chemistry and a stumbling block for many students. The purpose of the experiment was to test the idea that students who worked together in pairs to solve assigned problems would become more proficient at solving stoichiometry problems than those who worked alone and, as a corollary, that these students would change their concept of problem solving.

Nine sections (total N=210) were randomly assigned by section to treatment. Students in one group attended and took notes while an instructor worked problems; students in the second group were given a series of aids or "scaffolds" to help them work the problems and worked individually; those in the third group were given the same aids and worked in pairs. The scaffolds emphasized concepts underlying the problems rather than algorithms. Although preliminary observation indicated that students in the peer-interaction group were more engaged in learning, better understood the concepts related to the problems, and the majority of these students reported preferring to work with a peer than working individually, there was no difference between groups in score on the final test. Thus, the main hypothesis was not supported, and we are still in process of studying the transcripts of classroom interaction and other data to determine whether or how students' used concepts in problem solving and whether their concepts of problem solving itself changed.

Studying conceptual change in classroom settings is a challenging task. Conceptual change is a complex process that depends on many factors that can be assessed or diagnosed but are not within the control of the teacher. On the other hand, the way the classroom is organized for learning *is* the prerogative of the instructor, who can leave students to work alone and compete with each other, which is the usual way, or, as an alternative, set up a system in which students work together in pairs or groups and interact freely about their work. Our studies suggest that such methods may promote conceptual change and are certainly as effective as the traditional methods. Interviews, questionnaires, and anecdotal evidence in all three of the studies described here indicate that most students prefer an interactive learning environment to the isolation that is the norm in secondary and tertiary science classes. There is little to lose, and there may be much to gain in breaking away from our old model of the individual student working alone, competing with peers for grades and missing the opportunity to see science as a cooperative venture.

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Recovering the Voice of the Scientist—A Reconsideration of the Nature of Language and Its Role in Scientific Discovery

Clive Sutton

The Nature of Science and the Nature of Language

In most countries, science teachers are concerned about teaching not only the content of scientific knowledge but also something of the nature of science itself and its methods of inquiry. Their endeavors to do so have often led to a simplistic idea of "scientific method" as a process of straightforward "discovery" of clear "facts" directly observable from Nature. This image—variously described as "Baconian," "inductive," or "naive empiricist"—does not stand up to modern scholarship in the history of science. It totally neglects the role played by language in formulating what will be regarded as a significant "fact," and shows little of the process whereby the tentative ideas and claims of individual scientists are transformed into accepted public knowledge.

To project an image of science consonant with current understanding, it is necessary to shake off the "language-free" myth about science and to re-connect particular scientific thoughts with the people who first spoke them and who negotiated their ideas in scientific meetings and journals. Advantages to be expected from such an approach include not only a more adequate image of how science works, but also the re-humanizing of its study, with less alienation among those pupils who see it as mere information of no personal interest. In this paper, I suggest a stronger focus on language as *a medium of interpretation* when scientists face uncertainty, with correspondingly less emphasis on its role as *a system for describing* things about which we are certain. Some traditional distinctions between personal and impersonal, subjective opinion and objective fact, or between poetic and scientific language will have to be reconsidered and a new account given of the connections between these supposed opposites. This paper is a contribution to the development of such a new account, and it concentrates on historical examples to show how figurative or metaphorical language is transformed into taken-for-granted descriptions of truth. If we, as teachers, can make ourselves more conscious of this process, then our pupils may be able to hear again the voice(s) of the scientist(s) who developed some of our most important ways of talking; perhaps our students will then gain better insight into the nature of science as a human enterprise.

Poetry, Metaphor, and New Ways of Seeing

Writing to a colleague in 1845, Michael Faraday explained his search for new ways of seeing the topics that fascinated him, as follows:

> *You can hardly imagine how I am struggling to exert my poetical ideas just now for the discovery of analogies and remote figures respecting the earth, sun, and all sorts of things—for I think that is the true way (corrected by judgment) to work out a discovery.*
>
> (Michael Faraday (1845)
> in a letter to C.F. Schoenbein)

Do we get a sense of that way of working when we pick up a modern account of what Faraday helped to establish? School books tell us how the "field" around a wire can be traced with iron filings, or how the "ions" in a certain solution "migrate" to the "electrodes," as if these had always been obvious things that anyone could "see." The textbook writers present them with a certainty that seems to deny that anything like a poetic imagination was involved in coming to speak in that way. Yet it was, and if we are to represent the nature of science more effectively to modern learners, we have to teach them how that imagination works, and show these learners that even the most objective scientific knowledge has a personal human voice behind it.

Figuring Things Out With Words: A Basic Scientific Activity

Any figure of speech, such as Faraday's talk of something "migrating" in the solution, is a manifestation of a basic sense-making tendency in human beings. We try out a way of talking that has previously been used only in some other context, and the words help to organize our thoughts and what we choose to notice It leads our attention in new directions, and in successful science it makes us check our ideas until we and others are satisfied that the new way of talking is consistent with good evidence.

To take another example, Torricelli, pondering what held up the mercury in his inverted tubes, found himself writing: "We live submerged at the bottom of an ocean of air" (Torricelli, 1644). The word "ocean: had previously been used mainly in connection with a certain definite watery region (the great outer sea, away from the Mediterranean), and to some extent for a watery medium, but here it was pressed into new usage, transferred to a new context, placed as a metaphor. Torricelli and his correspondents thereby gained a new image of their surroundings and were led to think in new ways. There were and are many implications to explore. Does air extend above us to some definable limit? To a surface? Does it press down on us like water on the floor of the watery ocean? Does it move in similar ways? Not least among the implications in need of exploration is the question of what exactly we mean by an ocean, because as this way of talking about the atmosphere grew in acceptability, there was a broadening of the meaning of the word ocean, and we can no longer say that it properly belongs only to the world of water.

Figures of speech emerge whenever there is something new to be interpreted, or something old to be re-interpreted in a new way. Their production is a key feature of innovation in science. More than this, their shared appreciation is also central for communication with others who have not yet "seen" the new interpretation. Communication is the formation of a community of people who, to some extent, share the same view, and it is more than informing those people. Scientists within the academic societies and teachers in classrooms are engaged in acts of persuasion, with words, to create a new community of thought.

The figures of speech that emerge in the creative scientific imagination are not, as is sometimes thought, mere teaching devices, but are central to the generation of new systems of thought. They include metaphors, such as Darwin's "tree of life," and slightly more cautious similes, such as Hutton's view of the landmass as "like the body of an animal." Their initial effect is to tease the mind into action as one senses a tension and strange interaction of thought in the new use of language. This often leads to the elaboration of the figure into a model, in which some of the points of interaction are elaborated, or into a very explicit analogy that can be analyzed point by point as a comparison.

A Metaphor

Darwin's *Tree of Life*, branching through the generations:

> *. . . the great Tree of Life, which fills with its dead and broken branches the crust of the earth, and covers the surface with its ever-branching and beautiful ramifications*
>
> (Darwin, 1859, end of ch. 4)

A Simile

James Hutton, contemplating erosion of mountains and the formation of new sedimentary rocks, wrote:

> *This earth,* like the body of an animal, *is wasted*

> *at the same time that it is repaired . . . destroyed in one part, but it is renewed in another . . ." "We are led," he said, "to see a circulation in the matter of this globe" (Hutton 1795).*

Products of greater elaboration are described below.

A Model

In the *lock and key* model of enzyme-substrate interaction, the provocative power of the words to suggest an image of a good or poor fit is exploited to examine the idea in steric detail.

An Analogy

Robert Boyle explored his understanding of the spring of the air by considering how a non-compressible wooden block can be changed into a very springy heap of shavings, and he achieved only a partially successful analogy:

> *. . . I have, among other comparisons of this kind, represented the springy particles of the air like the very thin shavings of wood, that carpenters and joiners are wont to take off with their planers . . . And perhaps you may the rather prefer this comparison, because . . . these shavings are producible out of bodies, that did not appear . . . to be elastical in their bulk, as beams and blocks, almost any of which may afford springy shavings ...which may perhaps illustrate what I tried, that divers solid . . . bodies, not suspected of elasticity, being put into corrosive menstruums, . . . there will, upon the ... reaction that passes between them in the dissolution, . . . emerge a pretty quantity of permanently elastical air.*
>
> (Boyle, 1670)

Creativity in science depends especially on metaphors that lend themselves to elaboration into models, from which testable predictions can then be derived. The topic has been extensively explored by many authors since Black (Black, 1962) and Hesse (Hesse, 1966), and the literature has been summarized several times (See Bono, 1990, or Sutton, 1992, ch. 3).

New Ways of Seeing and New Ways of Talking: Science Begins with Re-Description

Many readers of this paper may be familiar with the work of N. R. Hanson on perception and discovery (Hanson, 1969). It is from his analysis of what he called "the linguistic factor in seeing" that we understand scientific innovations in terms of "new ways of seeing as." To talk of the heart as a pump and to see it as a pump is easy today, but before the time of Harvey and Descartes, the power of that way of seeing it had yet to be fully realized. To see it as a well or spring would have been commoner, and Harvey himself saw it in terms of political and domestic economy—the "sovereign" of the body and the "inmost home" (Harvey, 1628) where the blood could recover "its state of excellence and perfection." The move to later alternatives was made much easier, however, by Harvey's main shift of perception: "I began to think whether there might not be a motion as it were in a circle." Seeing the heart as a point in a circuit sharpened for him the relevance of calculating its throughput, and that became a crucial part of his argument. He also attended more closely to the spurting from cut arteries, wondered further about the valves in the veins, and speculated about transport of blood into and out of the seemingly sponge-like peripheral tissues.

New ways of seeing generate animated talk, as people try to share their vision, and plan further inquiries. In this case, the entailments of "circulation-talk" were enough to keep many people busy for a long time. One of the first additional outcomes was Malpighi's identification of "capillary" (i.e., "hair-like") channels linking arteries and veins in the tail of a tadpole. Older ways of talking about the blood and the heart began to fall into disuse, and when Descartes elected to see the whole human body as a set of mechanisms, circulation-talk and pump-talk became standard mental tools. A re-organization of perception that had begun in the minds of a few became the standard way of seeing, available to many.

New scientific insights are re-descriptions of the phenomena being studied. They depend on language imported from some other area of use, in an attempt to understand and re-interpret what is happening. They depend, that is, on metaphor. All around us, in our scientific language, we see the results of similar switches into new ways of seeing, and the talk-systems that go with them: "charges" "flowing" along a wire that seems to act as a pipe, conduit, or "conductor"; "fields" of influence around a magnet; and "pathways" of successive chemical reactions in a cell. Each of those systems in its turn has provided many extra points for scientists to investigate. Even some ways of seeing that have been superseded by more recent scientific thought still persist in the language, for example, seeing "heat" as a fluid that can flow into and out of objects. This was a highly productive branch of scientific conversation in its hey-day, and it led to the development of units for a "quantity of heat" and to the concept of varying "capacities" for heat in different materials ("specific heat capacity"). We find it still in expressions such as "heat flow," "thermal capacity," "heat sink," as well as in the word "conductor" itself.

Although metaphoric re-description is only the first stage in establishing public scientific knowledge, we can show it to our pupils. We can ask them "How did anyone come to talk like this What were the scientists who chose these particular words trying to say? What image did they have in their mind's eye?" We can revive some long-dormant metaphors, and to show that language functions as a flexible medium for interpreting what is hapening. (For a full discussion of interpretive and labeling language in the classroom, and of how to raise pupils' confidence in their own use of language for interpreting and not just reporting, see Sutton, 1992, chapter 7). It is important to keep alive the signals of tentativeness of the originators, in phrases such as "as if . . ." and ". . . as it were . . ." and Harvey's "I began to think . . ." We should show pupils that scientific ideas have been formulated by real people struggling for appropriate words.

Science Continues With Persuasion and Consensus in a Scientific Community

Researchesr with new insights also have to engage in persuasion before their ideas can be accepted as scientific knowledge. What emerges from several decades of scholarship in the social study of science is the importance of the learned societies and journals as new ideas are scrutinized; some are accepted but others rejected. Science is a social activity for the production of reliable knowledge, and it is performed in communities that build a provisional consensus of understanding. This then forms a basis for further semi-cooperative inquiry within the shared framework of thought.

The persuasive devices used by scientists in their writing are many and subtle. They are not only new metaphors, but also, in research reports, signals of caution and tentativeness that are carefully tailored for the potential readership. There is growing literature on the form and function of scientific writing and its place in the development of consensus, in books by Shapin and Schaffer, 1985, Vickers, 1987, Bazerman, 1988, Myers, 1990, and Dear, 1991. (See also Myers, 1992). It has also been shown (e.g., Cantor, 1989) that an account of an experiment is itself an act of persuasion, and not just a report. Persuasion by evidence involves gaining agreement as to what counts as evidence.

One area of interest in all those studies is the status and mode of formation of what people take to be "a fact," because the idea of a firm fact is the central device for achieving agreement. Sometimes, especially in the early scientific societies, the witnessing of an experiment was held to yield incontrovertible facts directly read from the natural world, but the earlier "seeing-as" argument throws doubt on this, because of the effect of the visual switch in shaping what one sees as "being there." The more usual practice in scientific societies is that there is a progression in which some assertion is put forward as a "knowledge claim" and then is gradually transformed to become an "accepted fact."

Early accounts of this sequence, by Fleck and Kuhn (See Fleck, 1978), considered the succession of three different genres of writing: the experimental report in a journal, the research handbook summarizing recent influential studies, and finally the textbook of current science. Each stage offers more definiteness in statement. Phrases such as "It is thought that . . ." or "So-and-so has suggested that . . ." are gradually reduced or omitted as the "fact" becomes something that one no longer needs to justify. As these qualifiers disappear, so does any sense that the ideas were ever the product of a human imagination. The knowledge becomes "objectified." The new facts serve as the starting point for further investigations, and this further reinforces the impression that there is nothing problematic about the facts. They are taken to be features of the real world. Those who were not involved in the hard work of establishing their "facticity" can then easily read the historical process the other way around, as if the facts came first. Thus, the linguistic practices of scientific communities help to sustain the conventional view of science, which suggests that we find some facts and then build our theories to account for them. The success of scientists in getting some claims to achieve the status of facts is closely linked with the impression that these facts are not person-made! The more one learns one's science from textbooks, the stronger this impression becomes.

To give another example, Joseph Black, the Scottish chemist, established the usefulness of a way of talking about heat that included the terms "specific heat" (or as we should say now, "specific heat capacity"), and "latent heat." Textbook authors subsequently wrote that he had "discovered" specific heat capacity, rather than that he and others "constructed" the idea. (See Sutton, 1992, chap 11). More generally, as new knowledge gets taken for granted, phrases like "We have devised a way of understanding such and such . . ." are replaced by "It has been discovered that . . .." Explaining an interpretation (a product of human figuring) is transformed into giving information. To help pupils reach an understanding of science as a human product, we have to restore the interpretive voice behind an idea like Black's, and reactivate the dormant metaphor of the fluid flowing into something with a certain "capacity," even if we also teach them that there are now better interpretations of what is happening when the water in the kettle takes so long to boil.

The Liberalization of Figurative Language as Ideas become "Set" and Taken for Granted

A distinction is sometimes drawn between a "live metaphor" (e.g.,"computer virus") and a "dead metaphor" (e.g., the verb "to test"). In the first case we recognize that a word from biology has been applied in the new context of a computer disc, and whatever someone is trying to say, it isn't meant quite literally. No one is saying that a piece of nucleic acid and protein has got onto the disc. Instead, the expression teases our thought. What features of a biological virus are we to use in understanding the ailment of the disc? Infection? Self-replication? Smallness? Danger? "Live" here simply means mentally provocative. In the case of "to test," the provocation no longer exists for most people. They are unaware of the earlier context of use and the allusion to the "testa" or small pot or cupel in which alchemists assayed their gold by fire to see if any dross would burn off. Gold that had survived the testa meant good and reliable gold, and playful use of the word gave us the phrase "tested gold" and the verb "to test." In Elizabethan England, an expression such as "Thou art tested, and found wanting" would have been a live metaphor, conjuring visions of trial by fire, but for most of us today these associations to the word "test" are not so prominent, even in an end-of-term school test, although "having your brakes tested," or "testing for starch" seem to have only a straightforward and direct meaning.

Although metaphors do die away, they can of course be revived, and for that reason it may be better to speak

Table 1. Features of Interpretive Expressions

A new speculative insight gained by metaphoric re-description of what one thinks is going on	— becomes —>	An accepted new view in the scientific community, with a taken for granted way of talking
Claims	— becomes —>	Facts
The ideas of human beings	— becomes —>	Objectified knowledge
Interpretive words	— becomes —>	Labelling words
Tentative constructs	— becomes —>	Re-ified objects
Recognisably figurative expressions	— becomes —>	Terms which have new 'literal' meanings
Live, active, thought-provoking metaphors	— becomes —>	Dead, dormant, unprovocative words-as-labels
"Think of it AS..."	— becomes —>	"This is how it IS..."

of active metaphors and dormant ones. Metahphors fall into dormancy as part of the normal process by which language changes, and new meanings become accepted in common use. The progression from live or active metaphor to dead or dormant one is, in effect, a progression from figurative to literal status. Computer virus is particularly interesting in this respect because the word virus is well on the way to being literalized in the computer setting, the meaning of the word having changed in such a way that for some people the phrase is no longer a metaphor at all. When it was very new, the mental interactions that it provoked worked in two directions. People's understanding of both biological and computer invaders was extended, for example, we became more conscious of Hepatitis B virus as "packaged information." The choice of the word virus for the two situations seemed apt, and we could agree, because of our changed understanding of virus, that the computer invader can reasonably be called a virus. Similarly, when people first spoke of the heart as a pump, the expression probably was not fully literal, for proper pumps were made of wood and brass and leather in those days. However, the semantic field of pump changed to include the heart, and the semantic field of heart changed to include pump, and so now we have no qualms about saying that the heart is a pump. This change from AS to IS, from the merely suggestive "Think of it as . . ." to the very definite "This is how it is . . ." is a further feature of the seeming disappearance of figurative expression when new ways of talking are accepted and totally taken for granted. Many new scientific terms arise in this way, and quickly leave their metaphor-state behind. We can see it again in an expression like "the noble gases," where the word noble—regardless of its origins and the reasons for its choice—now has a fairly precise chemical meaning that we no longer consider metaphoric at all.

Bringing together some of the changes mentioned so far, we can summarize some features of how flexible, figurative, and interpretive expressions tend to get fixed as an area of scientific knowledge matures and becomes taken for granted (see Table 1).

Science converts figurative expressions into accepted systems of speech that are so well supported by evidence and informed opinion that they gain the high status of "correct" descriptions, actual statements of truth rather than human interpretations. These statements—the end-product of science—appear in textbook accounts with the human voice of the originators largely lost. By exposure to such end-products, generations of pupils have been insulated from the debates that occurred in establishing the reasonableness of a particular idea, and some may fail to see language as a medium of interpretation at all. The tendency to regard it in that way has indeed grown as part of a received wisdom about science. Scientific language has been considered as essentially descriptive of things as they are: "a transparent medium for natural facts" (Bazerman, 1988, p. 14). This view can no longer be sustained. Scientific knowledge is not completely independent of the language in which it is stated. Words are not neutral to the facts, but make a particular selection of what is to be regarded as important and, thus, help to shape what we accept the facts to be.

If pupils are to understand the nature of scientific insight, and the problems that are involved in establishing firm knowledge, they also need experience of using language as an instrument of their own thought, in expressions of opinion related to evidence, just as a scientist would. In reading, they should be taught to look for a human voice behind the words, and to read these words as evidence of thought, not just as a report of information. That I am able to write this in 1993 is perhaps an indication of the weakening of the language-independent view of science. We are today more confident of the achievements made possible by some of the scientific ways of seeing, so we don't have to bolster their high status and can afford to explore the human aspects of their development.

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Language and Learning, Home, Classroom, Textbooks

Vinayak Kulkarni

Context

Several third-world countries, along with India, acquired political independence soon after the World War II. One of the major concerns of these countries is to convert their huge populations into people who are capable of generating the science and technology to overcome poverty. Attempts for development in the third world are often thwarted by lack of trained people while, at the same time, attempts to make even primary education universal cannot be accomplished because of lack of development, including communication systems and basic infrastructure for the education system. The problems of education in the third world are, therefore, qualitatively different from those in the industrialized western world. One of the major differences concerns awareness of the role played by language in education. This paper presents the view that socio-economic deprivation seriously affects language behavior, and lack of language development results in perpetuating deprivation.

Meaning of Language Behavior

Language plays a critical role, not only in school learning, but in socio-economic achievement in general. Here, the term language does not refer to the medium of instruction or to the difference between the so-called standard language and its dialect; it refers to language behavior that distinguishes various strata of the society. It is useful to consider the following four stages of language development through which individuals and societies pass. These stages are presented as a working hypothesis. The Homi Bhabha Center for Science Education (HBCSE) has been undertaking several action research projects in which evidence is being collected to test this hypothesis.

Stage One

Stage One consists of familiarity with names of objects and actions (nouns and verbs). Individuals operating in this stage can make statements such as, "the water is cold," or "the fruit is bitter," but cannot make an argument that, "I do not want to eat this fruit *because* it is bitter."

Stage Two

Stage two marks the ability to join two sentences using appropriate conjunctions—and, but, if, hence, since, because, therefore, and so forth. Language behavior at this stage is still restricted to simple situations where one cause leads to one effect. Multiparameter situations are still beyond the reach of individuals functioning in this stage.

Stage Three

It is in this stage of language development that individuals can perceive a multiparameter situation where several causes (or forces) act together and lead to a point of equilibrium that shifts if one or more of the causes (forces) are altered. The perception and description of a complex system, in terms of the response of the equilibrium point to applied forces or changes, is the hallmark of modern intellectual thought. It is not surprising that the development of this stage of language behavior saw, within a short span, the emergence of several conceptual breakthroughs such as Adam Smith's theory of the wealth of nations, Malthus's theory of population, Darwin's theory of evolution, and Karl Marx's theory of social conflicts .

Stage Four

Language, however developed, is incomplete without the mathematics that enables a person to extract an essence (knowledge) from natural experiences and to express it in a symbolic language that can be manipulated further to derive a deeper and richer meaning, which experiences in raw form could never reveal. It is mathematics that enables humans to convert great breakthroughs of the day into the common knowledge of tomorrow, and to achieve accelerated growth of S&T. Mathematics spells the difference between Faraday and Maxwell, Galileo and Newton. In fact, progress in modern science has often depended critically on development of the necessary mathematical formalism to achieve strategic breakthroughs.

The main objective of the social institution called school should be to take its entrants from the first stage of language behavior to the fourth stage. Several experiences gathered in HBCSE's field work will be presented in the context of this framework.

Home

It is necessary to distinguish between human language in its elementary form and the language of discourse necessary to conceive and communicate concepts. The field-work conducted by the HBCSE shows that first generation learners, who constitute the vast majority of student population today, grow in a linguistic environment where the language of discourse is absent. Peer group interaction is hardly any use because all of the members are at the rock bottom. Interaction with adults is confined to primitive commands of "dos" and "don'ts." It is interesting to note that within driving distance from metropolitan Bombay, so rich in public advertisements, billboards, and neon signs, there are hundreds of small villages that do not display a single written message—not even the name of the village.

Classroom

Unfortunately, the teachers (most of whom were recruited recently after the universalization drive was launched) are unaware of the implications of the poor linguistic background of their students. Their teaching continues to be traditional, aimed at the traditional learner receiving considerable input at home. Students, even in grade four, continue to answer questions with a single word. Even more importantly, teachers, unaware of this gap, tend to ask only such questions as can be answered in one word. When teacher training courses conducted by HBCSE focused attention on this aspect, teachers began to insist on answers in full sentences. By grade four some of the students could develop enough language capability to describe and interpret dreams and ambitions, and to present their own arguments such as, "All mammals give milk. But we keep a cow not a cat or a tigress because a cow is docile and more economic."

Textbooks

Studies conducted by HBCSE show that the language level of science texts (Marathi) prescribed for stds. V, VI and VII was higher than that of the corresponding language texts. HBCSE prepared linguistically simplified versions of these science texts, keeping all other factors constant, and tested their effectiveness. The project covered 29 experimental schools and an equivalent control group involving nearly ten thousand students.

Simplifying the language of exposition of science texts led to considerable improvement in pupil performance and to a much better teacher-pupil interaction. However, the most significant finding was the removal of disparity in the performance of students coming from different socio-economic environments such as slums and industrial labor areas, low income backgrounds, and white collar middle class areas. Students from these areas normally perform at different levels. However, with the introduction of linguistically simplified versions, this difference in performance is virtually eliminated. This finding is significant because it shows that a simple step, such as paying attention to the language level of science texts, can help overcome some of the barriers arising out of differences in home background.

The term "language" is not confined only to the written word. Textbooks for children are often illustrated liberally with pictures and diagrams. HBCSE's fieldwork, especially in the non-formal stream shows that it is not correct to assume that illustrations based on conventions like the use of an arrow or cross are interpreted uniquely. Systematic instruction is needed to impart pictorial literacy. This finding is significant because several programs of national importance—family planning, health and preventive medicine, and for improving agriculture output—depend critically on written and pictorial messages. HBCSE is developing materials for introducing pictorial literacy for these programs as well as for formal schools.

Science for Language Development

Although the importance of improving language skills for better science education is appreciated, the role science and mathematics can play in improving language skills is not yet fully realized. These disciplines are ideally suited for demonstrating the correct usage of various conjunctions, precision, and the range of validity of statements. Moreover, situations requiring the use of multiparameter arguments arise more often, more vividly and in earlier grades in these subjects. Science and mathematics, even at an elementary level, can be used in multiparameter arguments occurring in daily life. "Water boils at 100° C" only if it is pure and if the pressure is one atmosphere. All the three angles of two congruent triangles are equal; however its converse is not true. Curriculum designers should use this aspect of science sensitively. In the old days, the focus was on classics. Modern trends highlight science even at the expense of language. What is needed is a boot-strap approach using science and mathematics to introduce pupils to higher language skills that, in turn, could be used for better science and mathematics education.

Symbols and Codes in Children's Language

Luigia Bosman

Introduction

It has been at least 15 years since we began to teach science and technology to primary school pupils; our work has been aimed at helping children develop scientific abilities. Thus, we have had the opportunity to see the difficulties and the needs of children in that age group, particularly when they begin to learn reading and writing, although this process does not yet allow these students to record their experiences and observations in written form.

The project studied the development of quantitative communication skills in young children through the use of different methods of representation, such as sketches graphs, symbols, and codes.

Background

The teaching of science to primary school children, we think, should be aimed at familiarizing the students with the methodological aspects of science such as observations, relationships, and communication of quantitative information. Thus, children should learn how to record their observations so that the obvservations can be remembered correctly, which is particularly important in the cases where observations taken at different times have to be compared.

To achieve this aim, 6-year-old children need a method of representation different from the written language they are learning to use. We did not mean to offer them a ready-made code to learn, but rather to train the pupils to represent graphically what they were doing and to devise signs or symbols to indicate the practical and conceptual operations employed in their work. The apparatus and methods used in the project are presented by giving two examples of activities: "The word game" and "Decorated boards." The results of final tests (in the form of written and oral tasks) are also reported and described.

Example 1. "The Words Game"

The game was based on a rack ordering and sequencing words. The activities were tested the first year with children from three classes of grade 1 (50 pupils in total); in following years it has been proposed to test 600 children in total.

The necessary racks were built by us, and the pupils were involved in preparation of the cards: the students colored and pasted a lot of pictures of animals, vegetables, and clothes onto the cards . They also wrote the corresponding words. One rack was built for each pupil; 150 cards were made for each class. The racks and cards were then used for instructional goals, such as performing the alphabetical ordering of words according either to their first or last letter or selecting words containing **ch, ll, sch** digraph. Later, the pupils were asked to describe the procedure they had followed in sorting out and filing the cards. For that purpose, the students used a sketch.

The pupils were also asked to arrange the cards in alphabetical sequence order. The distribution of their performance was recorded in the form of histograms and analyzed. Besides this task, the children were also asked questions like:

> "How many words begin with B?"
>
> "Are there more words beginning with D than with L?"

"For which first letter are there more words?"

The pupils, in performing their tasks of sorting or sequencing, said "cards" and "words" to denote the name of pictures on the cards. It suggested that the pupils were considering the cards as the material support of both the images and the names of the objects: the words are figure symbols in the same way as the sketches are.

Then the following sketches were introduced:

A.......	represents a word beginning with **A**
..ch....	represents a word containing the **ch** digraph
M......o	represents a word beginning with **M** ending with **o**

Symbols were also used to help the children sort out, from a list, the words containing certain groups of letters.

For example,

The symbol before a graph word points to the presence of **tt** in that word.

The symbol before a sketch word points to the presence of **str** in that word.

Later, the pupils were able to understand and answer all the written questions of the following kind:

Operate on the list of words using the symbols proposed:

...ch... **...str...** **......a** **...gn...**

STAGNO
AGNELLO
STRADA
RAGNO
FINESTRA
CHIESA
ASTRONAVE
CHIOCCIOLA
TESSERA
CHIOSTRO
STAZIONE
STRETTO

In English the text could be the following:

CHURCH
ADMINISTRATOR
CHANNEL
SIGNAL
BIRCH
SIGN
STAMINA

How many have you obtained?

Are there more or less?

Which mark is dealing with more words?

Example 2. "Decorated Boards"

Another activity was introduced: the decoration of wooden boards with colored drawing pins. 12 cm x 12 cm chequered (1 cm x 1 cm) boards had been prepared, into which colored pins were driven.

The first kinds of decoration were in stripes with two colors and in squares like those on a chess-board. Then, to get more complex, decorative motifs with patterns, with which pupils had to work, were drawn on the blackboard. Later, codes were introduced to represent many colors patterns; the motifs were drawn using different symbols to indicate different colors. The pupils then had to transcribe these patterns into colored pictures; afterwards, they operated on the boards. Later, the two-color stripes decorating work was used to realize how many different boards could be obtained by pairing together 4 or 6 colors in all possible ways. Subsequently, the decorated boards were used to train the pupils to guess the symmetry properties of the figures and the regular recurrences of the colour sequence.

After these activities had ended, the pupils were tested in writing and orally.

Example of Written Test

Paul usually eats the cake on Sunday and Wednesday.

Mary eats the cake on Sunday, Monday and Thursday too.

Ann on Sunday only.

Henry on Sunday and Saturday.

Ethel on Sunday, Monday and Friday too.

Questions:

Who eats the cake more often in a week?

How many children eat the cake on Thursday?

On what day do all the children eat the cake?

On what day does not any children eat any cake?

Look at the histogram and verify if what is said is right (figure 3).

Examples of Oral Test

The pupil were given a set of patterns and were then asked to answer questions such as:

For example, look at the figures representing decorated boards and tell me: in which one are the black pins more than the red ones (figure 4).

Justify your answer.

Results of the Written Test

Most of the pupils answered all the questions correctly; only three children did not write the fourth and fifth answers. All pupils but two were able to understand the diagram and to notice two mistakes.

Oral Test Results

Two-color figures: every pupil was able to say whether the black or red pins were the most in each pattern; their answers have been summarized as follows.

1st Figure

The answer was "there are five red and four black equal squares: the red pins are the more."

2nd Figure

6 children answered "the black pins are the most: I just can see it."

30 children answered: the demarcation line between the two sets of pins does not halve the square: three vertices are black, the fourth is red: the black pins are the most."

The remainder of the children gave this answer: in the first row all pins are black, in the second all but one are black, in the third all but two are black. in the last one all pins but one are red: there is no complete row made up of red pins only so the black pins are the more."

3rd Figure

All the children answered: "the pattern is made up of alternating red and black frames, each one inside the other. Since the red frames are always the outer ones the red pins must be the most."

Conclusion

The results obtained in that year and in the next ones indicate that the pupils learned how to give one subject different names in different circumstances, to read histograms and use codes. The practical activities have also had a part in children's intellectual development; we think these have affected the way these children will learn. The pupils answered the questions on the oral test without counting the pins, which seems to suggest that their reasoning paths were the result of their concrete operating strategies.

Finally, we felt the children, using symbols and codes to represent the processes and procedures of their work, were going to see the sense of the written language. Once they were asked to write in words the meaning of some codified expressions they had used in their tasks, most of them gave written sentences without spacing the words. It suggested they were grasping the sense of completeness—that a proposition is dependent on the integral relationship of the words that compose it.

The Learning Environment in Science Classrooms and Its Effects on Learning

Barry Fraser

Introduction

Science educators often speak of the classroom's or school's climate, environment, atmosphere, tone, ethos, or ambiance and consider them to be both important in their own right and influential in terms of student learning. Despite the fact that the educational environment is a somewhat subtle concept, remarkable progress has been made during the last quarter of the century in conceptualizing it, assessing it, and researching its determinants and effects. Although important, educational climate work has been undertaken by researchers interested in a variety of school subject areas; clearly science education researchers have led the world in terms of developing, validating, and applying environment assessment instruments.

Many questions of interest to teachers, educational researchers, curriculum developers, and policy makers in science education can be asked about classroom and school environments. Does a classroom's environment affect student learning and attitudes, and does a school's environment affect teacher job satisfaction and effectiveness? What is the impact of a new curriculum or teaching method on the nature of a classroom's environment? Can teachers conveniently assess the climates of their own classrooms and schools, and can teachers change these environments? What are some of the determinants of classroom and school environment? Is there a discrepancy between actual and preferred classroom environment, as perceived by students, and does this discrepancy matter in terms of student outcomes? Do teachers and their students perceive the same classroom environments similarly? The above questions represent the thrust of the work on science educational environments over the past 25 years and constitute the main areas considered in this paper.

Traditionally, research and evaluation in science education have tended to rely heavily and sometimes exclusively on the assessment of academic achievement and other valued learning outcomes. Although few responsible educators would dispute the worth of outcome measures, they cannot give a complete picture of the educational process. This paper is devoted to one approach toward conceptualizing, assessing, and investigating what happens to students during their schooling. In particular, the main focus is upon students' and teachers' perceptions of important social and psychological aspects of the learning environments of school classrooms.

This paper is divided into five main parts. An introductory section provides background information about the field of classroom environment. A section is devoted to instruments for assessing perceptions of classroom psychosocial environment. An overview is given of several lines of past research involving classroom environment assessments. Consideration is given to teachers' use of classroom environment instruments in practical attempts to improve their own classrooms. Some recent developments are outlined. Finally, some implications of learning environment research for improving science education are listed.

Background

Approaches to Studying Learning Environments

Three common approaches to studying classroom environment involve systematic observation, case studies, and assessing student and teacher perceptions. Perceptual measures form the major focus in this paper, and this approach has several merits (Fraser, 1986).

First, paper-and-pencil perceptual measures are more economical than classroom observation techniques that involve the expense of trained outside observers. Second, perceptual measures are based on students' experiences over many lessons, and observational data usually are restricted to a very small number of lessons. Third, perceptual measures involve the pooled judgments of all students in a class, whereas observation techniques typically involve only a single observer. Fourth, students' perceptions, because they are the determinants of student behavior more so than the real situation, can be more important than observed behaviors. Fifth, perceptual measures of classroom environment typically have been found to account for considerably more variance in student learning outcomes than have directly observed variables.

Historical Background

It is now a quarter of a century since the Learning Environment Inventory was used as part of the research and evaluation activities of Harvard Project Physics (Welch & Walberg, 1972). Around the same time, Moos began developing social climate scales for a wide variety of human environments, including the Classroom Environment Scale for use in school settings (Moos, 1974). The way in which these two programs of research have developed and spawned many new lines of learning environment research is reflected in several comprehensive literature reviews (Fraser, 1986, 1989, 1993; Fraser & Walberg, 1991).

Although this paper focuses predominantly upon the classroom environment work that developed during the previous 25 years, it is fully acknowledged that this builds upon and has been influenced by two areas of earlier work. First, the influence of the momentous theoretical, conceptual, and measurement foundations laid half a century ago by pioneers like Lewin and Murray and their followers, such as Pace and Stern, is recognized (see Fraser, 1986). Second, research involving assessments of perceptions of classroom environment epitomized in the work described in this paper also was influenced by prior work involving low-inference, direct-observational methods of measuring classroom climate.

Distinction Between School and Classroom Environment

It is useful to distinguish the classroom or classroom-level environment from the school or school-level environment, which involves psychosocial aspects of the climate of whole schools (Fraser, Williamson, & Tobin, 1987). Despite their simultaneous development and logical linkages, the fields of classroom-level and school-level environment have remained remarkably independent. It would be desirable to break away from the existing tradition of independence of the two fields of school and classroom environment and for there to be a confluence of the two areas.

School climate research owes much in theory, instrumentation, and methodology to earlier work on organizational climate in business contexts. This point is clearly illustrated by the wide use of two instruments in school environment research, namely, Halpin and Croft's (1963) Organizational Climate Description Questionnaire (OCDQ) and Stern's (1970) College.

The Characteristic Index (CCI) relied heavily on previous work in business organizations. Consequently, one feature of school-level environment work that distinguishes it from classroom-level environment research is that the former has tended to be associated with the field of educational administration and to rest on the assumption that schools can be viewed as formal organizations. Another distinguishing feature is that, whereas classroom-level research has been concentrated on secondary and elementary schools rather than in higher education, a sizable proportion of school-level environment research has involved the climate of higher education institutions.

Measurement Level

Characteristics of the learning environment can be measured through the perceptions of students, teach-

Table 1. Overview of Scales Contained in Seven Classroom Environment Instruments (LEI, CES, ICEQ, MCI, CUCEI, and SLEI)

			Scales Classified According to Moos's Scheme		
Instrument	Level	Items Per Scale	Relationship Dimensions	Personal Development Dimensions	System Maintenance & Change Dimensions
Learning Environment Inventory (LEI)	Secondary	7	Cohesiveness Friction Favoritism Cliqueness Satisfaction Apathy	Speed Difficulty Competitiveness	Diversity Formality Material Environment Goal Direction Disorganization Democracy
Classroom Environment Scale (CES)	Secondary	10	Involvement Affiliation Teacher Support	Task Orientation Competition	Order & Organization Rule Clarity Teacher Control Innovation
Individualised Classroom Environment Questionnaire (ICEQ)	Secondary	10	Personalization Participation	Independence Investigation	Differentiation
My Class Inventory (MCI)	Elementary	6-9	Cohesiveness Friction Satisfaction	Difficulty Competitiveness	
College and University Classroom Environment Inventory (CUCEI)	Higher Education	7	Personalization Involvement Student Cohesiveness Satisfaction	Task Orientation	Innovation Individualization
Science Laboratory Environment Inventory (SLEI)	Upper Secondary Higher Education	7	Student Cohesieveness	Open-Endedness Integration	Rule Clarity Material Environment

ers, or observers to produce distinct variables, each of which has its own significance. Assessment involving student perceptions can be subdivided further into whether the assessment involves the individual student's perceptions or the intersubjective perceptions of all students in the same class. This distinction in past classroom environment research often has been important when choosing an appropriate unit of statistical analysis (e.g., individual student scores or class mean scores; see Fraser, 1986). Because of the great advances that have been made recently in *multilevel analysis*, more sophisticated techniques are available now for analyzing the typical data (e.g., with students nested within classes) found in much research on learning environments. Cheung's (1993) paper in this symposium uses multilevel analysis of data from the Second International Science Study in Hong Kong in examining the differential cross-level effects of the normative and psychological classroom contexts upon within-class science learning processes.

Instruments for Assessing Classroom Environment

This section clarifies the background and nature of several instruments commonly used in prior research to assess perceptions of classroom learning environment. The instruments considered here are the Learning Environment Inventory (LEI), Classroom Environment Scale (CES), Individualized Classroom Environment Questionnaire (ICEQ), My Class Inventory (MCI), College and University Classroom Environment Inventory (CUCEI), and Science Laboratory Environment Inventory (SLEI). Each instrument is suitable for convenient group administration, can be scored either by hand or computer, and has been shown to be reliable in extensive field trials.

Table 1 shows the name of each scale contained in each instrument, the level (elementary, secondary, higher education) for which each instrument is suited, the number of items contained in each scale, and the classification of each scale according to Moos's (1974) scheme for classifying human environments. Moos's three basic types of dimension are *Relationship Dimensions* (which identify the nature and intensity of personal relationships within the environment and assess the extent to which people are involved in the environment and support and help each other), *Personal Development Dimensions* (which assess basic directions along which personal growth and self-enhancement tend to occur), and *System Maintenance and System Change Dimensions* (which involve the extent to which the environment is orderly, clear in expectations, maintains control, and is responsive to change).

Learning Environment Inventory (LEI)

The initial development and validation of a preliminary version of the LEI began in the late 1960s in conjunction with the evaluation and research on Harvard Project Physics (Fraser, Anderson, & Walberg, 1982). In selecting the 15 climate dimensions, an attempt was made to include as scales only concepts previously identified as good predictors of learning, concepts considered relevant to social psychological theory and research, concepts similar to those found useful in theory and research in education, or concepts intuitively judged relevant to the social psychology of the classroom. The final version of the LEI contains a total of 105 statements (or 7 per scale) descriptive of typical school classes. The respondent expresses degree of agreement or disagreement with each statement on a four-point scale with response alternatives of Strongly Disagree, Disagree, Agree, and Strongly Agree. The scoring direction (or polarity) is reversed for some items. A typical item contained in the Cohesiveness scale is: "All students know each other very well." An item from the Speed scale is: "The pace of the class is rushed."

Classroom Environment Scale (CES)

The CES was developed by Rudolf Moos at Stanford University (Moos & Trickett, 1987) and grew out of a comprehensive program of research involving perceptual measures of a variety of human environments including psychiatric hospitals, prisons, university residences, and work milieus (Moos, 1974). Moos and Trickett's (1987) final published version of the CES contains 9 scales with 10 items of True-False response format in each scale. Published materials include a test manual, a questionnaire, an answer sheet, and a transparent hand scoring key. Typical items in the CES are: "The teacher takes a personal interest in the students" (Teacher Support) and "There is a clear set of rules for students to follow" (Rule Clarity).

Individualized Classroom Environment Questionnaire (ICEQ)

The ICEQ differs from other classroom environment scales in that it assesses those dimensions (e.g., Personalization, Participation) that distinguish individualized classrooms from conventional ones. The initial development of the long form ICEQ (Fraser, 1990) was guided by several criteria: the dimensions chosen characterized the classroom learning environment described in the literature of individualized and open education; extensive interviewing of teachers and secondary school students ensured that the ICEQ's dimensions and individual items were considered salient by teachers and students; items were written and subsequently modified after receiving reactions from selected experts, teachers, and junior high school students; and data collected during field testing were subjected to item analyses in order to identify items whose removal would enhance scale statistics. The final published version of the ICEQ (Fraser, 1990) contains 50 items altogether, with an equal number of items belonging to each of the five scales. Each item is responded to on a five-point scale with the alternatives of Almost Never, Seldom, Sometimes, Often, and Very Often. The scoring direction is reversed for many of the items. Typical items are: "The teacher considers students' feelings" (Personalization) and "Different students use different books, equipment, and materials" (Differentiation). The published form of the ICEQ consists of a handbook and test master sets from which unlimited numbers of copies of the questionnaires and response sheets may be made.

My Class Inventory (MCI)

The LEI has been simplified to form the MCI, which is suitable for children in the 8- to 12-year age range (Fraser, Anderson & Walberg, 1982; Fraser & O'Brien, 1985). Although the MCI was developed originally for use at the elementary school level, it also has been found to be very useful with students in the junior high school, especially those who might experience reading difficulties with the LEI. The MCI differs from the LEI in four important ways. First, to minimize fatigue among younger children, the MCI contains only 5 of the LEI's original 15 scales. Second, item wording has been simplified to enhance readability. Third, the LEI's four-point response format has been reduced to a two-point (Yes-No) response format. Fourth, students answer on the questionnaire itself instead of on a separate response sheet to avoid errors in transferring responses from one place to another. The final form of the MCI contains 38 items altogether. Typical items are: "Children are always fighting with each other" (Friction) and "Children seem to like the class" (Satisfaction). The reading level of these MCI items is well suited to students at the elementary school level.

College and University Classroom Environment Inventory (CUCEI)

Although some notable prior work has focused on the institutional-level or school-level environment in colleges and universities (e.g., Halpin & Croft, 1963; Stern, 1970), surprisingly little work that is parallel to the traditions of classroom environment research at the secondary and elementary school levels has been done in higher education classrooms . As one likely explanation for this shortage is simply the unavailability of a suitable instrument, the CUCEI was developed to fill this void and to be used in small classes, but not for lectures or laboratory classes (Fraser & Treagust, 1986). The final form of the CUCEI contains seven seven-item scales. Each item has four responses (Strongly Agree, Agree, Disagree, Strongly Disagree) and polarity is reversed for approximately half of the items. Typical items are: "Activities in this class are clearly and carefully planned" (Task Orientation) and "Teaching approaches allow students to proceed at their own pace" (Individualization).

Science Laboratory Environment Inventory (SLEI)

Because of the critical importance and uniqueness of laboratory settings in science education, a new instrument specifically suited to assessing the environment of science laboratory classes at the senior high school or higher education levels was developed (Fraser, Giddings, & McRobbie, 1992). This new questionnaire, the SLEI, has five scales and the response alternatives for each item are Almost Never, Seldom, Sometimes, Often, and Very Often. Typical items include: "We know the results that we are supposed to get before we commence a laboratory activity" (Open-endedness), and "The laboratory work is unrelated to the topics that we are studying in our science classes" (Integration). The response alternative are Almost Never, Seldom, Sometimes, Often, and Very Often. The Open-endedness scale was included because of the importance of open-ended laboratory activities claimed in the literature. A noteworthy feature of the validation procedures employed is that the SLEI was field tested simultaneously in six countries (the USA, Canada, England, Israel, Australia, and Nigeria) with a sample of 5,477 students in more than 269 classes to furnish comprehensive information about the instrument's cross-national validity and usefulness. Further information about the SLEI is provided in a paper in this symposium (Giddings, Fraser, & McRobbie, 1993).

Preferred Forms of Scales

A distinctive feature of most of the instruments in Table 1 is that, in addition to a form that measures perceptions of *actual* classroom environment, there is another form to measure perceptions of *preferred* classroom environment. The preferred (or ideal) forms are concerned with goals and value orientations and measure perceptions of the classroom environment ideally liked or preferred. Although item wording is identical or similar for actual and preferred forms, different instructions for answering each are used. Having different actual and preferred forms has enabled these instruments to be used for the range of new research applications that are discussed later in this paper. Although the LEI and MCI originally were designed only to measure actual environment, Fraser and O'Brien (1985) have used a preferred form of the MCI successfully with elementary school classes.

Short Forms of ICEQ, MCI, and CES

Despite the fact that the long forms of classroom environment instruments have been used successfully for a variety of purposes, some researchers and teachers have reported that they would like instruments to take less time to administer and score. Consequently, short forms of the ICEQ, MCI, and CES were developed (Fraser, 1982) to satisfy three main criteria. First, the total number of items in each instrument was reduced to approximately 25 to provide greater economy in testing and scoring time. Second, the short forms were designed to be amenable to easy hand scoring. Third, although most existing classroom environment instruments were developed to provide adequate reliability for the assessment of the perceptions of individual students, the short forms were developed to have adequate reliability for uses involving the assessment of class means.

Types of Research Using Classroom Environment Instruments

To illustrate the range of possible uses of classroom environment scales, this section considers research involving (1) associations between student outcomes and classroom environment, (2) use of classroom environment dimensions as criterion variables (including curriculum evaluation studies and investigations of differences between students' and teachers' perceptions of the same classrooms), and (3) investigations of whether students achieve better when in their preferred environments.

Associations Between Student Outcomes and Classroom Environment

The strongest tradition in past classroom environment research has involved investigation of associations between students' cognitive and affective learning outcomes and their perceptions of their classroom environments (Haertel, Walberg, & Haertel, 1981). Numerous research programs have shown that student perceptions account for appreciable amounts of variance in learning outcomes, often beyond that attributable to background student characteristics. The practical implication from this research is that student outcomes might be improved by creating classroom environments found empirically to be conducive to learning.

Fraser (1993) has tabulated a set of 40 past studies in which the effects of classroom environment on science student outcomes were investigated. Studies are grouped according to whether they involved use of the LEI, CES, ICEQ, MCI, or other instruments. This table shows that studies of associations between outcome measures and classroom environment perceptions have involved a variety of cognitive and affective outcome measures, a variety of classroom environment instruments, and a variety of samples (ranging across numerous countries and grade levels).

The findings from prior research are highlighted in the results of a meta-analysis involving 734 correlations from a collection of 12 studies of 10 data sets from 823 classes in eight subject areas containing 17,805 students in four nations (Haertel, Walberg & Haertel, 1981). Learning post-test scores and gains were found consistently and strongly to be associated with cognitive and affective learning outcomes, although correlations generally were higher in samples of older students and in studies employing collectivities such as classes and schools (in contrast to individual students) as the units of statistical analysis. In particular, better achievement on a variety of outcome measures was found consistently in classes perceived as having greater Cohesiveness, Satisfaction, and Goal Direction, and less Disorganization and Friction.

Fraser and Fisher's (1982) reported a study of the effects of classroom environment on student outcomes in which the sample consisted of a representative group of 116 Grade 8 and 9 science classes, each with a different teacher, in 33 different schools. Three cognitive and six affective measures were administered both at the beginning and end of the same school year; classroom environment was assessed by administering the CES and ICEQ at mid-year. In addition, information was gathered about student general ability. Overall, the study yielded consistent support for the existence of outcome-environment relationships and suggested some important tentative implications for educators wishing to enhance students' achievement of particular outcomes by creating classroom environments found empirically to be conducive to achievement. For example, practitioners are likely to find useful the finding that Order and Organization seemed to have a positive influence on student achievement of a variety of aims.

From Fraser, Giddings, and McRobbie's (1992) research involving use of the SLEI in science laboratory classroom environments, the most striking finding was that both cognitive and affective outcomes were superior in situations in which Integration (i.e., links between the work covered in laboratory classes and theory classes) is greater.

Use of Classroom Environment Perceptions as Criterion Variables

Fraser (1986) tabulated 39 studies in which classroom environment dimensions were employed as dependent variables in science education in (a) curriculum evaluation studies, (b) investigations of differences between student and teacher perceptions of actual and preferred environment, and (c) studies involving other independent variables.

One promising but largely neglected use of classroom environment instruments is as a source of process criteria in evaluating innovations and new curricula (Fraser, Williamson, & Tobin, 1987). For example, a study involving an evaluation of the Australian Science Education Project (ASEP) revealed that, in comparison with a control group, students in ASEP classes perceived their classrooms as being more satisfying and individualized and having a better material environment (Fraser, 1979). The significance of the ASEP evaluation, as well as Welch and Walberg's (1972) evaluation of Harvard Project Physics, is that classroom environment variables differentiated revealingly between curricula, even when various achievement outcome measures showed negligible differences.

The fact that some classroom environment instruments have different actual and preferred forms that can be used either with teachers or students permits investigation of differences between students and teachers in their perceptions of the same actual classroom environment and of differences between the actual environment and that preferred by students or teachers. Research into differences between forms reported by Fisher and Fraser (1983) revealed that, first, students preferred a more positive classroom environment than was actually present and, second, teachers perceived a more positive classroom environment than did their students in the same classrooms. These interesting results replicate patterns in other studies in school classrooms in the USA, Israel, and Australia (see Fraser, 1993), as well as in other settings such as hospital wards and work milieus (e.g., Moos, 1974). These studies inform educators that students and teachers are likely to differ in the way in which they perceive the actual environment of the same classrooms and that the environment preferred by students commonly differs from that actually present in classrooms.

The third group of studies overviewed by Fraser (1986) shows that other researchers have used classroom environment dimensions as criterion variables in studies aimed at identifying how the classroom environment varies with such factors as teacher personality, class size, grade level, subject matter, the nature of the school-level environment, and the type of school. A paper in this symposium (Rathaiah & Rao, 1993) reports differences between private and government schools in terms of classroom climate and achievement.

Do Students Achieve Better in Their Preferred Environment?

Whereas much past research has concentrated on investigations of associations between student outcomes and the nature of the actual environment, having both actual and preferred forms of classroom environment instruments permits exploration of whether students achieve better when there is a higher similarity between the actual classroom environment and that preferred by students. Fraser and Fisher (1983) used a person-environment interaction framework to explore whether or not student outcomes depend not only on the nature of the actual classroom environment, but also on the match between students' preferences and the actual environment. Fraser and Fisher (1983) reported a study whose basic design involved the prediction of post-test achievement from pre-test performance, general ability, the five actual individualization variables, and the five variables indicating actual-preferred interaction. The class mean was used as the unit of analysis.

Overall, the findings emerging from this study suggest the similarity between actual and preferred environment could be as important as individualization per se in predicting student achievement of important affective and cognitive aims. This research has interesting practical implications, but one must be careful to ensure that the implications drawn are consistent with the unit of statistical analysis used. It cannot be assumed that students' achievement would be improved by moving them to a classroom that matched their preferences. Rather, the practical implication of these findings for teachers is that class achievement of certain outcomes might be enhanced by attempting to change the actual classroom environment in ways that make it more congruent with that preferred by the class.

Practical Attempts to Improve Classroom Environment

This section reports how feedback information based on student perceptions was employed as a basis for reflection upon, discussion of, and systematic attempts to improve classroom environments. The basic logic underlying the approach has been described by Fraser (1986) and applied successfully in studies at the elementary, secondary, and higher education levels (Fraser & Fisher, 1986).

The attempt at improving classroom environment described below made use of the short 24-item version of the CES discussed previously. The class involved in the study consisted of 22 Grade 9 boys and girls of mixed ability studying science at a government school in Tasmania (Fraser & Fisher, 1986). The procedure incorporated the following five fundamental steps:

1. *Assessment.* The CES was administered to all students in the class. The preferred form was answered first; the actual form was administered in the same time slot one week later.

2. *Feedback.* The teacher was provided with feedback information derived from student responses in the form of profiles representing the class means of students' actual and preferred environment scores. These profiles permitted ready identification of the changes in classroom environment needed to reduce major differences between the nature of the actual environment and the preferred environment as currently perceived by students. The interpretation of the larger differences was that students would prefer less Friction, less Competitiveness, and more Cohesiveness.

3. *Reflection and Discussion.* The teacher engaged in private reflection and informal discussion about the profiles to provide a basis for a decision about whether an attempt would be made to change the environment in terms of some of the CES's dimensions. The teacher decided to introduce an intervention aimed at increasing the levels of Teacher Support and Order and Organization in the class.

4. *Intervention.* The teacher introduced an intervention of approximately 2 months' duration in an attempt to change the classroom environment. This intervention consisted of a variety of strategies, some of which originated during discussions among teachers and others of which were suggested by examining ideas contained in individual CES items. For example, strategies used to enhance Teacher Support involved the teacher moving around the class more to mix with students, providing assistance to students, and talking with them more than previously. Strategies used to increase Order and Organization involved taking considerable care with distribution and collection of materials during activities and ensuring that students worked more quietly.

5. *Reassessment.* The student actual form of the scales was readministered at the end of the intervention to see whether students were perceiving their classroom environments differently.

Some change in actual environment occurred during the time of the intervention. Pre-test/post-test differences were statistically significant only for Teacher Support, Task Orientation, and Order and Organization. These findings are noteworthy because two of the dimensions on which appreciable changes were recorded were those on which the teacher had attempted to promote change. (Note also that there appears to be a side effect in that the intervention could have resulted in the classroom becoming more task oriented than the students would have preferred.) Overall, the above case study and other previous ones suggest the potential usefulness of teachers employing classroom environment instruments to provide meaningful information about their classrooms and a tangible basis to guide improvements in classroom environments.

Current Trends and Desirable Future Directions

In this section, consideration is given to some of the recent new lines of research on educational environments which have implications for the improvement of science education.

School-Level Environment

Although the focus of this paper has been classroom-level rather than school-level environment, school-level environment work is also very important. Some promising recent work has combined the use of classroom and school environment measures to advantage within the one study (Fraser, Williamson, & Tobin, 1987), another study has involved the use of school climate scales to reveal interesting differences between elementary and secondary schools (Docker, Fraser, & Fisher, 1989), and other research has involved the successful application of the methods of improving classroom-level environments described in this paper to the improvement of school-level environments (Fraser, 1993). Overall, this recent research attests to the value of school climate research and suggests that the time is ripe for a better integration of the two research traditions of classroom environment and school environment, which historically have remained largely distinct and independent.

Combining Qualitative and Quantitative Methods

Although only limited progress has been made toward the desirable goal of combining quantitative and qualitative methods within the same study in research on classroom learning environments, the fruitfulness of a confluence of qualitative and quantitative methods is illustrated in detail in the studies reported below. For example, a team of 13 Australian researchers was involved in more than 500 hours of intensive classroom observation of 22 exemplary teachers and a comparison group of non-exemplary teachers (Fraser & Tobin, 1989). The main data collection methods were based on interpretive research methods and involved classroom observation, interviewing of students and teachers, and the construction of case studies. However, a distinctive feature was that the qualitative information was complemented by quantitative information obtained from questionnaires assessing student perceptions of classroom psychosocial environment. These instruments furnished a useful picture of life in exemplary teachers' classrooms as seen through the students' eyes. The results from use of the qualitative and quantitative data collection methods provided considerable evidence suggesting that, first, exemplary and non-exemplary teachers can be differentiated in terms of the psychosocial environments of their classrooms as seen through their students' eyes and, second, that exemplary teachers typically create and maintain environments that are markedly more favorable than those of non-exemplary teachers (Fraser & Tobin, 1989).

In another study, which focused on the elusive goal of higher-level cognitive learning, a team of six researchers intensively studied the Grade 10 science classes of two teachers (Peter and Sandra) during a 10-week period (Tobin & Fraser, 1989; Tobin, Kahle, & Fraser, 1990). Each lesson was observed by several researchers, interviewing of students and teachers took place on a daily basis, and students' written work was examined. The study also involved quantitative information from questionnaires assessing student perceptions of classroom psychosocial environment. An important finding was that students' perceptions of the learning environment within each class were consistent with the observers' field records of the patterns of learning activities and engagement in each classroom. For example, the high level of Personalization perceived in Sandra's classroom matched the large proportion of time that she spent in small-group activities during which she constantly moved about the classroom interacting with students. The lower level of Personalization perceived in Peter's class was associated partly with the larger amount of time spent in the whole-class mode and the generally public nature of his interactions with students.

School Psychology

Given the school psychologist's changing role, the field of classroom psychosocial environment provides a good example of an area that furnishes a number of ideas, techniques, and research findings that could be valuable in school psychology. Traditionally, school psychologists have tended to concentrate heavily and sometimes exclusively on their roles in assessing and enhancing academic achievement and other valued learning outcomes. The field of classroom environment provides an opportunity for school psychologists and teachers to become sensitized to subtle but important aspects of classroom life. For example, Burden and Fraser (in press) report the way in which classroom environment instruments were used in helping teachers change their classroom interactive styles and in using discrepancies between students' perceptions of actual and preferred environment as an effective basis to guide improvements in their classrooms.

Constructivist Learning Environments

Traditionally, teachers have conceived their roles to be concerned with revealing or transmitting the logical structures of their knowledge and directing students through rational inquiry toward discovering the predetermined universal truths expressed in the form of laws, principles, rules, and algorithms. Recently, developments in history, philosophy, and sociology have provided educators with a better understanding of the nature of knowledge development. At the level of the individual learner, there has been a realization that meaningful learning is a cognitive process of making sense, or purposeful problem-solving, of the experiential world of the individual in relation to the totality of the individual's already constructed knowledge. Because the individual belongs to a world populated by significant others, the sense-making process involves active negotiation and consensus building for the duration of the individual's life-time, regardless of the learning context.

A new learning environment instrument is needed to assist researchers in assessing the degree to which a particular classroom's environment is consistent with a constructivist epistemology, and to assist teachers in reflecting on their epistemological assumptions and reshaping their teaching practice. Therefore, the Constructivist Learning Environment Survey (CLES) was developed to meet this need and to assess the four scales of Autonomy, Prior Knowledge, Collaboration, and Reflection (Taylor & Fraser, 1991).

Researchers could make use of the CLES in (a) monitoring the effectiveness of pre-service/in-service attempts to change teaching/learning styles to a more constructivistic approach, (b) evaluating the impact of constructivistic teaching approaches on student outcomes, (c) guiding teacher-as-researcher attempts to reflect on and improve classroom environments, (d) reducing the amount of classroom observation needed in studies of constructivist teaching/learning (by collecting information from students via the CLES), (e) complementing qualitative information in constructing richer case studies that also include quantitative information based on student perceptions obtained with the CLES, and (f) investigating the relationship between teacher cognition and teaching practice.

Personal Forms of Scales

Potentially, there is a major problem with nearly all existing classroom environment instruments when used to identify differences between subgroups within a classroom (e.g., boys and girls) or in the construction of case studies of individual students. The problem is that items are worded in such a way that they elicit an individual student's perceptions of the class as a whole, as distinct from that students' perceptions of their own roles within the classroom. For example, items in the traditional Class form of classroom environment instruments might seek students' opinions about whether "The work of the class is difficult" or whether "The teacher is friendly toward the class." In contrast, a Personal form of the same items would seek opinions about whether "I find the work of the class difficult" or whether "The teacher is friendly toward me."

A vivid example of the way in which certain subgroups of students within a science class perceived different sub-environments because of the teacher's differential treatment of them is provided by a study of target students (i.e., pupils who monopolize the verbal interaction during whole-class activities) (see Fraser, 1993). It was found that target students perceived significantly greater levels of involvement and rule clarity than non-target students, which was consistent with classroom observations showing that the teachers directed more questions at target students and allowed the target students (and not other students) to call out answers without being asked. Similarly, in another study combining qualitative and quantitative methods (Tobin, Kahle & Fraser, 1990), case studies of individual students revealed that meaningful differences in classroom environment perceptions existed among certain students and that those differences were consistent with the teacher's expectations of and attitudes toward individuals. The findings of these two studies highlight the need for a new generation of classroom environment instruments that are more capable of detecting the differences in perceptions between individuals or subgroups within the class.

Fraser, Giddings, and McRobbie (1992) have developed and validated parallel Class and Personal forms of both an actual and preferred version of the Science Laboratory Environment Inventory (SLEI), and have reported three uses of the new personal form. First, students' scores on the class form were found to be systematically more favorable than their scores on the personal form, perhaps suggesting that students have a more detached view of the environment as it applies to the class as a whole. Second, an investigation of gender differences in student perceptions of science/laboratory classes suggested that, as hypothesized, gender differences in perceptions were somewhat larger on the personal form than on the class form. Third, although a study of associations between student outcomes and their perceptions of the science laboratory environment revealed that the magnitudes of associations were comparable for class and personal forms of the SLEI, commonality analyses showed that each form accounted for appreciable amounts of outcome variance that were independent of that explained by the other form. This finding serves to justify the decision to develop separate class and personal forms because they do appear to measure different, albeit overlapping, aspects of the science laboratory classroom environment.

Incorporating Learning Environment Ideas in Teacher Education

The improvement of pre-service and in-service education programs for science teachers requires the input of new ideas that will help teachers become more reflective and retrospective about their teaching. Despite the fact that the thriving field of psychosocial learning environment furnishes a number of ideas and techniques that potentially are extremely valuable for inclusion in teacher education programs, surprisingly little progress has been made in incorporating these ideas into teacher education. Fisher and Fraser (1991) reviewed some examples of successful past and current attempts to include learning environment work in teacher education programs and made suggestions about how teacher education in the future can be improved through the input of ideas from learning environment research.

In particular, Fisher and Fraser (1991) reported some case studies of how classroom and school environment work has been used within pre-service and in-service teacher education to:

1. Sensitize teachers to subtle but important aspects of classroom life,
2. Illustrate the usefulness of including classroom and school environment assessments as part of

a teacher's overall evaluation/monitoring activities,

3. Show how assessment of classroom and school environment can be used to facilitate practical improvements in classrooms and schools, and

4. Provide a valuable source of feedback about teaching performance for the formative and summative evaluation of student teaching.

It appears that information on student perceptions of the classroom learning environment during pre-service teachers' field experience adds usefully to the information obtained from university supervisors, school-based cooperating teachers, and student teacher self-evaluation.

Research in Third World Countries

Because most of the research reviewed above was conducted in industrialized nations, this section focuses on the classroom environment research that has been conducted in third world countries. For example, classroom environment instruments have been found to be useful in an evaluation of computer-assisted learning in Singapore (Teh & Fraser, 1993). The sample consisted of 671 students in 24 classes (12 experimental and 12 control). Relative to control classes, computer-assisted learning classes were perceived by students to have greater gender equity, investigation, innovation, and resource adequacy.

Baba and Fraser (1983) used student perceptions of several aspects of classroom psychosocial environment in evaluating a social science curriculum in Fiji. A locally-developed instrument was used to assess interest, ease, and adequacy of time among a sample of 834 seventh grade students in 30 classes in six schools on Viti Levu, the main island of Fiji. Examination of means on individual questionnaire items provided useful formative evaluative information by identifying certain curriculum activities requiring modification to improve the level of interest, ease, and adequacy of time. The finding that the mean score was relatively high for most questionnaire items provided summative evaluative information suggesting that the majority of activities in the curriculum were perceived by students as interesting and easy and having sufficient time for completion.

Lin and Crawley (1987) investigated differences in classroom learning environment and science-related attitudes in 1,269 Taiwanese junior high school science students. Using the LEI, it was found that urban science classes, compared with rural science classes, were characterized by more speed, friction, favoritism, difficulty, cliqueness, and competitiveness. No differences were found when students were grouped according to sex or ability. Urban students and higher-ability students tended to have more positive attitudes to science. It was found that differences exist in students' attitudes to science and that these differences depended on the school's location, sex of student, and student ability. Finally, classroom learning environment and students' attitude to science were related.

Most of the classroom environment research undertaken in third world countries has involved investigation of associations between student outcomes and perceptions of classroom environment. For example, Walberg, Singh, and Rasher's (1977) study in India involved administration of the 15 LEI scales translated into Hindi to a random sample of 3,000 tenth grade students in 83 science and 67 social science classes in 26 districts of the State of Rajasthan. The magnitudes of the simple correlation between raw end-of-course achievement scores and different LEI scales ranged from 0.41 to 0.70 for science and from 0.58 to 0.81 for social studies. When IQ was partialled out of the relationship, these correlations ranged from 0.17 to 0.57 for science and from 0.36 to 0.73 for social studies. Multiple regression analyses revealed that student perceptions on the block of 15 LEI scales accounted for a significant increment of 28% of science achievement variance and 44% of social studies achievement variance over and above that attributable to general ability.

Fraser, Pearce, and Azmi (1982) and Fraser (1984) reported a study in Indonesia involving an Indonesian translation of a modified version of all the ICEQ's five scales and four of the CES's nine scales (namely, Involvement, Affiliation, Teacher Support, and Order and Organization). The sample consisted of 373 students in 18 coeducational social studies classes at the eighth and ninth grade levels in Padang, the capital of West Sumatra. Measures of satisfaction and anxiety were used as outcomes. Using the individual as the unit of analysis, simple, multiple, and canonical correlations were reported to characterize associations between the two outcome measures and the nine environment scales. The set of environment scales accounted for 14% of the variance in both satisfaction and anxiety. It was found that satisfaction was greater in classes perceived as having less independence and greater involvement, and anxiety was reduced in classes perceived as having greater differentiation, involvement, and affiliation. In another study in Indonesia (Schibeci, Rideng & Fraser, 1987), a sample of 250 eleventh grade biology students was used to replicate the existence of associations between classroom environment and several attitudinal outcomes.

Fraser (1984) has provided cross-cultural data about the predictive validity of students' environment perceptions in Thailand. The sample consisted of 989 twelfth grade physics students in 31 classes in Bangkok or nearby provinces. Learning environment, measured with a Thai version of 10 of the LEI's scales, was used to predict three attitudinal outcomes (attitude to physics learning, enjoyment of physics, and attitude to scientists). Half of the correlations between an LEI scale and the post-test score on an attitude scale were significantly different from zero. Hierarchical multiple regression analyses revealed that the increment in post-test attitude accounted for by the set of environment scales—beyond that attributable to corresponding beginning-of-year attitude scores and numerous background variables including general ability, personality, sex, and curriculum materials—was significant for two of the three scales. More favorable attitudes to physics learning were expressed in classes perceived as having more cohesiveness, less friction, less cliqueness, and more satisfaction; greater enjoyment of physics was reported in classrooms characterized as having less speed, more satisfaction, less disorganization, and greater competitiveness.

The Science Laboratory Environment Inventory (SLEI) has been used in a study of outcome-environment relationships both in Paupa New Guinea (PNG) (Waldrip & Giddings, 1993) and Nigeria (Fraser, Okebukola, & Jegede, 1992). The study in PNG involved 1,707 students' scores on an external science achievement examination, 987 students' scores on a laboratory performance test, and 1,590 students' responses to a scale measuring students' attitude to science. Significant relationships emerged for each of the three outcomes, but associations were stronger for the attitude outcome than for either achievement of practical performance in the laboratory. In particular, integration (i.e., the link between theory and laboratory classes) was the strongest and most consistent correlate of students' outcomes. In a somewhat similar study in Nigeria (Fraser, Okebukola & Jegede, 1992) involving 218 senior high school students and 170 university students, all dimensions of the SLEQ except Open-endedness were found to be associated positively with student attitudes toward science.

Conclusions and Implications

In just 25 years, older classroom environment instruments have been more widely used and cross validated in various countries, preferred forms have been developed to augment the original actual forms, short and hand-scorable forms have been designed for the convenience of teachers, and new instruments have been developed to fill gaps (e.g., for use in higher education classrooms or science laboratory classes). Currently, workers around the world are continuing to translate and adapt instruments for use in different countries, to develop new instruments for settings not ideally catered for with existing questionnaires (e.g., computer-assisted instruction, pre-school classrooms, constructivist classrooms), and to use the instruments in settings (e.g., various special education classes) in which they have not been used previously. Some of the many current and promising recent lines of research on educational environments include the use of a Personal (as well as a Class) form of questionnaire and links between environments (especially the school and the classroom). Also, the topic of classroom environment is beginning to become included in pre-service and in-service courses for teachers around the world and is gaining attention among school psychologists.

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The Use of the Science Laboratory Environment Inventory (SLEI) to Compare the Psychosocial Environment of the Chemistry and Biology Laboratory Classes in Israel

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Introduction

The laboratory has been given a central role in science education, and science educators have suggested that there are rich benefits (cognitive and affective) in laboratory activities for the science students. One of the areas that has been neglected by researchers is the psychosocial environment of the science laboratory. Hofstein and Lunetta (1982) suggested that:

> *Laboratory activity has the potential to enhance constructive social relationships as well as positive attitudes and cognitive growth. The cooperative team effort required for many laboratory activities may promote positive social interactions involving cohesiveness, task orientation, goal direction, democracy, satisfaction and other factors measured by learning environmental instruments.*

They call for expanding research in this area to assess how students' experiences in laboratory affect the learning environment, and how it is reflected in students' perception. We expected that the investigation on students' perception of the actual and preferred laboratory learning environment may help teachers to evaluate the effectiveness of the instructional strategies used in the laboratory on student-student and student-teacher relationships and students' perceptions of the material environment. This information may provide a basis for guiding systematic attempts to improve these dimensions of the learning environment in the laboratory.

The Study

The present study attempts to measure the learning environment in the context of the Israeli educational system. The Hebrew version of the Science Laboratory Environment Inventory (SLEI) originally developed by Giddings and Fraser (1990) was used as the research instrument. This version consisted on 70 items covering 8 scales of the laboratory learning environment: Teacher Supportiveness, Involvement, Student Cohesiveness, Open-Endedness, Integration, Organization, Rule Clarity and Material Environment. We used this instrument to get answers to three main questions:

1. Is the preferred students' perception of their laboratory learning environment different from the actual one?
2. Do chemistry and biology students have different perceptions about their laboratory environments?
3. Do boys and girls have the same perceptions about their laboratory learning environments?

The sample consisted of 8 classes of biology students (N=188, boys N=62, girls N=126) and 7 classes of chemistry students (N=183, boys N=88, girls N=95) in urban and suburban academic high schools in Israel. All were eleventh grade students.

Results

Comparison of the Actual and Preferred Learning Environment in Biology and Chemistry Laboratories

The actual and preferred students' mean scores of their perception of the learning environment in biology and chemistry classes were compared using Hotelling T^2 statistics. The following results were obtained:

- For the chemistry sample: $F_{(8,175)} = 34.9$; $p < 0.001$
- For the biology sample: $F_{(8,179)} = 11.5$; $p < 0.001$

From the results it is seen that students usually tend to prefer a different environment on dimension of laboratory learning environment (as measured by the Science Laboratory Learning Enviroment Inventory [SLEI]). A series of t-tests conducted showed that for *all* the scales, the differences between the actual and preferred were significant, (i.e., Preferred > Actual).

These findings may be seen as a normal phenomena of the evaluation of the reality versus the optimal learning environment. But one must consider that, on the whole, the mean of the actual is fairly high; thus, this could be an indication of students' satisfaction with the existing chemistry and biology curricula.

Comparison of the Actual and Preferred Laboratory Learning Environment of Biology and Chemistry Students

Actual Laboratory Learning Environment

Students' perceptions of the *actual* learning environment of their biology laboratories were compared with students' perceptions of the actual learning environment of chemistry laboratories. A multiple discriminant analysis was used to derive weights for the eight S.L.E.I. scales to maximally separate them in discriminant space. The value of Wilk's l associated with one discriminant function was 0.62 and the value of $chi^2 = 172.0$ (with df = 8). The probability of obtaining such value by chance is less than 0.1%. This finding suggests that the learning environments in chemistry and biology laboratories are different and supports the idea that the S.L.E.I. is sensitive to different approaches to the science laboratory.

On the basis of a series of t-tests conducted to compare the mean perceptions of the actual laboratory learning environment in chemistry versus biology, it was found that the most pronounced differences are on the scales "open-endedness," in which biology classes scored higher compared with chemistry classes and in the "integration" and "rule clarity," in which the chemistry classes scored higher.

Preferred Laboratory Learning Environment

With regard to the preferred learning environment, the differences were less pronounced (Wilk's l=0.57, $Chi^2=50.0$ df=8 $p<0.01$). Highly significant differences were obtained on the scale "integration," in which again chemistry classes scored significantly higher compared with their biology counterpart.

Comparison of the Perceptions of Chemistry and Biology: Boys and Girls

The perceptions of boys and girls in each of the disciplines (chemistry and biology) were compared using a series of t-tests. On the whole, in chemistry no gender differences were obtained. On the other hand, in biology differences between boys and girls were obtained both in the actual and preferred perceptions.

Discussion

The two distinct differences between biology and chemistry students are found on the "integration" and "open-endedness" scales. These differences between chemistry and biology could be attributed to the differences in the two curricula. Biology in Israel is taught using the BSCS yellow version, which emphasizes the approach of "invitation to inquiry" (Schwab, 1963), whereas chemistry labs are more structured and linked to the concepts taught in the class at the same period. The chemistry textbook used by the students is written in a way such that the experiment is presented as an integrated ingredient of the topic taught.

As a result, chemistry students perceive that practical work is more integrated with the concepts and topics that are taught at the same time in the theoretical classroom sessions. In biology, on the other hand, "invitations to inquiry" used in the laboratories are learning episodes that aim at practicing general inquiry skills and sometimes have no direct baring on the topics discussed and learned in the biology classroom. It seems to us that these differences in the teaching approaches in the two disciplines explain the different results obtained. With regard to gender differences, in the chemistry population no significant differences were obtained. On the other hand, comparison of boys' and girls' perceptions of the biology laboratories' learning environment showed that both for the actual and for the preferred laboratory learning environment the two populations differed. In the preferred mode of perception, the differences are more pronounced. On most of the scales, girls' mean scores of preferred perception is significantly higher than those of boys. This trend could also be seen from the size of the sub-samples: 95 girls and 88 boys in the chemistry classes, compared with 126 girls and 62 boys in the biology classes. This shows that, in general, girls tend to enroll in greater numbers in biology courses.

Summary

The results of this study show that the SLEI instrument is sensitive both to different science curricula and different instructional methods. Studying the relationships between the structure of science curricula and instructional methods and students' laboratory learning environment may provide teachers and curriculum developers with valuable tools to make the laboratory more effective for attaining both cognitive and affective goals.

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The Effectiveness of Particular Instructional Strategies in the Context of Both Developed and Developing Countries

Geoff Giddings

Introduction

It is not unreasonable to suggest that the problems faced by developing countries in developing and refining their education systems are similar across many such countries. However, it should not be assumed that the structures, strategies, and even the research performed in what we may term relatively "developed" countries are able to be directly translated to a particular developing country. The context is different. The function of the education system is different. The result may well be different (Kahn, 1990).

For instance, within many developing countries, the level of employment can be low and the majority of the population may not complete high school education. This low level of employment may cause the focus of curriculum development and syllabus content to be directed toward providing those skills that will be most useful in the community after schooling has been completed. It should also be noted that, within a developing country context, the majority of the students often come from a rural, basically non-technoscientific background.

Effect of Language

In many developing countries the language of instruction may not be the mother tongue of either the students or the teacher. This is a particularly important point if the indigenous language does not contain the concepts and terms that are identical with those of the more developed country from which the language of instruction was adopted (Boeha, 1988; Caillods & Postlewaite, 1989; Strevens, 1976). Consequently, many students in developing countries have difficulty with both the interpretation and retention of what has been learned (Yeomen, 1988). By failing to understand the meaning of many words and related terms, many of these students survive by the adoption of such strategies as rote memorization (McLaughlin, 1991).

Teachers, as well as being concerned with their own understanding of the language of instruction, must constantly be sensitive to those ideas that may confuse the student. This may be particularly difficult for teachers who are teaching in a second language. Heyneman and Loxley (1982) found that student achievement in such settings was related to the quality of the teacher's English. Thus, if the teaching approach adopted by teachers requires a higher level of understanding of the language of instruction than that with which the teachers feel able to cope, these teachers may adopt those teaching strategies that enable them to meet the demands of the language. Hence, less than optimal teaching strategies may be adopted by teachers.

Effect of Resource Levels

Many developing countries (as well as so-called developed countries) have been identified as having inadequate school science laboratory facilities, science equipment, and supplies (Charakupa, 1991; Urevbu, 1984; Van den Berg & Lunetta, 1984), and budgetary restrictions have restricted expenditure per pupil in non-salary areas such as textbooks and teaching aids.

Other studies (Fuller, 1987; Ogunniyi, 1986) have shown a relationship between school expenditure per pupil and achievement. This is especially true at the secondary level. Interestingly, any increase in expenditure per pupil is only likely to help the lower-achieving students. However, Fuller (1987) also claims that increasing expenditure on resources is likely to have a larger effect on student achievement than would, say, decreasing the size of classes. Importantly, there is evidence that per-student spending in the poorest developing countries declined during the 1970s and 1980s by about one third in real terms (Fuller & Heyneman, 1989).

As an example, in a study that examined the government expenditure patterns on education and the quality and quantity of schooling in five African nations (Botswana, Burkina Faso, Cameroon, Ethiopia and Senegal), Ogbu and Gallagher (1991) noted that as capital expenditure was reduced, often the quality of schooling also declined. Increased dependence on poorly trained teachers as a result of this expenditure decline was reflected in mixed students' performance on national examinations. Ogbu and Gallagher (1991) also suggested that the effects of declining government expenditure on education may be somewhat offset by a judicious reallocation of resources and may result in an improvement in the educational opportunities for the students. It was also argued that creating a balance between elementary, secondary, and tertiary educational outcomes is most important and that resources should be directed to areas of greatest need.

Cultural Effects on Teaching Strategies

Some of the cultural variables that appear to have an effect on the selection and use of particular teaching strategies include the specific indigenous customs of a country or region, related cultural views on learning, and a number of gender-related factors. Many citizens of developing countries have traditionally shown great respect for the age and the accompanying wisdom of their elders. They are often taught about the need to work collectively and to be respectful of those with more authority (Buseri, 1987; Kay, 1975). As a result, teachers in some of these countries tend not to encourage probing or critical questioning and may even resent being questioned. One implication for science teaching is that some students may not want to be seen as lacking understanding or as challenging authority. It is perhaps not surprising that such students do not ask many classroom questions and wish only to answer questions if they are feel they are correct. Further, Ogunniyi (1983) found that it was common for students in developing countries to copy large quantities of blackboard notes and for the student to listen passively as the teacher lectures. This obviously has important implications for the possible adoption of student-centered inquiry approaches to science teaching in such settings.

Young learners in many developing countries are taught the importance of accurate reproduction of received knowledge and customs. To question or innovate in this way would likely result in alienation from the adult society. This fear of alienation may have strong implications for the selection of appropriate classroom teaching strategies to cope with such fears (McLaughlin, 1991).

Further, in developing countries, the culture and traditions are people-based, whereas science tends to be based on an examination of the nature of phenomena and exploring relevant explanations. This may cause tensions when teaching science. This tension may often result in the school and the home developing two different sets of values and attitudes leading to a conflict for the student as to which set of values and attitudes to adopt. Knowledge about the potential conflicts may also affect the teaching methods of the teacher. As a result, a form of compartmentalization occurs. Compartmentalization can result in the student and the teacher adopting two, sometimes conflicting, sets of beliefs. One of these sets of beliefs is based on traditional beliefs or experiences; the other is based on what is taught in the schools.

In some developing countries, girls are often denied equal access to education despite their ability level (Theisen, Achola, & Boakari, 1983). As girls are more readily withdrawn from the school system because of the parents' desire for the girl to be married, or because of the need for the girl to help produce income for the family, it is not surprising to find that the girls left in school do less well than boys in school (Duncan, 1989; Lockheed & Komenan, 1989).

Effect of Western Science Programs

The science programs used in developing countries have often been taken with little or no adaptation from Western nations' science programs (Ingle & Turner, 1981; Ogawa, 1986). This is a further example of education systems within many developing countries still being tied to their source. Besides the obvious problem of terms and concepts from such sources perhaps not having a traditional equivalent, these same terms and concepts are often strongly opposed to the local cultural values and understandings (Kay, 1975).

In the post-Sputnik Western reappraisal of their science programs, key Western nations produced many elegant science programs, versions of which still exist in many developed and developing nations. In the following two decades, these programs were replaced by curricula and associated teaching strategies that placed a much higher value on a more hands-on, discovery-oriented approach to science teaching (Kahn, 1990).

This period of time also coincided with a period of rapid decolonization around the world. Many developing countries, often having only just won their independence, turned to science as a tool for the growth and development that they required. Thus, a large number of "new" science programs were adopted and adapted from Western science curricula. For instance, many ex-British colonies (e.g., Malaysia, Fiji) modified British GCE-type science curricula in their schools. It was the curricula and school practices of the elite schools that provided the basis of post-independence growth in education in many of these countries. For example, these elite schools were often the ones in which the new generation of post-independence leaders had their formative educational experiences. These new science curricula claimed only varied measures of success, though the impact on the school system, particular at the secondary level, was substantial and lasting (Kahn, 1990; Lewin, 1990). As the more developed and industrialized countries began to be aware of serious shortcomings of the outcomes and the nature, relevance, and teaching strategies inherent in many of their "new" programs, many developing countries continued the implementation of the very same curricula. The end result is that the vast majority of educational systems within developing countries are still inevitably linked to those of their former colonizing power.

Directions of the Symposium

As noted, many of the "traditional" teaching strategies utilized in science teaching have proved ineffective for teaching science in the classrooms of developing countries. On the other hand, there are many general principles that have been validated in both developing and developed countries. For instance, research has suggested that those science teachers in high-performing schools and classrooms tend to use more teacher-developed materials and activities, they lecture less, and they give their students the opportunity to take part in and be more closely involved in simple investigative classroom activities, rather than be forced into a passive learning role.

This symposium presented a number of papers that examine in detail the results of attempts to utilize such practices through the design and development of a range of innovative science teaching strategies. Some papers examined more effective use of laboratory facilities and resources, instructional/learning materials, and assessment techniques. Other papers outlined innovative teaching strategies involving senior students dealing with controversial issues on science, technology, and society (STS) issues. A further paper examined strategies based on the premise that meaningful learning can only occur with strategies that maximize student involvement in the learning process. Another key paper critically reviewed and compared the effectiveness of those strategies that are teacher-centered (lectures, discussions, demonstrations) with those that are student-centered (inquiry laboratory activities, individualized learning, small group-work and computer simulations).

It is hoped that the underlying message of this symposium reflected the need for all countries, whether viewed as developed or developing, to identify the most appropriate strategies for their specific teaching context, carefully match the available strategies to the specific needs, motivations, and desired outcomes of the particular students, and to implement these teaching strategies using a carefully designed and adequately resourced implementation plan.

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Dealing With Controversial Issues: An Experience With Students Involved in Role Play Methodology

Elena Camino and Carla Calcagno

Controversial Issues

School is committed to teaching subjects of various disciplines, but usually does not offer the students the opportunity to reason about complex and controversial problems. In dealing with such issues as development and environment, it is important to be aware of their complexity: the problems that such topics imply rise from different cultural roots of human societies, from the interplay among local ecosystems and the global ecosystem, from how scientific knowledge is achieved and is applied by means of technology, from the economic system, and from the political and social values. It is the very structural connection among science, technology, and society that gives rise to controversial issues. People may disagree at various levels: on facts, on probabilities, on hypotheses, on provisions, on risk/benefit evaluation, and—more deeply—on individual and social values, that is to say, on ethical principles.

Often positions differ at many levels: on facts *and* on values. But let's consider the simplest situation: a controversy on data. How is it possible? There are various reasons why people do not agree on data—even if the scientific concepts about a question are clear, difficulties may arise because:

1. The documentation is inadequate, because it is not possible to have access to it;
2. The measures have been taken with dishomogeneous and not comparable techniques;
3. The interpretation of data is different, owing to different schools of thought; and/or
4. The research is in progress, and conclusions have not yet been drawn.

When data do not refer to the natural world, but to human affairs, things are still more complicated, because cultural and political values are inevitably introduced.

It is evident, then, that it is not possible to find the "right" solution to controversial problems. Nevertheless, often people must make decisions about these problems. So it is important that people are aware of the many possible solutions, of the non-predictability of their choice, of the possibility of making a mistake. Decision makers who acknowledge that they may be wrong will choose a way from which they can come back; in other words, they will give preference to reversible solutions that can be corrected.

How to Deal with Controversial Issues

Good teachers help their pupils to build their knowledge in an active and critical way. This means that students learn to uncover the connections among specific subjects of different disciplines and also to recognize the same conceptual structures when common to different subjects. The goal of such a constructive way of learning is to achieve knowledge that can be used to solve problems. Operativeness in school, however, does not always imply the solution of practical, manual problems: it may refer to the ability to apply acquired concepts to a real problem, to understand it, and to find a solution. Knowledge is not only taught by putting it into words: it can also be acquired by practicing, when a real problem on a world scale has to be faced. This is not an easy task, and to reach such a goal, many teaching strategies should be used.

One of these strategies is the role-play methodology, where the teacher's purpose is to help the students to strengthen some concepts that have already been explained and to organize them within a conceptual frame. The educational goal of the role-play is not to acquire new knowledge, but to consolidate some concepts and to learn how to connect them with the pre-existing knowledge.

Moreover, during the role-play the participants are given the opportunity to improve their ability to organize their own work in view of specific goals, which are shared with other students. The discussion and communication among peers gives the chance to experience a condition both in teaching and in learning that is different from the traditional lectures. The rule to prepare a common strategy of action within each group encourages the members to give a good performance and to listen carefully to one another. Last, when participants take their roles, they have to put themselves in other people's shoes. This emotional involvement can facilitate a deeper understanding of the ideas and perceptions of other people.

In the classroom the role-play activity is run in three stages: the preliminary arrangement of the groups for the debate, the public discussion on the controversial issue, and the evaluation of the decisional processes that have led to the final choice. During the whole activity the role of verbal and written communication is essential. In the preliminary phase, players have to introduce themselves to the group; after that, all the students are supposed to read texts and documents and to identify and select relevant data; then they have to organize the acquired information in a coherent form, to support their points of view during the public debate. At this stage of the play verbal communication is again crucially important: spokespeople have to express the most important arguments of their groups clearly, briefly and convincingly.

Our Proposal

We have published a booklet in which a controversial issue is faced with role-play strategy. We addressed the booklet to teachers and students of secondary school level (15 to 19 years age group). The problem deals with the use of water in a sahelian country.

First Stage

Participants are introduced to the environment of the controversy: a N-W region of Burkina Faso, in the Sahel region, that is characterized by scarce water supply and by land aridity, and where heavy rains fall in a very short period and cause land erosion. The controversy arises on the choice between two possible actions.

1. The first possibility is to build some new wells and to deepen the old wells, with a loan from the World Bank. The project aims to give availability of safe water. It makes use of modern technologies, and it requires a huge investment of money. The duration of the project is clearly defined.

2. The second possibility is to build small stone walls along the contour lines to hinder soil erosion, to reinforce the banks of the streams with gabions, and to build small dams with a mud wall to collect water at the bottom of the valley. The project is financed by an Italian NGO in association with a local organization, the NAAM group organization of Burkina Faso.

The two technical solutions are explained to the students with a series of slides. The controversial issue does not concern only the choice between two different technical solutions, a modern one and a traditional one—it is also rooted in different cultures and traditions.

Preliminary Discussion

After the two projects are discussed, the students are invited to take part in a general discussion. It will soon be evident that they do not have enough information to express their opinions or to defend their arguments, and thus, they will ask for access to documents and data on the various aspects of the problem: the rainfall measures, the statistics on water consumption, the economic consequences of a loan, the evaluation of the attitude of the local population for collective work, and so forth.

Document Consultation

Some information sheets are then distributed to the participants. These texts offer geographic, scientific, historical, economic and cultural documents and data about Burkina Faso and the management of water in the Sahel region. All the students are encouraged to read the material in view of the role-play.

Second Stage

This meeting is devoted to the role-play. It consists on the preparation and the course of a public debate where two groups express their preferences toward the "well solution" and the "small dams solution." A third group listens to their arguments, asks questions, and at the end decides for one of the two solutions. The decision makers' group has to justify its choice on the basis of risks versus benefits evaluation.

At the beginning of the role-play each participant receives a role card (there are a total of 22). Each card gives an outline of a person: age, sex, residence, profession, mentality, traditions, aims, and so forth. Among the roles there are people from Burkina Faso (both from villages and towns), and people fr 1 the North of the world who are involved in cooperation at various levels (technical, sanitary, economic). On each role card an opinion is clearly expressed about the water controversy, so that every student has to play the role described in the assigned card during this session.

According to the opinions expressed in the cards, the participants form three groups. Group A includes all the people who are willing to accept the loan form the World Bank for the project of digging wells; Group B includes those who favor the construction of small dams with stones and mud to catch the surface water, built by local people with the financial help of an NGO; and Group C, formed by people who have the responsibility of making the decision. The roles of those in Group C are to manage the discussion, to listen to the reasonings of the two opposing groups, and to make a choice between the two projects.

An agenda, some worksheets for the groups, and some methodological suggestions for the management of the activity help the students go through the various steps of the role-play.

Third Stage

This last session may be managed in a number of ways, according to how the role-play has been performed. Teachers choose the alternative that they consider most suitable to the situation and to the students' reactions. Some possible scenarios are just outlined here.

1. The role-play has ended up with enjoyment of the participants. It can be useful to make a flux diagram to investigate the decisional processes which have led to a certain decision; or to investigate how the roles have been played, how the students have been involved, and so forth.
2. The conclusion of the role-play has given rise to dissatisfaction and conflicts about the decision. The teacher can propose to replay, after distributing the roles among the students in a different way; to investigate the decisional process, to identify the steps which caused conflicts;or to present examples of real situations to the students, to make them aware that often decisions are made in situations similar to those that emerged during the role-play.
3. The students were not emotionally involved. It might be useful (to help them to grasp the situation properly) to plunge them into the sce-

nario—by projecting films and videos on arid land environments and populations, so that traditions, cultures, abilities, problems are described in deeper detail; by inviting "witnesses" (an inhabitant of Burkina Faso, or a volunteer on an NGO), so that they can tell them their own experiences; or by suggesting that students play the roles of Italian and Burkina young people, and explain to each other how they spend their everyday life, which kind of problems, duties, dreams they have.

Assessment

During a refresher course for secondary school teachers this role-play has been proposed to 20 classes. The teachers participated in a series of meetings (lectures and discussions) about the theme "environment, development, culture: a knot not to be untied." Thereafter, the role-play was proposed to their classes, and conducted in each class by two young animators, all volunteers in NGOs or conscientious objectors doing civil service.

The occasion allowed us to assess our educational material from various points of view. In fact, we gathered remarks and opinions of the teachers, who participated as "observers"; of the animators, who conducted the activities with the students in the three meetings; and finally the feelings of the students who participated in the experience.

The balance—even bearing in mind that the sample was small (400 students)—is positive so far, as it can be appreciated by reading some observations of the students:

> *This is the most interesting activity we have done at school since the beginning of the year.*
>
> *I was deeply involved emotionally: for a while I moved away from everyday life.*
>
> *Usually we analyse things from far away: but this time it has been different.*
>
> *During the role-play I really believed in what I said, and my position was clearly the best one.*

Practical Activities in Science Teaching in Developing Countries

George Za'rour

Introduction

The term "practical" in the title of this paper refers to hands-on classroom or laboratory activities involving students performing specific tasks related to the topic. The intent is to provide concrete experiences of phenomena or to utilize an activity-oriented approach. This is to be differentiated from using the term basically to describe activities aimed at the development of manual or utilitarian skills (Rowell & Prophet, 1990).

The goals of pre-university science education have been undergoing a fundamental transformation during the past decade. In all regions, involving developing and developed countries, science curricula increasingly call for an approach in teaching/learning that emphasizes inquiry, problem-solving, and decision-making through the utilization of practical activities. With the shift of emphasis toward objectives that stress the processes of science, the expected role of practical activities has evolved to become as a catalyst for concept formation and a developer of the methods and spirit of science. Another major shift centers around a growing emphasis on tackling issues and problems that stem from the local situation or environment, and/or are related to the interactions among science, technology, and society and their impact.

The Role of Laboratory Work

The general position of scientists and science educators is that laboratory work or involvement in practical activities is the essence of science teaching. Any questioning of the importance and function of experimentation and laboratory activities in science teaching may be viewed as a blasphemy—an unscientific attitude indeed. But during the past decade there have been serious statements indicating that the search for evidence to substantiate the glorified claims related to laboratory activities in the manner that they are generally performed was not successful. Serious skepticism has arisen about the soundness of practical activities that exist in most educational systems of even developed countries (Anderson, 1981; Blosser, 1983; Haddad & Za'rour, 1986; Tamir & Lunetta, 1981; Penick & Yager 1986). In other words, the great halo that scientists and science educators ascribe to the role of laboratory in science teaching is backed more by opinions and is more a reflection of a firm conviction in the important role of science activities rather than a product of the findings of research.

In developed countries where shortage of materials and equipment is not a severe problem, the situation of unsubstantiated contribution of laboratory work does not pose a major problem. But in developing countries, especially the poorer ones, it raises questions about the cost/benefit ratio of laboratory instruction. The support in the form of grants or loans that international donor agencies extend to developing countries in the field of science education or pre-university science is also partially based on a conviction on the part of all concerned that science is important for the economic development of developing countries and that laboratory instruction is an essential component of science.

Laboratory Activities: Realities vs. Goals

The predominant classroom picture worldwide is that of lecture-discussion and questioning. With respect to developing countries, one of the problems is that many are still struggling to catch up with the situation in which the developed countries existed several decades ago. Is it necessary for the developing countries to go through the process? Is their situation comparable to the current situation of developed countries, considering the fact that many are still enrolling, in secondary education, less than 20% of the cohort compared to the much higher figures in developed countries? Do they have to perform chemistry experiments at the macro level before they shift to the micro level? Even in situations where science teaching is deemed to be appropriate, it has been argued that preparation for university science courses at the secondary level does not meet the needs of a large majority of secondary school student populations who either do not pursue higher education or do not major in a science-based university field of study.

There is pride and prestige in acquiring modern and sophisticated equipment, regardless of the potential for its utilization. The behavior sometimes tends to suggest or reflect an attitude of equating acquisition of advanced equipment to development. In one country, the Director General for Secondary Education wanted to acquire computers for all intermediate schools in the country at a time when many towns in rural areas—where more than half of the population live—did not have electricity. If you ask why they wanted computers for the intermediate and not upper secondary schools, it is because the project concentrated on the intermediate cycle. When told that the country could not afford such a luxury and had higher priorities, they questioned the motives behind the "advice," as if the intent was to inhibit the country's advancement.

Wellington (1990) described the position as follows:

> *School science, as those of us who have been through the school system know, seems to have an existence of its own. It has its own apparatus, creating a world of conical flasks, test-tube racks, Pyrex beakers and all the other bits and pieces which remind adults instantly of school science. It has its own laboratories which by necessity combine working space with learning and teaching space. The world of school science bears little relation to the world outside where science and technology are everywhere. In playgrounds, kitchens, on sports fields and golf courses, in shops windows, in the back garden or on rubbish tips there is enough science to keep people going for a lifetime.*

When the question is posed about why laboratory activities are not performed, developing countries tend to consider lack or inadequacy of physical facilities and materials as the major obstacle to the implementation of science courses that require practical activities to be conducted by students in small groups. If one is conscious about costs, as is the situation in most developing countries, one would agree that practical activities need to be selected carefully and restricted to topics that cannot be treated by more cost- and time-effective modes of delivery. Time effectiveness enters into the picture because a number of developing countries resort to the utilization of school premises in double shifts to accommodate increasing numbers of students. Can students truly perform a creative problem-solving experiment within a single teaching period of 40 minutes in an overcrowded classroom? It also should be recognized that practical activities do not necessarily require highly sophisticated equipment and structured settings. Furthermore, it is well known that provision of equipment, by itself, is not sufficient to introduce a basic change in the strategies of science teaching. Even when equipment and materials are available and used, practical activities are, in many cases, inappropriately performed. In discussing shortcomings of laboratory instruction, Harbeck (1976) cites problems related to cost of equipment, maintenance, capability of teachers in using the discovery method, student and teacher time needed for practical activities, and the potential discipline problems that are specific to practical activities.

Needed Research

Research should emphasize what actually happens in the laboratory, detailed investigations about students' actions and perceptions in the laboratory (White & Tisher, 1986) as well as specific conditions and strategies of laboratory work (Hofstein & Lunetta, 1982), and exploration of the processes involved in students assisting one another to learn (Tobin, 1990).

From another angle, it is important to find out how practical activities can be used as motivational tools to attract students to science careers and develop in the students positive attitudes towards science. Action in the right direction is represented in the cross-national study of senior high school and university science laboratory classroom environments that was undertaken in Australia, the U.S., the U.K., Canada, Israel, and Nigeria, which involved the development, cross-national validation, and application of a new instrument for assessing the learning environment of science laboratory class instruction (NARST News, 1992).

Involvement of International Agencies

It is not the purpose of this presentation to argue a case for or against the importance of practical activities in science teaching. As this conference is specifically concerned with developing countries, my special interest is to present concrete suggestions for science teaching in developing countries, particularly in relation to the potentially costly laboratory component. A redefinition of the role of practical activities in science education is needed not only on pedagogical grounds, but cost is also an important factor, especially in developing countries. I do hope that some of our conclusions and recommendations address these special needs in an effective manner and not just assume that whatever is appropriate for developed countries is good enough for developing countries.

In a report commissioned by the World Bank, Ware (1992) calls for a reconceptualization of the role of laboratory in science instruction in all countries and reiterates that the utilization of laboratory facilities and equipment in many countries is poor. As pointed out by Tobin (1990), laboratory activities are not necessary for problem solving, as students might do that by engaging in thought experiments. A number of objectives are not exclusively limited to practical activities, as they are equally claimed by expository methods and secondary inquiry techniques (e.g., discussion and reporting of inquiries), and others seem to be equally related to other disciplines and even out-of-school influences. The breakdown of the boundaries among the science disciplines has implications that should be taken into consideration in formulating policies and developing approaches.

Priorities need to be established, and there is no use for generalization to all countries. Different practices can be identified in the same country, city, or school. Would I advise a country to have provisions for individual/small group laboratory work when the classrooms in many of their primary schools are in the open air all the time, rain or shine, with part of the surrounding wall painted black to serve as a crude blackboard? In that country, when they asked for a laboratory room in each intermediate school, I advocated emphasis on demonstrations and utilization of materials from the environment. I recommended larger than usual apparatus and objects, so they could be seen from the back of long and overcrowded rooms. I am not convinced that my advice was the best, and I am not sure that it will work, but what would you have done in my place? In other settings I have seen apparatus including lots of locally produced or internationally donated/purchased materials under lock and key, hardly ever used, years after procurement or acquisition. Would teacher training do the trick? It may help but other serious factors interfere: teachers being charged for broken/lost items at a time when their salaries are miserable; teachers need to rush to teach in another school for extra income or to another job; and, in my judgment worst of all, teachers need to rush to tutor their own students.

Taking advantage of the illustrations of scientific concepts that surround us in the environment and planning teaching strategies around them not only renders science education more relevant and useful but has the potential of enhancing the quality of life by applying basic scientific knowledge in connection with health, hygiene, nutrition, agriculture production, manufacturing, and environmental issues among others (El-Hage et al., 1992). But this requires special orientation of teachers in the training program and building capabilities and interests as well, as it may be more demanding on the teacher's time. It is easier to depend on the content of textbooks and perform standard experiments. A co-author of a physical science textbook, which we published in Lebanon in 1972 and of which we were proud because it compared well with imported books and had good design and layout (e.g., all the activities were printed in blue and were well-differentiated), told me years later that his nephew thought that the book was awful. When asked why, the nephew stated that the teacher required them to memorize all the blue parts. That is much easier than going into the trouble of collecting materials, trying an activity, and then performing it as a demonstration, or in small groups, or individually.

There is no one answer that meets the need in every situation, and policy papers that tend to have a universal remedy for all cases tend to cause more harm than good. As teachers are required to meet the individual needs of students in a classroom or in a school, we are required to meet the individual needs of countries and try to advise/recommend solutions that effectively respond to those needs in light of their unique circumstances.

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Chapter 5

The Curriculum

Introduction to Strand D: A Focus on the Curriculum

Rodger Bybee and Nava Ben-Zvi

Introduction

Educators around the world agree on the need to reform the science curriculum. Although this deceptively simple statement generates wide agreement, it also contains a central point that must be resolved—How can educators both reform the science curriculum to achieve a common goal, such as scientific literacy, and accommodate the unique needs of their region or nation?

The answer to this question may be contained in the sub-theme of the conference *From Theory to Practice* and in the perspectives developed by the presentations in this strand on curriculum.

Rethinking the Goals of Science Education

The process of curriculum reform must begin with, and be informed by, goals (theory) on which we can find common agreement. In this strand, the goal of scientific and technologic literacy transcend the unique requirements of more- and less-developed countries. Presentations by Haggis (France), Coburn (U.S.), Whittle (Malawi), D'Ambrosio (Brazil), and Roseman (U.S.A.) developed the important first step of curriculum reform, namely the reappraisal and reformulation of goals.

Policies for Curriculum Development

A second step, and one that is too often neglected, consists of the translation of goal statements into curriculum frameworks and the need to address the critical issues in design and development of new science curricula. These are for specific components of science education programs such as teacher education and assessment. In the specific context of curriculum, the curriculum frameworks must attend to issues such as grade level, appropriate science content and processes, strategies for instruction, implementation, and assessment. In this strand, presentations by Coburn (U.S.), Kahn and Levy (South Africa), Schneider and Arbuckle (U.S.), deVoe (Netherlands), Adeyegbe (Nigeria), and Schuster (South Africa) all discuss policy issues in the design and development of science curriculum. This discussion of policy issues and the development of curriculum frameworks makes the general and abstract nature of goals more specific and concrete, thus taking an initial step toward the resolution of the aforementioned problem of achieving a common goal while recognising the requirements of one's region or country.

Curriculum Development

We considered models and examples of curriculum development and implementation, that is, the process of curriculum development. This is the essential process of translating policies to programs. Presentations on this theme include Bybee (U.S.) and King (West Indies). Science curriculum represents the best efforts of individuals to translate the goals and policies into actual curriculum materials appropriate for schools, teachers, and students. Fearn Wannon (Australia), Webb (South Africa), and Steinburg (U.S.) describe different science curricula. Curriculum materials should represent both the common goals of science education and the unique needs of the region or country.

Science teaching, the final translation of a curriculum into actual teaching and learning, must be considered as an important aspect of any curriculum. The final translation of any curriculum is up to the teacher. Likewise, the responsibility for accommodating the needs of diverse learners falls to the science teacher. In this strand, presentations by Milgrom (Israel), Sapir and Liebermann (Israel), Pratt (U.S.), and King (West Indies) focus directly on the issue of adapting curriculum materials to the needs of the students.

Assessment and Evaluation

Finally and essentially, there must be the assessment and evaluation for curriculum modification. Assessment has a vital role in science education. Science teachers often overlook or ignore the varied purposes of assessment and confine their assessment practices to single means, such as a test. Worse yet, some science educators perceive assessment as separate and distinct from the curriculum when, in fact, students perceive, prepare, and learn science for tests, regardless of what may be taught. Raizen (U.S.), Ben-Zvi (Israel), and Schuster (South Africa) describe various aspects of assessment.

Discussion

Woven through all presentations are themes common to the contemporary reform of science curricula—the problem of students' misconceptions and conceptual change; the issue of curriculum emphasis, such as science-technology-society (STS); the role of assessment; and the importance of implementation. Themes that marked this conference included the potential conflicts between Western and non-Western cultures, and the appropriate exchange of goals, policies, and curriculum between less-developed countries (LDCs) and more-developed countries (MDCs). We can benefit from the experiences and insights of our colleagues through active and open listening and the constructive adaptation of ideas and recommendations.

To initiate that constructive adaptation and cooperative development, we propose four core ideas about which we think common agreement exists. We present these ideas from the perspective of the science curriculum, but our general view is that they represent a synthesis that incorporates all the conference strands.

Student learning neither begins nor ends with the science curriculum designed, developed, and implemented.

The constructivist literature informs us that students already have conceptions of the material and designed world and that they have developed explanations from many phenomena. In addition, an individual's science education occurs beyond schools in other settings, such as the family and peer culture, and through other social influences, such as the media and religion. It is possible to question the form and accuracy of the science education a student receives in these factors, but not the fact of its occurrence and influence.

All of this suggests the need for individuals to recognize the current understandings by, and the meanings of those understandings for, the students, as science programs are designed, developed, and implemented.

The design and development of science programs must include, from the beginning, strategies and materials for content, instruction, assessment, and implementation.

In the past, priority has focused first on the content, and second on instruction, leaving assessment and implementation for the last or to others. The design and development must incorporate assessment as a part of the curriculum and instruction. It must account for who is going to use the science program, where they are going to use the program, and how they are going to learn about the program.

This recommendation places an additional burden on those responsible for new science programs but it assures a complete, coherent, and consistent program that is actually used. Certainly, the burden is a challenge but it is worth the effort.

We must recognize and incorporate the essential role of science teachers in the translation of the curriculum to actual practices that optimize the learning and development of students.

Any curriculum must meet general criteria such as accurately representing science content and processes and appropriately accommodating students' learning and development. The curriculum developers have their responsibilities. They also have some responsibility to accommodate science teachers' needs, such as management and effectiveness. It is, after all, the science teacher who has to establish the connections between the curriculum and students and use those connections to enhance learning. Development of science programs must be done with a sensitivity to the environments and situations in which teachers use the materials and the fact that any new program requires more change on behalf of those teaching the program than on those designing and developing the program.

Science teachers have the responsibility to adapt materials for their unique situations and, to be very clear, to modify their teaching to new content and approaches and to accommodate the requirements of student learning. The changes in science teaching suggested in this discussion will result in stress on the teachers responsible for implementing the program. To avoid stress is to avoid implementing a new program and improving science education. So, what can be done? On the part of those developing science programs, we must recognize the changes that will occur and design programs that best meet the science teachers' needs, such as management, effectiveness, and efficiency. Others in the educational system must assume responsibility for supporting the implementation process through adequate materials, supplies, equipment, and staff development. The stress associated with change cannot be avoided, but it can be recognized, and adequate support can be provided for the science teacher who must assume responsibility for implementing the program.

Design and development of science curricula should consider the culture and educational system from which, and into which, you plan to implement the curriculum.

It is possible to maintain both the integrity of science and education of cultural diversity. We can avoid the pitfalls of one region or nation dictating curriculum, even unintentionally. To do this, we must be sensitive to the educational needs and requirements and center on the issue of helping the classroom teacher adapt the curriculum framework to usable materials and adapt the materials to effective practices. Science education personnel and programs can be considered resources; it is simply true that some nations, regions, territories, and schools have more resources than others. The critical issue is not the fact of resources. It is the way the resources are used, the way they are exported and imported, and the way they are modified to meet the needs of science teachers.

Conclusion

In this review, we have attempted to synthesize the many excellent ideas from diverse presentations on the general theme of curriculum. Collectively, the papers convey a message of hope that we can help students progress toward a goal of scientific literacy. Individually, the presentations suggest that reaching this goal will take the creativity, insight, understanding, and skills of those who understand the unique requirements of their nations, schools, and teachers.

Effective Instructional Strategies in Science

Avi Hofstein and Geoffrey Giddings

Introduction

In the teaching of science, as for any subject, one has to consider the specific problems inherent in the subject and try to tailor curriculum materials and instructional strategies to enhance the abilities and aptitudes of the students. The overall objective is to create an effective classroom in which students interact physically with instructional materials whenever possible, through handling, operating, and practicing; effort is made by the teacher to provide materials and instruction that give reality and concreteness to scientific concepts; and teachers vary instructional strategies, materials, and classroom procedures with the aim of increasing the impact and effectiveness of their teaching.

Instructional strategy refers to the way in which a science teacher uses materials, media, setting, and behaviors to create an environment to produce an effect. Instructional strategies can be located on a spectrum, one end of which is *teacher-centered* (i.e., with the teacher being active and the student being less active, but not necessarily intellectually passive), and the other end is *student-centered.* Strategies that are student-centered include laboratory activities, inquiry techniques, small-group discussions, individualized learning, computer simulations, and field trips. Strategies that are teacher-centered include lectures, classroom discussions, demonstrations, and questioning techniques.

Student-Centered Strategies

Inquiry Learning

Despite the level at which students study science, they ought to receive an undistorted view of scientific activity, which implies an appropriate development of scientific skills and understanding of content. Inquiry learning, in the sense that it simulates real scientific activity, has a considerable role to play. Inquiry learning places a major part of the learning activity on the student. Welch et al. (1981) describe inquiry learning as generally associated with complete involvement on the part of the student. Teaching and learning by inquiry provides first-hand experience of doing science and, in addition, develops inquiry skills such as identifying and defining a problem, formulating a hypothesis, designing experiments, and locating, analyzing, and interpreting data. Students who learn by inquiry are responsible for developing their own answers to questions, rather than relying exclusively on the teacher and textbooks.

Inquiry teaching and learning have been prevalent topics in the science education literature in the past quarter of century. Welch et al. (1981) wrote that "the science education community has advocated the development of inquiry skills as an essential outcome of science instruction, and for an equal number of years science educators met with frustration and disappointment" (p. 1). Unfortunately, in spite of new curricula, better-trained teachers, and improved facilities and equipment, the optimistic expectation that students would become inquirers seldom has been fulfilled.

Science Laboratories

For a long time, the science laboratory has had a central and distinctive role in science education in involving students with concrete experiences of concepts and objects. In the 1960s, as part of the reform in science education, practical work was supposed to be used to engage students in investigations, discoveries, and problem-solving. The laboratory became the center of science education.

The laboratory is a unique educational setting in which students, usually in small groups, interact with materials and equipment and observe phenomena. These laboratory experiences can have different levels of structure specified by the teacher or laboratory handbook. They include four broad phases of activity: planning and design, performance, analysis and interpretation of results, and application (Kempa & Ward, 1975).

Goals of Laboratory Work

Laboratory work and activities traditionally have been used for a wide variety of cognitive, practical, and affective goals (see comprehensive list provided by Shulman & Tamir, 1973). "Laboratory work is an accepted part of science instruction. Given its important place in the education of youth, it is surprising that we know so little about its functioning and effects. (p. 301). The findings of research studies on the effectiveness of laboratory work were reviewed critically by Bates (1978) and Hofstein and Lunetta (1982). One of the causes for the lack of information about the effectiveness of the laboratory would seem to be that past, research was not sufficiently comprehensive. It generally examined relatively narrow bands of laboratory-related skills, and the conclusions that were drawn applied to a narrow range of teaching techniques, teacher and student characteristics, and learning outcomes.

Teacher Roles in Laboratory Work

The massive curriculum development of the 1960s showed that teachers play important roles in student learning (Welch, 1979). The best curriculum materials can result in limited student growth if a teacher is insensitive to the intended goals, student needs, and appropriate teaching strategies. The teacher provides an organization and environment that affect whether or not students meet certain instructional goals. If a teacher's goal, for example, is to teach observational skills and not just facts that can be observed, this goal should be apparent in the things that the teacher says and does. Shymansky and Penick (1978) wrote that:

> *Teachers are often confused about their role in instruction when students are engaged in hands on activity. Many teachers are concerned about an adjustment they may have to make in their teaching style to facilitate hands on program as well as how students will react to increased responsibility and freedom. An activity oriented classroom in which hands on materials are made available to students is often a very new experience for teacher as well as for his students.*
> (p. 1)

Science Laboratories in Developing Countries

Research on the effect of laboratory work in low-income countries is as inconsistent as it is in high-income countries (Haddad, 1986; Walberg, 1991). Large-scale science achievement surveys in developing countries have shown the positive effect of school quality and teaching practices, but the effect of laboratory work has been inconsistent. For example, the survey conducted in low-income countries by Heyneman and Loxley (1983) has shown that laboratory facilities had very little effect on science achievement.

Allsop (1991) argued that the case for laboratory work in secondary schools in low-income countries is rather complex because the laboratory is just a part of a larger disfunctionality in secondary schooling. In some developing countries, practical work continues to be viewed as a luxury that no one can afford, except as a part of a final practical examination that is based on the tradition of the colonial educational system (i.e., the British system).

Computer Simulations

The term "simulation" has been used in several ways in natural and social sciences. To simulate means to imitate a real system (e.g., an economy) or a process (like the flow of fluid through a pipe). Often the simulation operates on the basis of a mathematical or logical model. The model is intended to imitate the original faithfully, but generally includes fewer details. Instructional simulation enables learners to understand better the real system that is being simulated. Instructional simulations, as well as laboratory activities, enable students to interact with models of reality. Within contrived settings, both can enable students to confront and resolve problems, to make decisions, and to observe effects.

The discussion here is limited to computer simulations that students use as an alternative and/or complement to laboratory work. Even in high-level inquiry laboratories, curriculum developers and teachers usually have to limit the scope of the activity because of constraints of time, equipment, space, materials, and measurement error. Thus, computer simulations can provide an effective substitute or enhancement for some laboratory activities. Simulations can be planned to provide meaningful learning and to engage students in interactions with problems, models, or experiments that are too complex, dangerous, expensive, fast, slow, or time- and materials-consuming. As a resource for inquiry, computers can assist in the collection, interpretation, and analysis of data; as an instrument in the laboratory, they provide instantaneous digital and graphic readouts of variables such as temperature, time voltage, velocity, and so forth.

Pedagogy of Student-centered Activities Based on Experimentations

In the school laboratory, students generally are assigned to groups of 2-4 students for practical work. When used optimally, the small-group cooperative learning environment enables students to share ideas, question each other, consider alternative ideas, and assist each other in understanding and problem-solving. Small-group, cooperative learning can be identified by the following four elements: (a) positive interdependence, (b) face-to-face interaction, (c) individual accountability, and (d) the use of interpersonal and small-group skills appropriately (Slavin, 1983). Students work independently and in competition with each other, and many do not know how to cooperate in achieving a group goal. When given a choice between working with others and working independently, more students choose to work alone. The task of the teacher who wants to foster improved interpersonal skills is to structure the classroom and learning activities to help students to use cooperative learning skills (Slavin, 1983).

Field Trips/Outdoor Activities

Visits to parks, school camps, nature centers, and other outdoor education enrichment settings are standard practice in education, and much has been written concerning their educational desirability (e.g., Koran & Baker, 1979). However, most of what has been written is based on intuition, and surprisingly little research evidence about field trips is available (Falk, 1983). Do children learn from field trips? If so, what do they learn? What are the factors that influence what and how much they learn? How can schools use field trips more effectively? Only recently have such questions begun to be investigated. For example, according to Koran and Baker (1979), field trips can be successful as an instructional strategy provided that:

1. Prior to visiting a field setting, the teacher is familiar with the area;

2. Students are prepared and clear about the objective of the field trip; and

3. The field trip provides a meaningful experience that concentrates on experiences unavailable in classrooms.

Distance Education

Distance education can free students from the limitations of space, time, and age, and has a record of success in high- and low-income countries. It can include correspondence texts, books, newspaper supplements, posters, radio and television broadcasts, audio and video cassettes, films, computer-assisted learning, and self-instructional kits, as well as such local activities as supervision, supplementary teaching, tutoring, counseling, and student self-help groups. Scarce resources of scientific, pedagogical, and media expertise concentrated in development centers for science education can be shared more widely using print and broadcast media. Books and other printed material are prime examples that have worked consistently better than only oral teaching, which ordinarily absorbs most education costs in Third World countries (Fuller & Heyneman, 1989).

Teacher-Centered Strategies

Conventional Teaching

Direct or conventional teaching has predominated throughout the history of universal education. The National Science Foundation studies (Wise, 1978), conducted in the late 1970s in the US, indicated that the dominant method of teaching observed was recitation, with the teacher being in control and supplementing the lesson with new information (i.e., the teacher lecturing). The key to the new information was the textbook. In any classroom discussion, most of the questions asked were posed by the teacher and were factual, low-level questions. This strategy can require little preparation and planning by the teacher. The discussion approach can be educationally sound provided the following conditions are fulfilled:

1. An attempt should be made to ask more questions that require students to demonstrate the ability to comprehend, apply and analyze. According to McGlathery (1978), managerial questions are usually at a low cognitive level. Closed questions, also known as convergent questions, need not be of a low cognitive level, and they can be phrased so as to encourage students to classify, make comparisons, use their judgment, or focus on a particular point. Open (or divergent) questions have a variety of "fight" answers and generally lend themselves to a higher order of reasoning.

2. Teachers give students reasonable time to respond to questions and wait longer before they act (i.e., more "wait time"). Tobin (1987) indicated that teacher wait-time is a promising variable for use in research context and that, with few exceptions, the use of an extended wait-time has resulted in significant changes in teachers' and students' behavior.

Teacher's Demonstration

One of the most frequently observed activities in the science classroom is the teacher demonstration, which has been found to be conducted at least once a week in two out of five classes (Wise, 1978). Demonstrations can be conducted deductively, with the student involved in verification and observation, or inductively, with the student involved in high-level inquiry skills. According to Trowbridge et al. (1981), well-planned inductive demonstrations provide students with a stimulus to think, with immediate feedback from the teacher. The feedback acts as a guide for further questioning until the student discovers the principles involved in the demonstration.

Whether conducted by the teacher or presented by another vicarious technique (e.g., films or videotapes), demonstration can be justified as an alternative to student-based laboratory work (Garrett & Roberts, 1982). This is especially so in situations where, as a result of administrative, economic (cost of equipment), time, and safety problems, a truly student-centered laboratory approach to science is not readily implemented.

Matching Instructional Techniques to Student's Motivational Traits

The notion that instructional techniques in science education should be matched to learner needs and char-

Table 1: Relating Instructional Features to Students' Motivational Characteristics

Type of Activity (Suitability Unsuitability)	Examplars	Comments
Discovery/inquiry-oriented learning methods/Problem-solving	Advocated in many science USA and UK during the 1960s and 1970s	Suitable mainly for students with curiosity'-type motivational pattern. Insofar as problem-solving activities are likely to require students to engage in judgement and evaluation situation (both tend to involve 'high risk' taking), these are disliked by both 'achievers' and 'conscientious' student.
Open-ended learning activities (student-centered)	These are learning activities without clearly specifiable goals, except those relating to scientific processes (i.e., those associated with project work or student research)	Strongly preferred by the 'curious' but not other motivational groups which prefer clear teacher directions regarding educational goals.
Formal teaching with emphasis on information and skill transfer	Conventional 'traditional' instructional procedures, involving frontal teaching (e.g., with clear goals and objectives)	Preferred by 'achievers' and 'conscientious' students because only low level of risk-taking is needed.
Collaborative learning activities	Games, simulations	The majority of games and simulation exercises, devised for science education are 'interactive' and, hence, particularly suitable for learners with a strong social motivation pattern However, 'achievers' are likely to be opposed to an involvement in this type of learning activity.

acteristics to maximize the effectiveness of the teaching/learning process has been accepted widely for a considerable period of time. Learner characteristics that have received attention include cognitive characteristics, such as student achievement; cognitive style; students conceptual level; and certain affective traits, such as student attitudes, interests, and motivation (reviewed by Kempa & Diaz, 1990a, 1990b).

Hofstein and Kempa (1985) suggested that students possess preferences for particular types of learning activities and that these reflect their motivational traits or "motivational pattern." The notion of "motivational pattern" itself is derived from the work of Adar (1969) who identified four such patterns, based on the predominance in a learner of one of the following "needs": the need to achieve, the need to satisfy curiosity, the need to discharge a duty, and the need to affiliate with other people. The types of learner corresponding to these need patterns were referred to by Adar as achiever students, "curious students," "conscientious students," and "sociable students," respectively.

When Adar (1969) studied the relationship between students motivational pattern and their preference for particular teaching and learning strategies, it was concluded that "The application of different teaching techniques will affect a student's motivation only if the method interacts with the student motivational pattern." Hofstein and Kempa (1985) elaborated this theory for science education. They postulated that a number of relationships exist between students' motivational characteristics and their preferences for particular modes of instruction in science education. These attempts to relate the most significant instructional features associated with teaching/learning to the learner's motivational pattern are summarized in Table 1.

A study by Kempa and Diaz (1990a, 1990b) suggests that students have different motivational traits that lead to different preferences or dislikes for certain instructional strategies used in science education. This finding is important and should be taken into consideration in the design and planning of learning experiences and teaching interventions, both by teachers and curriculum developers, as well as those who are responsible for the organization of science education in schools.

Concluding Remarks

Generally speaking, it is true that research has failed to show simple and clear-cut relationships between various instructional strategies and student learning in science. Furthermore, it is unreasonable to expect that any of the methods discussed in this chapter could be an effective and efficient teaching and learning medium for achieving all goals in science education. On the other hand, sufficient data exist to suggest that some of these instructional techniques can play an important part in attaining some of the goals of science learning.

Appropriate instructional activities can be effective in promoting the development of logical thinking, as well as the development of some inquiry and problem-solving skills. Some instructional techniques could assist in the development of manipulative and observational skills and in the understanding of scientific concepts. Some could provide opportunities for fostering the development of skills in cooperation and communication. More research and information are required on the enhancement of the application and orchestration of these strategies.

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Education for a Changing Future

Jo Ellen Roseman

Introduction

Science for All Americans (SFAA), published in 1989 by Project 2061 of the American Association for the Advancement of Science, defines a set of literacy goals in science, mathematics, and technology. It draws upon the work of scores of natural and social scientists, mathematicians and engineers, and educators who struggled to describe a common core of learning for all high school graduates. It favors high quality learning over sheer coverage so that as students mature intellectually they are able to pursue significant topics in depth and in a variety of contexts.

Chapters 1-3 focus on the *Nature of Science, Mathematics* and *Technology* as human enterprises, how they differ, and how they are alike—their reliance on evidence, their use of hypothesis and theories, the kinds of logic they use, and their attempt to identify and avoid bias.

Chapter 10, *Historical Episodes*, illustrates that en terprise with 10 concrete examples that are of surpassing significance to our cultural heritage—the planetary earth, universal gravitation, relativity, geologic time, plate tectonics, the conservation of matter, radioactivity and nuclear fusion, the evolution of species, the nature of disease, and the industrial revolution.

Chapters 4-9 present a scientific view of the world—a common core of knowledge in natural and social science, mathematics, and technology that can serve as tools for thinking about everyday phenomena and for learning more, as needed, to inform decisions and solve practical problems. Included are *The Physical Setting*, which describes basic knowledge about the overall structure of the universe and the physical principles on which it seems to run, with emphasis on the earth and the solar system; *The Living Environment*, which gives basic knowledge about how living things function and how they interact with one another and their environment; *The Human Organism* as a species that is in some ways like other living things and in some ways unique; *Human Society* in terms of individual and group behavior, social organizations and the process of social change;*The Designed World*, that is, the world shaped and controlled largely through the use of technology—agriculture, materials and manufacturing, energy sources and use, communication and information processing, and health technology; and*The Mathematics World*, which gives basic mathematical ideas, especially those with practical application, that together play a key role in almost all human endeavors.

Chapter 11, *Common Themes* that cut across disciplines, can serve as tools for thinking for areas as diverse as ancient civilization, the human body, or a comet.

Chapter 12, *Habits of Mind*, presents recommendations about values, attitudes and skills—mathematical manipulation and observation, communication and critical response skills—in the context of science education.

Chapter 13 lays out the principles of *Effective Learning and Teaching* that underlie all of the curriculum models being developed by Project 2061. Even now, educators are using these recommendations to stimulate thought and discussion about classroom changes such as:

1. Finding out how students already think about every major topic;

2. Giving students enough evidence and time to actually change their inappropriate ideas;

3. Increasing the use of team approaches that allow more active participation by every student;

4. Shifting classwork toward ideas and thinking and away from vocabulary and predetermined answers;

5. Making sure that girls, minorities, and the disabled are fully engaged in all class activities in science, mathematics and technology; and

6. Expecting and rewarding clear and accurate reports, both written and oral, of students' thinking and activities.

> *In learning science, students need time for exploring, for making observations, for taking wrong turns, for testing ideas, for doing things over again; time for building things, constructing physical and mathematical models for testing ideas, time for learning whatever mathematics, technology and science they may need to deal with the questions at hand; time for asking around, reading and arguing; time for wrestling with unfamiliar and counterintuitive ideas and for coming to see the advantage in thinking in a different way.*
>
> (AAAS, 1989)

Benchmarks for Science Literacy

SFAA presents only exit outcomes. It does *not* describe the progress students can make toward these goals at various grades. That information can be found in *Benchmarks for Science Literacy*, published in fall 1993 (AAAS, 1989). *Benchmarks* describe the kind of progress students might make towards each of the learning goals in SFAA—specifically, what students should know and be able to do by the end of grades 2, 5, 8 and 12.

Benchmarks maintains the same organization as SFAA; for each SFAA section there is a corresponding set of benchmarks. This was done so that people could easily go back and forth between the exit outcomes and the steps leading to them. The steps appear as lists, which itemize what students should know and be able to do by the end of grade 2, 5, 8 and 12. For example, the following excerpts from chapter 12 of the *Benchmarks* draft illustrate how critical response skills might develop:

> *By the end of the second grade, students should typically ask "How do you know?" and attempt reasonable answers when others ask them the same question.*
>
> *By the end of the fifth grade, students should "seek better reasons than 'Everybody knows that' or 'I just know' and discount arguments in which celebrities make claims outside their own field.*
>
> *By the end of the eighth grade, students should "Recognize that 'Does the evidence really show that?' is an important question (even though they may not answer it very well)." They should also "Question vague attributions used in place of specific references (such as 'Leading doctors say . . .') and claims that experts make outside their own field.*
>
> *By the end of the twelfth grade, students should "Suggest alternative ways of explaining data and criticize arguments in which data, explanations or conclusions are represented as the only ones worth consideration . . ."*

Thus, by the time they graduate from high school, students will have acquired "the ability to decide what evidence to pay attention to (and what to dismiss) and to distinguish good arguments from shoddy (one's own and others)."

Project 2061 chose grades 2, 5, 8 and 12 as checkpoints rather than the popularized 4, 8 and 12. This was because the teams of teachers and consultants who have worked on benchmarks decided that a single benchmark grade between kindergarten and the 8th grade provides insufficient guidance to those who design curriculum and instruction for young children. Another example comes from chapter 1 of the *Benchmarks* draft. The following excerpts from the Nature of Science benchmarks, illustrate how students might come to understand the role of bias in scientific inquiry:

> *By the end of the second grade, students should know that "Sometimes we can imagine why things are the way they are, but other people may imagine other reasons for the same thing."*
>
> *By the end of the fifth grade, students should know that "Scientists' explanations about what happens in the world come partly from what they see, partly from what they think. Scientists may explain the same observations in different ways."*
>
> *By the end of the eighth grade, students should know that "What people expect to see often affects what they do see . . . Scientists know about this danger and take steps to try to avoid it."*
>
> *By the end of the twelfth grade, students should know that "Scientists in any one group tend to see things alike, so even groups of scientists have trouble being objective about their work . . . Checking each other's results and explanations helps, but is no guarantee against bias."*

We decided to express each stage of sophistication in terms of what students will *know*, instead of specifying a set of behaviors. Rather than recommend a single (out of many possible) *means* for students to demonstrate understanding, we elected to specify the *goals* and leave to teachers and curriculum designers decisions about how a particular benchmark would be measured or how it might be learnt. Moreover, we don't intend for individual benchmarks to be taught or assessed separately. We hope curriculum will be designed to embed the teaching (and assessing) of multiple benchmarks in rich learning contexts.

A final example, from chapter 5 of the *Benchmarks* draft, illustrates some of the benchmarks that would lead to an understanding of natural selection.

> *By the end of the second grade, students should know that "Living things are found in many different kinds of places and have features that help them live where they do."*
>
> *By the end of the fifth grade, students should know that "Individuals with some features are more likely to survive and reproduce."*
>
> *By the end of the eighth grade, students should know that "Some inherited traits help living things to survive and reproduce."*
>
> *By the end of the twelfth grade, students should know that "Over generations, a population will increase its proportion and advantageous traits."*

The explicitness of the benchmark statements is meant to guide curriculum developers, helping to differentiate what about a topic is to be learned from what is not.

Lists tell what students should know and be able to do at the various grades. But the lists don't indicate why precursors were placed at particular grades. Sometimes there was research to guide our decisions. For every SFAA section, we examined available research about how children learn those ideas. But because research is limited, we have relied on teams of teachers who are knowledgeable about what kids typically say in various learning situations. Benchmarks contain *essays* that comment on the available research and suggest kinds of activities that might help. These are modest suggestions to help to clarify the lists and to stimulate thinking about how benchmarks might be learned.

For example, the essay on the evolution of life in the current *Benchmarks* draft makes the following points:

Evolution by Natural Selection Challenges Beliefs and Observations

No scientific theory has been more difficult for people to accept than evolution—(a) it appears to violate strongly held, age old beliefs about when and how the world and the things in it were created; (b) it hints that humans have lesser creatures as ancestors; (c) it flies in the face of what we can plainly see, namely that generation after generation of species don't change—roses stay roses, worms stay worms; and (d) new traits arising by chance alone is a strange idea to most people, aesthetically unsatisfying to many, and spiritually offensive to some.

There are Numerous and Diverse Precursors

Students have to draw from knowledge of phenomena occurring at several different levels of biological organization and over frequently unimaginable time scales. Moreover, some understanding of mathematics of profitability is required to think in terms of population changes (in contrast to individual changes) and to grasp why some kinds of evidence are rare.

Terms used are Confusing

Research suggests some student difficulties have to do with differences in the way scientists and non-scientists use such terms as "adaptation," "fitness," "mutant," and "theory."

The Goal is Understanding, Not Belief

A proper goal of science education is to help students *understand* evolution so that they will have an informed basis for making up their minds on what to believe; indoctrination, on the other hand, is not in the spirit of science. Research shows that children may understand a scientific explanation of phenomena before they believe it.

This argues for using the early grades to build a knowledge base about biological diversity and to capitalize on children's natural interest in fossils and dinosaurs that will be needed later to understand evolutionary change. In middle school, the fossil evidence can be expanded beyond extinctions and survivals to the notion of evolutionary history. By the time they enter high school, students should know what evolutionary change is and how it played out over time. Teachers can draw upon the children's familiarity with artificial selection used to produce plant varieties and domesticated animals as the students consider natural selection as an evolutionary mechanism. Adding DNA to the picture contributes to the evidence for life having evolved from common ancestors and provides a plausible mechanism for the origin of new traits.

There are some limitations to lists that aren't easily dealt with in essays. It's hard to trace how a single idea develops over time when the steps are embedded in much longer lists. And sometimes understanding an idea from one *Benchmarks* chapter depends on understanding precursors from other sections or chapters. For this, we needed a map that showed all the relevant benchmarks and the connections among them. Maps can illustrate the progression from simple precursors to more sophisticated concepts. In fact, it was the process of mapping the progress of understanding toward various SFAA goals that originally led to the development of *Benchmarks*. Map-making is interesting work. The process engages scientists and educators in reflection about the logical precursors (e.g., how fossils form precedes fossils as evidence for changing life forms) and reflection about experimental precursors (e.g.. evolution as phenomenon precedes natural selection as explanation). The process of refining maps results in a systematic evaluation of the lists, highlighting the need for additional precursors and calling attention to inconsistencies across grade levels. Maps themselves may provide helpful graphics for *Benchmarks* users, but we suspect that the most important value of maps is as heuristics—maps and map-making stimulate discussion and debate that can lead to studies about when various ideas might be learned, what difficulties students encounter, and what kinds of activities are helpful.

Other parts of *Benchmarks* will (a) pull together a coherent story about teaching and learning the various benchmarks at each grade range, (b) illustrate how progress toward collections of benchmarks might be measured, and (c) discuss the contribution of published research to Benchmarks development.

Uses of *Benchmarks*

Benchmarks are intended primarily as a guide in developing curriculum. They are useful for decisions about when and in what order to teach various concepts. They provide a filter for the review of existing materials (e.g., What benchmarks are targeted?). Project 2061 teams of K-12 educators are helping to identify alternative materials and resources to help students make progress toward benchmarks. In doing so, we are finding topics for which little or no material exists. We hope to influence materials developers to pay particular attention to those topics.

Development of *Benchmarks*

Benchmarks evolved out of the work of our six teams of K-12 educators who were charged with developing curriculum models (K-12 teams included elementary-, middle- and high-school teachers of science, math, technology, and social studies principles and curriculum specialists). To maintain coherence in their models for 13 years of schooling, Project 2061 design teams typically worked in cross-grade and cross-subject groups, instead of in traditional isolation by grade level and subject matter. As they attempted to plan how students would achieve the 12th grade learning goals in SFAA, teams needed to think about the prerequisite knowledge, skills, and habits of mind. For 3 years, teams worked with Project 2061 staff and university faculty—in many cases sketching maps for every section—as they imagined first what the precursors were and then estimated when they might be learned. Eventually, as teams compared their maps and charts, they found they could agree on a common set of precursors, which led to the development of *Benchmarks*.

More than 5,000 copies of the draft are currently being reviewed by science, mathematics, and technology educators and the organizations that represent them (e.g., NSTA), scientists, and other organizations interested in education (e.g., National Middle Schools Association, National PTA, and Business Roundtable). In addition to our site teams, more than 100 school district and statewide teams of K-12 educators are involved in the review. We are analyzing the huge volume of thoughtful comments that are being returned and plan to revise the draft for publication this fall.

Review, in a grand sense, will last several years, even after the first edition of *Benchmarks* is published. We view the initial *Benchmarks* as a first approximation and plan to revise them as new knowledge accumulates about how students learn these ideas. We hope that the discussion and debate that starts with the review of *Benchmarks* will continue, stimulating classroom research about when students are able to learn particular content and skills. Results of this research about children's learning and materials that promote it will be incorporated in to *Benchmarks* revisions.

Reform Tools

Project 2061 is not in the business of producing a national curriculum. Instead, it is developing, with the assistance of its school district teams, a set of tools to help schools and school districts assemble their own. Science For All Americans (1989) defined a coherent set of learning goals for high school graduates. *Benchmarks* elaborates the SFAA recommendations in terms of progress students should make along the way. We're also working on:

1. Curriculum *blocks* that can be assembled;
2. K-12 curriculum *models* from which local curriculum designers can construct alternative K-12 curricula;

3. A dozen commissioned *blueprints* that describe how various aspects of the system—assessment, teacher, education school organization—need to change to support new curriculum models; and
4. A computerized system that combines a resource database with all of the other tools, allowing designers to draw on them in a coordinated and guided fashion.

We hope this set will assist educators in designing their own K-12 curriculum and planning the systemic reform that will support its implementation.

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Rethinking Goals of Science Education in the Light of Our Current Views of the Learning-Teaching Process

Elizabeth Hegarty-Hazel

Introduction

With increasing urgency beginning in the early 1980s, there have been calls to the international community of science educators for changes in the goals and delivery of science education at the school and university levels, as well as in lifelong education. The slogans "Education for All," "Science for All" and "Inclusive Science" help name the challenges. In these terms, rethinking the goals of science education means addressing the issues of how science education can contribute to a society characterized by individual fulfillment, equality, freedom, diversity, care for others, and concern for social justice. It means addressing the issues of science for all, scientific literacy, mass education and elite science education—and the places and levels where each may be appropriate. There is a need for science education to be grounded in the world of the student, acknowledging their experiences and the needs of their society, and fully inclusive of their gender, ethnicity, and culture. The current process of rethinking the goals of science education can draw on international work on student learning and conceptions of teaching and the work on cultural and gender standpoints.

Goals in Education for All, Science for All, and Traditional Science

Important calls for reform are embodied in the phrases "Science for All" "Education for All," and "Inclusive Science." These slogans do much to encapsulate the best of contemporary thought and challenges in science education. They have been used as the titles of international conferences, as the titles of sets of resolutions from international agencies, as well as in the titles and text of numerous books and articles; the words have become part of the common parlance of science education. A danger is that by their very currency, they set up false or unrealistic expectations of their accomplishment, or indeed complacency that they have already been accomplished.

Exploring the idea of "Education for All," a world conference was held in Jomtien, Thailand, in 1990 under the sponsorship of United Nations. The Education for All issues are of immediate relevance for science education—the role of science education in primary school education and the nature of the preparation provided in primary schools for later education. The basic knowledge and skills that allow adults to improve their quality of life and opportunities to participate in and benefit from social and economic development would include basic knowledge where science plays a central role such as health, nutrition, safe water, and child rearing. Targets for women are of great importance in the concept of Education for All (the literacy rate for women is lower than that for men in numbers of countries), and this is linked to the crucial role women play in traditional child rearing and the maintenance of health as well as their participation in the wider scientific and technological education.

The place of science and technology in the curricula of formal education and lifelong education has been the focus of a series of UNESCO conferences (UNESCO 1983a,b, 1986, 1988, 1989) with the idea of Science for All as a theme for school curriculum development. It has been repeatedly argued that any new curriculum developments at school level must learn from the results of earlier reforms. It has been argued that better curricula have been developed for the education of the small proportion of an age group from whom the future scientists and science-related professionals will be drawn. However effective, science education has not been achieved for the larger group who will not complete secondary education or will not continue with any formal education in science after they leave school. It should also be recognized that there is a comparable situation at universities in an era of mass education. In those universities changing to a pattern of generalized and specialized degrees and in universities with more traditional patterns where discipline majors and non-majors are taught together, the question is what science and for whom.

Science educators have regularly turned to describing the desiderata of reformed school science programs. The characteristics described by Hurd in 1985 were:

1. School science should reflect modern science and technology.
2. The subject matter should have both personal and social relevance and scientific and technological validity.
3. Scientific literacy, intellectual skills, and knowledge should be a major goal so future citizens can make reasonable decisions about such issues as environment, nuclear power, and human transplants.
4. Students should learn that decisions should be well founded on evidence as well as value and ethical judgments.
5. School science should provide concepts and skills necessary for self-directed life-long learning.
6. Part of the science curriculum should be devoted to current technological and social issues such as food and energy resources, space exploration, and pollution.
7. Science courses should be a part of general education, but advanced, specialized courses should be offered for secondary school students who may pursue scientific and technical careers.

Whilst some of the desiderata might apply more to industrialized countries, Lewin's (1990) picture for developing countries was very similar in emphasis, if not identical in content, including:

1. Science and society, and environmental issues, will appear frequently in new curricula as their importance for the preservation of global equilibria becomes ever more apparent.
2. Technology will form a new focus of interest in curriculum development, complementing or even leading new science curricula with an emphasis on the skills needed to solve real-life problems.
3. Broader definitions of science education that absorb health education, nutrition, earth sciences, and so forth will become more acceptable, as will links with other curriculum areas.

Reflecting on the similarity of these goal statements with others developed over a decade earlier, Lewin is inclined to believe that the continuing statements of goals yet to be achieved represent the hopes and dreams of science educators whose views have not been congruent with those of their ultimate clients (parents, students, politicians, and employers) and whose insights have not proved compelling to policy makers The implied challenge to science educators is obvious. What would be the characteristics of a Science for All? The desiderata outlined by Fensham (1985) were similar to those described above by Hurd but went further in specifying the nature of learning and teaching:

1. Its pedagogy should exploit the demonstration and practical modes that are inherent to much science and also to the cultural learning that occurs prior to and outside schooling.

2. The learning of practical and cognitive skills should flow naturally from the relevant nature of the science topics rather than be themselves a primary focus of the learning.

3. Its assessment should recognize both the prior knowledge that the learners have of scientific phenomena and their subsequent achievements in all the various sorts of criteria for learning that make up the curriculum.

How might Science for All occur? Fensham (1985) explored the advantages and disadvantages of three options: a policy of containment (where traditional elite education might be confined to an upper level of schooling), identification of Science for All as a limited form of science education that is a precursor to specialized vocational education or as one possible course of study within the curriculum that a school offers. Many writers have warned of the potential incompatibility of science for all and traditional science. In the United States context, Klopfer and Champagne (1990) reviewed the "ghosts of crisis past," analyzing problems in the provision of general science education as centering on the professional perspective, the chimera of a national curriculum, curriculum reforms starting too late in the education cycle and top-down, and the distribution of ownership of reformed curricula.

Finally, what are the characteristics of the traditional curricula, the prevailing science curricula in many countries that serve both preparation and selection for higher study? Many science educators (see for example, Fensham, 1985; Lewin, 1990; Walberg, 1991) seem to agree that traditional curricula involve the rote recall of a large number of facts and methods that lack social usefulness, do not allow the scientific usefulness of concepts to be experienced, involve an abstract system of scientific knowledge, use life experiences and social applications as exemplifying rather than as the essence of science learning, justify practical activity by its relationship to conceptual learning rather than by its provision of essential skills, and value the quantitative more highly than the qualitative In the light of research and practical experience of teachers and students, it may be judged that many of these characteristics are described in a pejorative sense.

It is one of the great values of the Science for All idea that it has not only created a sense of urgency about the provision of general science education but has also illuminated the need for change in traditional elite science education.

Goals and Student Learning

The goals for science education as a whole could include learning in some or all of the following content areas (adapted from Fensham 1985):

1. Knowledge: facts, concepts and principles used in science;
2. Applications of knowledge: in real or idealized situations;
3. Intellectual skills used in science, for example, classifying, control of variables;
4. Practical skills: psychomotor operations in use of equipment and instruments, ways scientists investigate the natural world;
5. Problem-solving: the combination of scientific knowledge and intellectual skills to solve theoretically presented problems;
6. Science traits and attitudes;
7. Applications of science and technology;
8. Personal and social needs;
9. The evolution of scientific knowledge; and
10. Boundaries and limitations of science

However, a glance at the list rapidly shows it to cover a wider and richer range of learning types than are found in most traditional curricula, where, despite some lip service in statements of overall goals, the learning types are often limited to the first four, with the last three not addressed at all. The goal statements of the new national curriculum in the United Kingdom would, by comparison, seem to be more those of a "traditional" curriculum than a "new" curriculum. There are, however, numbers of developing countries where a much broader and indigenous curriculum has been established (Lewin, 1990).

What factors influence students' learning? We can turn first to international syntheses of research studies conducted on learning at school level and consider the factors that would influence students' performance on standardized tests. Walberg (1991) points to 9 factors that have been shown to increase learning in science.

Student Aptitude

1. Ability or preferably prior achievement as measured by the usual learning tests
2. Development as indexed by chronological age or stage of maturation
3. Motivation or self concept as indicated by personality tests or the student's willingness to persevere intensively on learning tasks

Instruction

4. The amount of time students engage in learning
5. The quality of the instructional experience including method (psychological) and curricular (content) aspects

Psychological Environments

6. The "curriculum of the home"
7. The morale or climate of the classroom social group
8. The peer group outside school
9. Minimum leisure-time television viewing

In some ways these named factors speak for themselves. With aptitude and reasonable instruction, a student will learn. In a good psychological environment, a student will learn better. The answer to the question "Do teachers and instruction make a difference?" is "Yes" and the mechanism is via quantity and quality of instruction.

According to Walberg, improving the quantity of instruction means more time spent on science, where students could decide to spend more hours studying with fewer hours watching television, schools could allocate more hours in the day to science, or schools could operate on more days per year. In Walberg's terms, improving the quality of instruction may be thought of as more efficient enhancement of learning time. His syntheses suggested that general teaching methods that have increaseed learning rates include conventional teaching when well done, mastery learning and comprehension teaching; specialized science teaching methods include fostering learner autonomy in science and activity-based teaching.

Walberg (1991) found the Japanese education to be superior to that of the U.S. in a number of ways—although aiming for high levels of mass scientific literacy rather than high levels of participation in elite science or mathematics, Japan nonetheless ranks first in international science and mathematics achievement score comparisons. A rigorous nationalized curriculum with very carefully graded work with a mastery orientation is credited with contributing greatly to the success of Japanese students. This occurs in a cultural setting for learning that is different from that in Western countries, in the responsibility of students and their families for learning, and in the attribution of success, hard work ahead of ability.

Many studies at school and university levels have shown that traditional science courses, as distinct from traditional courses in other areas, seem to be characterized by heavy emphasis on rote recall of facts. Presumably, in each science discipline there is a "vocabulary" to be acquired—most chemistry graduates can see the merits of having the elements of the periodic table ready to mind without the need to consult a book each time. But what emerges as important is the intention behind a student's decision to commit to memory some science material. It should be part of their meaningful learning rather than empty memorization of material that is not well linked in cognitive structure and that will be forgotten as soon as the examination is completed.

The forms of assessment play a crucial role in determining students' approaches to study. The widespread use of multiple-choice questions and short, quantitative questions may give students the message that what is required is recall of isolated bits of knowledge On the other hand, the moves from a traditional science culture to what has been called a "portfolio" science culture have been accompanied by the development of portfolio assessment, more attuned to the needs of individual students, and, it is hoped, more encouraging to conceptual change in science and to improved attitudes to science, especially in girls (Duschl & Gitomer, 1991; Walberg, 1991).

Research on student learning has shown that an important dimension is the role of a student's prior learning in affecting any new learning task. This has been established and explored by those working with Ausubel's theory and its practical implications (Novak, 1977; Novak & Gowin, 1984; Novak, 1990).

Students can take different approaches to their learning: different students may take different approaches and the same students may take different approaches in different subjects or on different topics (ability plays only a relatively small role). Most teachers say they would greatly prefer that students take a thoughtful approach to their work, yet students often do not. The use of interviews and questionnaires has lead to a better understanding of students' approaches and the factors affecting them and a contrast is made between deep and surface approaches (Entwistle & Ramsden, 1983; Ramsden, 1984; Biggs, 1987,1989). Science educators in this tradition have argued that comparisons such as those reported by Walberg (1991) may be concerned with notions of quantity or efficiency but are unable to shed much light on the nature of student approaches and the quality of their learning outcomes.

The following account of student approaches to learning is adapted from Ramsden (1992):

Deep Approach

Intention to understand. Student maintains structure of task.

> Focus on "what is signified" (e.g., the author's argument, the concepts applicable to solving a problem, the processes of scientific inquiry being used or the hypotheses being investigated)
>
> Relate previous knowledge to new knowledge.
>
> Relate knowledge from different courses.
>
> Relate theoretical ideas to everyday experience.
>
> Relate and distinguish evidence and argument.
>
> Organize and structure content into a coherent whole.
>
> Emphasis is internal: "A window through which aspects of reality become visible and more intelligible."

Surface Approach

Intention only to complete task requirements. Student distorts the structure of task.

> Focus on "the signs" (e.g.. the words and sentences of the text, unthinkingly on the formula

needed to solve the problem or on the requirements for recording laboratory data).

Focus on unrelated parts of the task.

Memorize information for assessments.

Associate facts and concepts unreflectively.

Fail to distinguish principles from examples.

Treat the task as an external imposition.

Emphasis is external: demands of assessments, knowledge cut off from everyday reality.

International evidence suggests more strongly than ever the need to distinguish between mindless rote learning and the committing to memory of meaningfully understood material (Watkins, 1993). It is assumed that rote learning alone would lead to poor performance. Some research at school and university levels has found that teachers tend to portray their Asian students as rote learners, but it has also been found that students from Hong Kong, Nepal, and the Philippines are less inclined to take surface approaches that some Western students (Australian). When Chinese and Japanese students in their native countries outperform Western students in theirs, their success has been attributed to hard work. This is only part of a picture that is showing Chinese conceptions of success and responsibility for academic performance to be radically different from that of Western cultures. Watkins describes memorizing and understanding to be discrete in Western cultures but interwoven in Chinese culture.

Conceptions of Learning and Teaching

How do students think of their learning? In research based on interviews with university students, Saljo (1979) found two qualitatively different conceptions of learning. On the one hand, learning is thought of as absolutist: students feel that learning involves a quantitative increase in knowledge, learning involves memorizing, and reproducing facts and skills that are learned can be retained for later use. On the other hand students may have a conception of learning that shows the more internal or personal aspects—students feel that learning is making sense or abstracting meaning; learning is interpreting and understanding reality in a different way.

Implicit in these descriptions of students' conceptions of learning there are students' views of teaching. Students who think knowledge is absolute and learning is reproducing are likely to think of the teacher as information giver who takes all responsibility for selection and presentation of content. Students who think of knowledge as relative and learning as making sense are likely to think of their learning as independent of the teacher, with the teacher as facilitator. Correspondingly, teachers may view their teaching more as an information giver, or as a tour guide, or a facilitator of students' development.

For some students, having a restrictive view of the nature of learning is likely to prevent them from taking deep approaches to their study. Teachers will be interested in fostering changes in such restrictive students' views and can do much to encourage students to reflect on and change their own views of learning.

Rethinking Goals of Science Education

As we go about the task of rethinking the goals of science education in the light of what we know about learning and teaching, we would do well to heed criticisms of the explicit and implicit goals of traditional curricula to date, especially the emphasis on rote recall of facts lacking social usefulness and the use of social applications as exemplary rather than the essence of science learning, in short, lack of connection with the world of the learner.

If science education is not well linked with the world of the learner, it risks being alienating, unsatisfying, and unsuccessful. If it excludes some distinguishable groups in society, it obviously cannot claim to be inclusive science or science for all. Discovery-oriented science curriculum materials may be biased toward children of the middle and upper classes and to particular cultural groups, and gender bias operates or is reinforced in many ways ranging from enrollment patterns in science to access to science tinkering activities (Fensham, 1990). According to Lewin (1990), gender bias is more an issue in industrialized countries where only with recent efforts have some curriculum materials begun to portray women scientists at work and to recognize their achievements. In developing countries, gender has been less of an issue than the avoidance of ethnic stereotyping, the provision of national role models, and a change from showing science as foreign, expert, and culturally unsympathetic. Questions of world view and compatibility of world view with modern science have rarely arisen in industrialized countries until recently, but these are questions of central interest in some developing countries.

These issues are being explored in great depth in research on student learning, feminist scholarship in science and science education, and by observers of non-Western social thought. At the heart of the exploration is the gap between the self of the learner and the phenomenal world in which the learner lives. What is needed is rethinking of the goals of science education with the learner at center.

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Rethinking the Goals of Science Education in the Context of Meeting Basic Learning Needs

Sheila Haggis

Rationale

The World Declaration on Education for All, adopted unanimously by delegates from more than 150 countries at the UN World Conference on Education for All, Jomtien, Thailand, March 1990, is a call for action to meet the basic learning needs of all children, youth, and adults throughout the world. As part of meeting basic learning needs, the Conference recognized the urgent need for a world community of scientifically and technologically literate citizens.

For basic education to be viable in any society, it must address the issue of the impact of unprecedented scientific and technological development. To be truly independent, a country needs to be able to ensure that all its citizens are given the opportunity, starting from the earliest stages of education, to gain an understanding of science and technology and with it the capacity to put them to appropriate use, adapting, and developing them to meet collective needs. Although the great majority of people may not work directly with new technology, all live in societies where technological innovation is increasingly permeating almost every aspect of daily life, no less in rural areas than in urban communities. Basic scientific and technological knowledge and skills have become indispensable. A country's engagement in the development and use of new technologies has profound implications for employment and skills requirements. As new technologies (especially those involving applications of informatics) are introduced, both skilled and unskilled jobs that have predominated in many areas of employment are disappearing. In contrast, there are new job opportunities for high- and middle-level professional personnel who, equipped with creative skills, are able to improve the quality and the management of their work. Sound basic literacy and numeracy skills and, to an increasing degree, problem solving and abstract reasoning abilities constitute the cornerstones of sustainable social and economic life today .

The ability to cope with issues such as population, health, environment, energy sources, finite resources, risk assessment, global change and sustainable development at the local, national, and international levels is a basic learning need. Such social and environmental issues all call for an increasing degree of scientific literacy on the part of the populace for the understanding and for the decision-making required to stimulate the necessary action. Science and technology are part of the culture of all societies and should not be conceived as mental and manipulative pursuits isolated from society. Even where basic education in schools includes a component of science and technology, bridges need to be built linking formal and non-formal education with real life so that what is learned in school comes to be applied naturally and effectively when dealing with everyday problems.

The Nature of Scientific and Technological Literacy

Science and technology are inter-related but contrasting activities. The role of science is essentially a quest for knowledge—a process of discovery, of exploring the world. It includes processes such as observing, posing questions, suggesting reasons for events and phenomena, predicting, finding patterns and relationships, and manipulating materials and equipment effectively, to name but a few. These are things that children love doing, and the earlier the age at which they are introduced to these processes, the better.

The role of technology is to use and apply knowledge in the service of humanity. Today, technology is more and more concerned with the application of scientific knowledge to fulfill particular individual, community or national needs. Thus airplanes, insecticides, preserved food, computers, wine and bio-genetically produced vaccines are all direct products of technology. The know-how and creative processes (including designing) that utilize tools, resources and systems to solve problems, to enhance control over the natural and man-made environment, and to alter the human condition are all characteristics of technology.

One project aimed at reforming education in science, mathematics, and technology with a view to promoting scientific literacy is based on the belief that a scientifically literate person is:

> *. . . one who is aware that science, mathematics and technology are interdependent human enterprises with strengths and limitations; understands key concepts and principles of science; is familiar with the natural world and recognizes both its diversity and unity; and uses scientific knowledge and scientific ways of thinking for individual and social purposes.*
>
> AAAS, 1989

This project has put forward an agenda for action that suggests steps that individuals, institutions, organizations, and government agencies can take in working together for reform. The agenda advocates the following:

1. Establishing scientific and technological literacy as a national goal;
2. Reaching an understanding of what constitutes scientific and technological literacy;
3. Clarifying the long-range goals of scientific and technological literacy in the particular socio-economic context;
4. Clarifying the significance of such goals for the learning needs of all children at different levels of the formal education system, and for non-formal and lifelong education;
5. Developing educational materials that are consistent with the specified objectives and content;
6. Training and re-training teachers so that they can implement the new curricula; and
7. Bringing about collaboration between the educational community and the scientific and technological community.

This is but one agenda for characterizing scientific literacy and putting into operation a program for its attainment. Each country needs to develop its own conceptual framework and plans for designing and putting into operation its own program, and each can learn from others.

Issues Concerning the Curriculum

Science and technology education should be integrated into basic education. The skills of reading, writing, and calculating, for example, can be learned quite as well in the context of science and technology as in the more conventional contexts. Fears that the subject area is hard and remote must be overcome, preferably by initiating children in appropriate ways into science and technology concepts and processes at an early age. Data from almost 100 countries in all parts of the world, gathered by an international study (UNESCO, 1986), of the extent to which science, mathematics, and technology are currently taught in schools, have made it possible to begin to identify issues which call for consideration in future curriculum planning.

Science

Although science is firmly entrenched in secondary school curricula world-wide, it is much less prevalent in the early years of schooling. Although, in many countries, the aims of primary schooling include nurturing scientific concepts, it is a goal difficult to achieve because most primary teachers have a weak background in science, lacking exposure to the concepts and processes of science in their own education and lacking both pre-service and in-service training in science teaching methods. This is extremely serious. For many children, particularly in developing countries, primary education is the only formal education they are likely to receive, and it is thus specially important for any science teaching to be closely related to the local environment of the young child.

Technology

The most surprising finding of the study relates to the place of technology in school curricula. Universally, country by country and region by region, it appears that technology education is almost entirely absent. One difficulty is to attach an agreed meaning to the term. There is no precedent in school for teaching it. As a concept, it is little understood, and it is often confused with technical education such as metal-work, woodwork, or needlework. Technical skills are, of course, needed in a technological enterprise, but if the role of technology is to apply existing knowledge to solve human problems, it is evident that education in technology should cultivate problem-solving and creative processes, such as planning and designing. It is important, too, for it to cultivate an entrepreneurial approach to invention and "creative" problem solving in practical ways. For many learners this could, later in life, provide a key to survival, notably in small-scale enterprises and in self-employment.

Science and Technology in Primary School Education

It is well known that in many countries efforts are being made to introduce science into primary school curricula. Unfortunately, this is often seriously hampered by the inadequate background and preparation of teachers and the lack of adequate materials. It is, however, encouraging to note that in recent years, countries in Asia and the Pacific, among others, have been responding to the challenges of science and technology by attempting to relate teaching in these content areas to practical problems in the community concerned with the environment, agriculture, health and other contemporary issues of development.

Science

It is now widely recognized that the most effective and relevant science learning takes place through the process of solving problems that occur in or are immediately "connectable" to the life of the learner, rather than in contrived situations in a classroom. For example, good science education and health education can go hand in hand. Learning in science must also be based on the pupils' own knowledge and experiences so that they can achieve real understanding; this means beginning with familiar objects and phenomena encountered in the student's own world. At the primary level it is quite possible, even with minimal apparatus, to embark on a program of active inquiry, investigation, and problem solving that provides experience of ways of handling evidence. Children can be encouraged to observe, raise questions for further inquiry, generate hypotheses, plan their investigations, record and present results, interpret data, and so on. It is useful, whenever possible, for these activities to take place outside the classroom. Such an approach can promote the development of thinking pupils who will become thinking citizens, and teachers must be encouraged to put it into practice.

Technology

The difficulty of attaching an agreed meaning to the term "technology" is compounded by the fact that so far comparatively little work has been done with regard to what technological activity is appropriate at the primary school level. It is necessary in every country for the relevant educational authorities to specify the overall meaning to be attached to the term "technological literacy" and then to relate this to the predominant technology areas in a particular setting. In a rural setting, the predominant technology is likely to be found in agriculture; in an urban setting, particular manufacturing processes may provide the focus of attention. Even the most technologically literate citizens do not understand all technologies. There are some that each person uses and should understand, such as those of simple tools. Although few will need to master in depth the technologies involved in the design and production of complex machines such as the motor car, television, or radio, all should be educated in the use of basic technologies essential for the effective and safe use of the highly complex, sophisticated and often potentially dangerous machines and equipment that have already entered into the day-to-day life of ordinary people in virtually all parts of the world.

Science and Technology in Out-of-School Education and in Non-Formal Programs

Throughout the world increased attention is being paid to the promotion of out-of-school activities and non-formal programs in the fields of science and technology. They include science clubs and fairs, and the popularization of science and technology through mass media, museums, and science centers. Such activities and programs are important because they serve a wide variety of educational objectives related to a varied clientele. This includes school children (through enrichment activities that supplement formal science and technology programs), early school leavers and drop-outs (in remedying gaps in scientific and technical knowledge and skills), and the general public (in promoting the understanding of scientific and technological developments).

The nature of out-of-school science and technology education should be such that it both complements and supplements science education in school. It should include those activities that are not easily provided at school, and also those that the constraints of the curriculum or time usually exclude. The co-ordination of in-school and out-of-school experience can help children to take on roles that they have to play in society after leaving school. In many countries there is a wide variety of out-of-school activities relating to science and technology education. They include:

1. Visits to industry and field trips organized by the school;
2. Field or environmental studies centers that children can attend, with their teachers, for short periods during school terms or vacation;
3. School farms, where children can study animal and crop development;
4. Science and technology fairs, exhibitions, and clubs that encourage children to collect together experimental work relating to projects. These science exhibits can lead to displays in regional and national science fairs or science exhibitions.

In all these activities, the teachers should be involved as coordinators, animators or advisers. Specialists should also be involved, for example, qualified agricultural extension experts, directors of field studies centers, and scientific advisers on project work. A proper structure for out-of-school activities should be provided and further guidance should be made available through case studies and country reports.

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An Alternative View for Constructivism and Non-western Science Education Research

William Cobern

Introduction

Educators have long viewed science as either a culture in its own right or as transcending culture. Recently, many educators have come to see science as one of several aspects of culture. In this view it is appropriate to speak of western science because the west is the historic home of modern science, modern in the sense of a hypothetical-deductive, experimental approach to science. It follows that science education is an aspect of culture, and thus, it is appropriate to speak of western science education (Ogawa, 1986; Cobern, 1991). It is likely that a simple transfer of Western educational practices to other cultures, including ethnic minority cultures within the West, will not do.

Educators tend to focus solely on the careful explication of scientific concepts, the "domestic affairs" (Hills, 1989, p. 183) of science education leading to the view that science curricula are readily trasferable. Instead, educators must grapple with how to help students make sense of science concepts that are often quite foreign. This "foreign affairs" focus is based on two premises. All science exists in cultural context, and the teaching and learning of science is often a cross-cultural activity.

Science makes more than scientific sense to a scientist. It makes sense within the scientist's entire view of reality and significance. A classroom lesson seeks to make scientific sense of a scientific concept, but this becomes a cross-cultural activity when the scientific sense does not automatically fit with the students' more global views of reality. One would think then that the further students are culturally removed from the west the more seriously one ought to address the relevance of culture in science education.

In 1980, Lutterodt noted that to significantly improve science learning in developing nations, researchers and educators needed to know more about the influence of local culture on science learning. Ten years later, Lewin observed that the profession still had "a long way to go in developing ways of representing science that are not foreign, expert, and culturally unsympathetic" (1990, p. 18). Whether among ethnic minority cultures in the west or in non-western developing countries, the role of culture in science learning requires greater attention. To date, approaches to science teaching among ethnically diverse students that use transferred, marginally adapted curricula have not been effective, and it is time to consider a change of focus. I believe that researchers can use a constructivist model of learning to both support the need for, and the facilitation of, investigations of how science education can be formulated from cultural perspectives.

Rationality is Not the Issue

In the west, science is assumed to be an integral part of western culture. In theory, science is not alien to people of western culture. What interests western educators and policy makers is achievement in science, particularly the comparative achievement in science among students of various western nations and Japan. Although educators in non-western, developing nations share an interest in achievement, questions arise in these nations that rarely arise in the west: questions about one's understanding of the natural world, one's relationship with the natural world, and the understanding of casuality. These are cultural questions about world view and the compatibility of various non-western world views with modern science (e.g., Abimbola, 1977; Ogunniyi, 1988).

To date, Piagetian developmental theory has been the framework of choice for most cross-cultural research in education. However, developmental theory has never quite escaped the charge that it is provincially western (Modgil & Modgil, 1982) because non-western students typically do not perform as well as western students on Piagetian-based tests of reasoning ability. The problem stems from a paradoxical relationship between logic and understanding. Piaget designed a set of clinical interviews based on formal propositions of logic. He inferred levels of cognitive development from performance on interview tasks. For use in education research, others have designed paper-and-pen assessments of reasoning ability based on Piaget's clinical interview procedures (e.g., Lawson, 1978). In either case, the inference is that people are logical if they can successfully complete the assessment tasks. These devices, however, involve the research with a rather problematic assumption. To assess reasoning ability, the researcher must first assume that the premises of the assessment procedures are correctly understood by the subject being assessed.

Taking as opposite tact, Smedslund (1970) noted that this assumed understanding can only be determined by "observing agreement or disagreement as to (1) what statements are *equivalent with* the given one, (2) what is *implied by* the given statement, (3) what is *contradicted by* the given statement, and (4) what is *irrelevant to* the given statement" (p. 217).

The difficulty is that if the subject cannot reason logically, the subject will not be able to note equivalence, contradictions, implications, or irrelevance, leaving the researcher unable to determine whether the subject actually understands the premises of the task. Thus, for the researcher to measure use of logic, the researcher must make the counter-intuitive assumption that the subject *understands* what is happening. Moreover, if the researcher persists in the counter-intuitive assumption of understanding, there remains a further dilemma. In effect, the research assumes what is being tested.

In recent years, numerous western scholars have turned to misconception and alternative framework research. The researcher probes for understanding, implicitly assuming that the subject is logical. If this reversal of assumption and variable is tenable *within* western culture, how much more tenable must the reversal be for cross-cultural research? In cross-cultural research involving western-derived developmental theory and its measures of reasoning ability, for a researcher to assume understanding virtually assures a negative finding. Abiola (1971) concurs:

> *In many investigations, including those conducted by Africans, the imported research instruments . . . have been taken out of the conceptual context in which they were developed . . . If you use a culture-bound normative instrument, you end up with a better/worse comparison inference or "explanation"; in most cases it is worse.*
> (p. 63)

To be otherwise in such research, the non-western subjects would need to have acquired the particular understanding assumed by the western-oriented theory. That this will happen is the implicit assumption undergirding the straight transfer of curricula. Students must conform to a particular understanding to avoid the label of irrationality.

Horton (1967) and Elkana (1977) argued persuasively that the cognitive activity of traditional cultures is far from primitive though clearly not scientific in the modern sense. Jean Lave's studies of mathematical problem solving among Africans involved with traditional trades empirically corroborate the Horton/Elkana thesis (Lave, 1988) as does other research on everyday cognition (e.g., Hatano, 1990). Traditional culture poses no threat to logic and thus, on these grounds, need not be view as an impediment to the learning of modern science. Logical thinking in much research assumes a western-based understanding of phenomena. Clearly, anyone who maintains a culturally specific view of the world is not going to score well on these measures of logic. This is unfortunate because the promotion of science learning does not require a focus on logical thinking, but a focus on understanding.

Cultural Issues and Curricular Adaptation

Garrison & Bentley (1990) called the decade of the 1960s the "golden era" of North American and European science education curriculum development. Prather (1990) called the events of the 1960s a "revolution in science education" (p. 12). UNESCO and other governmental agencies arranged for the transfer of many of these curriculum developments to non-western, Third-World nations to aid technological development and modernization. The prevailing attitude toward the transfer of scientific knowledge was little concerned with culture. Through education, modern science is brought into developing societies where it can displace non-scientific ideas. However, all too often educators held naive views about adaptation. Cultural adaptation simply meant changing to "terms of tropical ecology and meteorology, and increased rates of reaction in the warmer climate [and substituting] Lagos for London, cedis for dollars, mangoes for apples" (Wilson, 1981, p. 27).

Based on his extensive research in Papua, New Guinea, Maddock (1981) called for a more anthropological approach to science education. Yet, 6 years later, Urevbu (1987) observed that concerns about cultural sensitivity in science education had yet to be heeded. Lewin repeated this observation in 1990. Lewin noted that at the end of the 1980s indigenization had succeeded to the point that most former colonial nations had developed their own science programs, but too often indigenization continued to mean the superficial adaptation of essentially Western curricula. The profession *still* has "a long way to go in developing ways of representing science that are not foreign, expert, and culturally unsympathetic" (Lewin, 1990, p. 18). Science textbooks from around the globe remain strikingly similar (Altbach, 1987; Apple, 1992). Some similarity is to be expected. For example, one expects a discussion of the observed phenomenon known as photosynthesis to appear in all basic biology textbooks regardless of cultural location. However, science is far more than a distilled and purified set of objective facts that compel acceptance. It is no longer tenable for teachers to claim that they are teaching *only* science (Fourez, 1988; Eger, 1989). It makes sense that an isolated scientific concept (e.g., photosynthesis) is acultural, but not the milieu in which the teacher, textbook, or curriculum situates the concept. The degree of similarity among science textbooks and curricula across cultures is unwarranted.

Assumptions about knowledge and reality, values and purpose, and people and society that undergird modern science are grounded in western secularism. This point has been thoroughly addressed by those interested in feminism, culture, and religion (e.g., Deloria, 1992; Johnson, 1991; Whatley, 1989). However, curriculum adaptation too often has simply meant the exchange of textbook examples or photographs (e.g., wheat to rice or white scientist to black), without addressing underlying assumptions. The failure to recognize the need for authentic cultural sensitivity with regard to these assumptions has led Third World science education into difficulties. In a series of studies between 1972 and 1980, Maddock (1983) found that science education in Papua, New Guinea had a significant aleinating effect that separated students from their traditional culture: "... the more formal schooling a person had received, the greater the alienation ..." (p. 32).

The good of any nation or society involves several, often competing, interests. The good is rarely based on a single issue, even one as important as the advancement of scientific learning. However, the advancement of science and science education often competes with national interest in maintaining the integrity of traditional culture. One should ask to what extent efforts to promote scientific literacy in non-western nations have inadvertendly and unnecessarily pronoted a western, or otherwise alien, world view?

I take to task the implicit assumption in much of the literature that non-western, non-scientific ideas are inherently irrational, an assumption grounded in the positivist ideology that scientific thinking is the ultimate measure of rationality (Adas, 1989). People do not believe things that do not make sense. They believe precisely because sense *is* being made—because there is rationality. A reader would be mistaken to infer that this discussion is soft on superstition, or that science is being reduced to an aspect of cultural relativism.

My view is that *there is* middle ground to be discovered, but it will not be discovered if the focus of attention is always on the matter of traditional culture and its potentially adverse influence on science education.

Science content is science content regardless of culture, to be sure, but not so with its communication. Communicated science, which includes science education, is inculturated (Apple, 1992). In the jargon of education, there is always a hidden curriculum. This raises two issues that have received little attention. The first issue is the potentially adverse influence of an alien hidden curriculum on the integrity of a traditional culture. The second issue concerns the potentially adverse influence on science education among those who are alienated by an alien hidden curriculum. We may not understand the complexities of culture change and adaption, but culture does change. Any new idea brings change as people in the host environment react and adapt to the new idea. Modern science will influence a non-western culture as surely as it has influenced western culture. My concern is not about change per se, but about unwarranted influence. Must African nations, for example, adapt to science and adapt science to African culture exactly as the western nations have done? To what extent can science be taught without the cultural dress of the west? To what extent does western garb inhibit the learning of scientific concepts? What cultural changes are necessary for effective science learning? What changes are unnecessary? These questions arise because, relatively speaking, modern science and science education are newly imported phenomenon in the cultures of most developing countries—and for the most part, imported in Western packaging (Ladriere, 1977). To effectively address these questions, researchers must have a view of learning that is transferable across, and appropriate for, different cultural environments. Constructivist thought supplies this view.

Constructivism

In marked contrast to developmental theory, constructivist theory facilitates a focus on understanding. Constructivism is a model of how learning takes place (Yager, 1991), rather than a theory of how rationality develops. The focus of constructivism is the content of thought rather than the formal operations of logic that thought can involve. Yeany (1991, p. 1) alluded to a Kuhnian paradigm shift and suggested that constructivism may lead "to a gelling of existing thought as well as the stimulation of new ideas." The existing thought includes Piaget's concept of accommodation and assimilation, Ausubel's concept of meaningful learning, and post-empiricist philosophies of science. Moreover, one of the attractions of constructivism is its utter simplicity. However, the widespread adoption of the term constructivism in various areas of education has actually created considerable confusion and controversy. For all its simplicity, the term is defined differently by different people. Many take a pragmatic approach to constructivism focusing on constructivism as a description of learning that can be turned about and used to guide teaching. Much of the research on models of conceptual change is pragmatically oriented (e.g., Driver, 1989; Osborne & Wittrock, 1983). Ernst von Glasersfeld (1989) has argued for the more philosophical view that constructivism is essentially an epistomological commitment to instrumentalism grounded in philosophical idealism. For him and other radical constructivists, it is fundamental that "cognition is adaptive and serves the organization of the experiential world, not the discovery of ontological reality" (Wheatley, 1991, p. 10; also see Tobin, 1991). So, what is constructivism?

In an effort to foster an intuitive grasp of constructivism, what follows is a descriptive narrative intended to evoke an understanding of learning that is transferable across, and appropriate for, different cultural environments. I believe that this is best done by focusing on the post-empiricist roots of constructivism.

All people in every culture wish to know about the world around them, whether one speaks of the world in physical, social, or even spiritual terms. Science is a discipline that tells us about the physical world, and in modern science one's senses are critical. One uses sight, hearing, feel, and taste to learn about physical phenomena. Instruments as simple as an ordinary ruler or as complex as a radio telescope or mass spectrometer extend the range of basic human senses. The naive view of empirical science is that human senses provide authentic data corresponding to the real world. Experimentation keeps subjectivity in check. But is that realy how our senses work? Consider that science exclusively focuses on measurable sensation. For example, physicists typically are not nearly as interested in the color of an object as they are in measurable electromagnetic wavelengths emitted or reflected by the object. If you want to build a color television, knowledge of electromagnetic wavelengths in necessary. However, who can say that a wavelength of 4.0 X 10^{-7} meters says any more about the reality of an object than does blueness? In fact, philosophers of science tell us that there is no answer to this question. Scientists focus on measurable attributes simply because they have chosen to do so—it works for what they want to do.

There is another question that confronts human efforts to understand reality, regardless of the physical attributes on which one chooses to focus. How do we know that the objects of perception are actually there as peceived? As early as 1604, Kepler demonstrated that the physical image on the retina of the eye is inverted. Yet that is not how we perceive objects. We perceive them right side up. In other words, even though we *see* an object upside down, we nevertheless perceive it right side up. How then can we say that what we perceive is actually what is there? Perception appears to involve interpretation rather than simple transmission. To further illustrate the difference between sight and perception, try to imagine a person born without functioning sense organs. Somehow the person survives and one day after many years, the person's eyes suddenly start functioning. His eyes would see reflected light as ours do, but what would he preceive? A mass confusion of light, a jamble of hues and intensities, a tumult of sensation, all signifying absolutely nothing! He would not recognize a tree in front of him because he could not have had any prior knowledge of the concept of tree. Perception is the *act* of one who sees, not the passive reception of light reflected by objects. To make this more personal, I spent my first year in Nigeria going from one faux pas to the next because I simply did not understand much of what was going on around me. On the other hand, my Nigerian colleagues who had studied in America would roar with laugher recounting tales about their first exposure to American culture. This illustrates what modern developments in the philosophy of science have clearly shown—all observation is theory laden.

There are then two profound limitations on scientific knowledge. First, science is limited by its focus on selected attributes to the exclusion of others. This is a choice made by scientists, not a limitation imposed upon science by physical reality. Second, one can perceive an object only when one has pre-existing knowledge of what is being examined. The result is that scientists cannot say that they have exact knowledge of what reality is like. Rather, the scientist, drawing upon previous knowledge, interprets experience following rules agreed upon by the community of scientists. A scientist constructs knowledge to fit experience and that knowledge is fallible by virtue of lacking exactitude and comprehensiveness. Ultimately, one can never know for sure how close knowledge approximates reality. Rather, knowledge is a meaningful interpretation of one's experiences of reality, where "meaningful" means that the interpretation is externally bounded by experience and internally by what makes sense to an individual or community of individuals. Instead of a photograph of reality, scientific knowledge is much more like an artist's impressionistic painting of reality. Here lies the link with the teaching and learning of science—within and across culture.

If there were a direct link between the scientist and a physical reality independent of the scientist, one could argue for a direct link between scientific knowledge independent of any knower and the acquisition of scientific knowledge by a learner. "This follows from the principle that the appropriation of knowledge demands cognitive performance similar to the original acquisition of that knowledge" (Eger, 1989, p. 90). Direct linkage is the viewpoint of naive realism. It implies that knowledge can have an existence independent of a knower. It, thus, implies that teaching is best done by careful, methodical, detailed explication of scientific knowledge with the expectation that students will learn by receiving (i.e., memorizing) the knowledge. In fact, under the influence of positivism that taught that rationality and objectivity resided exclusively in quantitative experimental science, that is exactly how science has been taught for many years (Duschl, 1985). Moreover, this viewpoint supports curriculum transfer because it does not recognize any significant cultural influence on science.

However, if scientific knowledge is scientists' meaningful construction based on their experiences of reality, how can the learning of scientific knowledge be any different? If I cannot know reality for sure, what is it that I am learning, when I learn? In one very important aspect, there is no difference between the original deviation of scientific knowledge by a scientist and the learning of scientific knowledge by a student—both are acts of interpretation. When I learn a science concept I am constructing a personal understanding of the concept based on what I perceive the textbook, or activity, or teacher to be saying. Just as a scientist interprets experience in light of a personal background of knowledge, I learn by interpretation in light of *my* personal, culturally embedded, background of knowledge. In contrast, rote memorization involves no interpretation and is rarely meaningful; therefore, students soon forget most of what they memorize.

Constructivism is an apt metaphor. Learning is the active process of constructing, or putting together, a conceptual framework by a process of interpretation. No one learns science by transmission, at least not meaningfully. Consider the following simple dialogue:

Teacher: I say to you the man is coming.
Student: I hear you say that the man will be here in a few minutes.
Teacher: No, the man will be here tomorrow.
Student: Now, I understand that by the word "coming" you do *not* mean coming "*right now.*"
Teacher: Yes, but you are saying that for you "coming" means coming now.

Both teacher and student are learners trying to understand how the other interprets the meaning of "coming." Each has to build a concept version of "coming" that makes sense to the builder while appearing to correlate with the other's concept. The teacher here cannot communicate effectively unless he or she comes to an understanding of the student's viewpoint, that is, that the student interpreted "coming" to mean "coming right now." In constructivist thought, it is fundamental that learning involves negotiation and interpretation influenced by prior knowledge. Moreover, successful communication requires a threshold of shared prior knowledge.

In science education, it is of considerable significance that the researcher can use constructivism and meaningful learning to help make sense of a widespread occurrence among people. It is widely reported in the literature that people hold many different ideas about phenomena such as motion, force, life, and gravity (e.g., Helm & Novak, 1983; Novak, 1987). These are often common-sense ideas that frequently differ from accepted scientific viewpoints even when the people are students of science. A science teacher carefully explicates a concept, yet students still come away with quite different interpretations of that concept. Clement (1982) found that even graduate-level physics students held views of the concept *impetus* that varied considerably from the scientifically orthodox view. If learning occurred by transmission rather than construction, learners would either have a concept, a piece of it, or nothing at all. What they would *not* have are idiosyncratic versions of a concept.

Common experience clearly demonstrates that meaningful learning for some students takes place when instruction is didactic and direct. Constructivism avers, however, that this happens because an individual student has been able to make sense of what the teacher says, *not* because the teacher made the sense for the student. These students, who can successfully negotiate and interpret scientific meaning with little or no assitance, are the ones teachers consider scientifically-inclined. However, teaching for construction rather than transmission suggests that teaching ought to facilitate negotiation and interpretation based on the learner's prior knowledge. For example, this suggests that discourse between students and teacher and among students will facilitate learning. it also suggests that activity, or hands-on learning, by itself are not enough. An otherwise good inquiry lesson will fail for students if the lesson does not allow for a meaningful grappling with the concepts under study. In 1978, Novak pointed out that educators tend to conflate learning and presentation. Presentation of material, by whatever method, never guaranties learning. In summary, constructivism is a model of learning that implies that a student is always an active agent in the process of meaningful learning. A student learns not by receiving a transmission, but by interpreting a message. One's interpretations are always influenced by prior knowledge, and a treshold of shared prior knowledge is essential for communication. This raises a question. Is any textbook or curriculum ever authentically transferable, given that a textbook or curriculum written in one culture implicitly, and of necessity, assumes a shared background in that culture?

The Cross-cultural Application of Constructivism

Construction involves interpretation influenced by prior knowledge, and this suggests a conceptualization of scientific knowledge in which it is reasonable to expect culture-specific understandings of science. For example, one should not expect Nigerian students to understand science exactly the way students in western countries understand science (Cobern, 1991). This does not mean Nigerians will be *un*scientific. Rather, their scientific viewpoint will reflect their Nigerian world view and, to that extent, there will be differences.

Feminist literature argues that "the problem is not making women more scientific, but making science less masculine" (Fee, 1981, p. 87). Similarly, the problem in non-western science education is not to make it more scientific, but to make it less culturally western.

There is a balance between science culture and the problems specifically posed by science curricula. For example:

1. What do students and teachers believe about the world around them, especially the physical world?
2. How do students and teachers understand their own place in the world, especially their relationship to the physical world?
3. What is the cultural milieu in which these students' and teachers' beliefs, values, and relationships are grounded and supported?
4. What is the culture of science, and how is that culture interpreted in the school science classroom and curricula?
5. What happens when student cultures, teacher culture, and the culture of science meet face-to-face in the classroom?

6. When science is resisted, is it the science to which people object, or is it the curricular context of the science?
7. When pupils are influenced by the science curriculum, are they influenced solely by science, or are they influenced by science plus the context in which it is presented?

It is important for science educators to understand the fundamental, culturally based beliefs about the world that students bring to class and how these beliefs are supported by students' cultures, because science education is successful only to the extent that science can find a niche in the cognitive and socio-cultural milieu of students.

The importance of constructivism is that it allows one to see the naturalness of variation. It provides a promising direction for research, specifically, the exploration of cultural and metaphysical issues that are at the heart of understanding. Research must illuminate what it means to understand science from different cultural perspectives. It is, thus, crucial to ask what a uniquely African, Arabic, Asian, or Latin perspective science might be like and be incorporated into their local cultures.

Conclusion

> *In all countries, one of the major educational issues centers on education of youth in science . . . But most national leaders recognize that education of youth in science is not a simple matter. It is complicated by . . . difficulties in teaching science to many youth, especially those from social and cultural groups whose belief systems are at odds with the belief systems underlying science.*
>
> (Gallagher & Dawson, 1986, p. 1)

This attitude is grounded in a long history of the west judging non-western people with the standards of modern, western science and technology (Adas, 1989). From a constructivist perspective, it is easier to see that modern scientists and traditional people are, in one important aspect, engaged in the same activity. Both are attempting to make sense of the world around them. Rather than focusing on their different conclusions, I would focus on this commonality. As the Soviet scientist Zinchenko (1989) commented, there is no guarantee that science divorced from culture can sustain itself. There also is no guarantee that interest in science, once divorced from culture, can be sustained among students. In constructivism, the science education research and curriculum development communities have both a model of learning and a view of knowledge that is authentically sensitive to both culture and science.

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Resources for Teaching and Learning Secondary School Science in Africa

Patrick Whittle

Introduction

Most science teachers in the developed world expect to have a wide variety of resources available. These may range from printed matter such as texts, workbooks, background readers, and libraries to audio-visual aids like projectors, radio-cassettes, and video-recorders. They expect to have computers and laboratory facilities, with some sophisticated demonstration equipment and with enough apparatus and materials for all the pupils to do individual practical activities. Science teachers' associations hold meetings and publish journals to interpret well-researched curricula with clearly expressed aims and objectives, appropriate attainment tests, and thick teachers' guides. Furthermore, their pupils come with rich experiences of a world full of scientific and technological devices that pupils meet daily and about which they learn in a variety of non-formal educational experiences.

In contrast, teachers in the developing countries of Africa may face classes of 75 pupils, sharing three or four battered old textbooks, in a laboratory with only intermittent water and power. Initially, enthusiastic pupils, intelligent, hardworking and eager to learn, are discouraged to find science is all chalk and talk. Out-of-date equipment, supplied many years ago, may be in need of repair, chemicals are in short supply, and replacements are often unobtainable. In such circumstances it is easy to despair, for it is no exaggeration to say that often the science teachers themselves are frequently the chief resources. These teachers may also be underqualified and lacking in practical experience of real science or technology. Yet some imaginative African science teachers still manage to use what is available to effectively teach their subject. Many years ago in Uganda, one physics teacher said to me "I think if I had to, I could teach the whole of the syllabus, using a portable radio, a bicycle and the headmaster's car, as resources!" This may not be a desirable situation, but it is a highly desirable attitude.

One of the arguments in this paper, therefore, is that training of, and in-service courses for, African science teachers should aim to prepare them realistically for the poverty of the situation in the schools. Flexibility and resourcefulness should be characteristics that are sought and rewarded in students and practicing teachers. However, although the pupils and the environment may well have rich resources that can be tapped for teaching science, teachers will be inhibited by the nature of a western-oriented curriculum, imported books and materials, or by an examination system rewarding mainly recall of memorized factual knowledge. It follows, therefore, that for teachers in Africa to maximize the limited resources that are available, attention should be given to the following issues, which are discussed later in this paper:

1. Relevant school science curricula for each society's needs;
2. Examinations testing process skills rather than knowledge;
3. Locally researched and written school science materials;
4. Sufficient locally designed/produced appropriate apparatus; and
5. Associations and journals to share science education ideas.

African Science Curricula

The type of western education introduced into Africa at the turn of the century was closely modeled on those of each colonial master, anglophone countries using the pattern of a British grammar school. Consequently the first African secondary school science curricula were very closely related to School Certificate (or GCE) syllabi that were then in use in Britain. At first these often reflected such irrelevant topics as European flora and musical instruments or industrial processes wholly unknown in Africa (Whittle, 1977). In most countries, the curricula have now been indigenized to the extent of replacing foreign examples with local ones, but much of the original material and emphases may have remained. One notable exception is the Zimbabwean Core Science curriculum, which is still examined by Cambridge, but which has the very distinctive flavor of its strands based on the science of local agriculture, industry, energy use, structures and mechanical systems, and community life.

Purpose in School Science

In his seminal article advocating a restructuring of school science curricula, Jenkins (1992) identifies the following characteristics that are most likely to result in effective scientific literacy:

1. An imaginative, creative, stimulating subject;
2. Re-articulation of science in terms of technology;
3. Relating science to social concerns and values;
4. Empowering pupils to be effective citizens; and
5. Taking account of cognitive research.

If African countries are to produce the scientifically literate and technologically aware school-leavers the countries require for development in the twenty-first century, their science curricula will also have to move in these directions. One country that has taken action to do so is Ghana. Basing its philosophy on Horton's work on African and western thinking, Yakubu (1992) reported on the Ghanaian project to develop teacher's resource materials related to local industries and probing societal attitudes towards science and technology.

Practical Work in School Science

Woolnough and Allsop (1985) challenged science teachers to review the purpose of practical work. They highlighted the following goals to develop: (a) manual skills, (b) cognitive skills, and (c) meaningful concepts. Although Hodson (1992) has advocated a shift away from practical work in school science, in favor of computer-assisted learning, few in developing countries would be able or willing to adopt this policy. Kahn (1990) has emphasized the value of practical work for African pupils. Hodson does, however, advocate greater variety of learning activities (including practical work) in school science and clear identification of the goals for particular types of lessons. All of these could apply in Africa, where practical work is neglected, and group discussion about science and society are almost unknown. Many standard experiments could be replaced by simpler ones that could achieve the desired outcomes, and pupils and teachers would both benefit from the change. Furthermore, the relevance of school science lessons is enhanced by the use of local materials and contemporary applications from the immediate environment.

African Science Education Research

Adequate financial and human resources for thorough research and development in science education are rarely available on the African continent. Although foreign donors have sometimes made significant and well-intended inputs, these have not always been appropriate (Knamiller, 1984). It is also clear that this kind of aid is on the wane (King, 1991). A corporate body of expertise in African science education does exist, however, if only means could be found to effectively exchange information and to work together on the areas of common concern. One significant recent move in this direction has been the founding of a Southern African Association for Research in Mathematics and Science Education. One hopes its initial promise will be fulfilled so that this and other similar organizations in East or West Africa can become vehicles through which initiatives and findings may be shared. Although there are special needs in each individual country, comparison of areas of concern in science education indicate sufficient common ground to warrant a unified regional approach. This is not to suggest that Africa is likely to diverge significantly from the international movements in science education, because we all need to interact as widely as possible. However, curriculum workers in Africa do need a firm foundation of local research findings, as well as valuable input from elsewhere, from which to develop effective new science curricula.

African Curriculum Adaptation

Constraints such as those mentioned above have often resulted in attempts to base local science curricula on foreign paradigms, to adapt overseas curricula or texts, or change only one key element in the teaching of school science. The East African School Science Project and the CESAC/Aiyetoro Project in Nigeria are well-known examples of the former, while the Boleswa and Nigerian Integrated Science projects, both based closely on the Scottish "Science for the Seventies" books, illustrate the latter. Their partial success cannot be denied, and their importance in influencing later trends in science curricula have been significant. But frustrations are inevitable if, for example, textbooks are used that illustrate apparatus that is not available, or materials are developed that reflect a change of philosophy but have to be used within the framework of an old-fashioned syllabus and examination system.

In a recent feasibility study, it was suggested that a physics curriculum from Israel could readily be translated and adapted for use on the PROTEC program in South Africa, which is designed to augment formal science learning and improve Black students' career prospects in technology (Finegold, 1992). Ideas are always adapted from one curriculum to another. It will be interesting to see how the early American PSSC materials, modified for Nuffield Physics, and further modified for PTS in Israel, emerge when they have been adapted for the South African PROTEC! If there is similarity in the goals of the programs, and the students have similarities in their background, the experiment may well be more successful than some earlier adaptations for Africa. Educational experiments are notoriously long-term so that formative evaluation and further modification in the light of experience will surely be necessary.

Goals of African Science Education

In 1961, the Addis Ababa conference of African states set priorities for education for economic development, so that since then successive African nations have identified detailed aims to meet this goal. For science such aims are typified by the following quote from Ghana:

> *To develop attitudes of . . . critical thinking, awareness of cause and effect, confidence in solving problems, honesty and accuracy in reporting, awareness of the unit and limitations of science . . . in reporting, awareness of the unit and limitations of science . . . To develop knowledge of . . . the ways scientific ideas develop . . . phenomena encountered in the physical and biological environment, abilities to . . . manipulate apparatus, classify and quantify data, extract common features and patterns, solve unfamiliar problems.*
> (Whittle, 1977)

Such goals do, however, depend very heavily for their implementation on the perception of the nature of science and of education by teachers and pupils. The South African S.E.P. teachers' resource file includes one module entitled "Why Teach Science?," which emphasizes process-centered rather than product-centered science teaching and discusses some desirable outcomes for the pupils of effective science learning (Moodie, 1986). The aims of S.E.P. are laudable, but their task exemplifies that of science educators in most of Africa where the most immediate and pressing goal is to gain the all-important leaving certificate. Time-consuming discussions of science and society may be vetoed by pupils who have been known to say to the science teacher: "Let's not bother with the experiment, just tell us the result!"

Science Examinations as a Resource

The science curriculum and the examination are intimately linked, and it is difficult to change one without the other (Ware, 1991). African pupils are good at memorization, which is culturally more acceptable than critical processes (Whittle, 1982), and therefore examinations that demand mainly recall of factual knowledge are popular with both pupils and teachers. It is not advisable for science subjects, already regarded as "difficult," to suddenly increase the demands made on candidates by examination questions. They could become even less popular than other subjects that do not have the extra hurdle of the dreaded practical examination. Examination changes can only be introduced gradually after much consultation with teachers.

And yet syllabi and past examination papers are an important resource for science teachers and have a profound effect on styles of teaching. Examination syllabi that are well-framed toward clear instructional objectives and questions that are designed to test a range of abilities could have a considerable effect on the quality of African science teaching. Teachers will however, require assistance in teaching towards these objectives in the form of guides, like the S.E.P. guide, and advice from the examiners reports, interpreted through in-service workshops and meetings of science teachers' associations. African examination boards, inspectors, and teachers organizations may well require injections of assistance and support from developed countries in order to develop such guidance.

Human and Physical Resources

Children bring to school a background of experiences upon which the science teacher can draw in developing scientific thinking. Swift (1992) has shown that every country has its body of indigenous knowledge that may be more important than "imported" knowledge for meaningful learning. Secondary school pupils come with a variety of primary school experiences, often related to community life, that are frequently ignored by the secondary science teacher. They feel more at ease teaching a western view of the world than trying to incorporate traditional ideas into their teaching. At Zomba some of my colleagues are studying the thinking of Malawian children so as to improve communication and assist teachers in helping pupils restructure their knowledge in building more meaningful scientific concepts (Whittle, in press). More work of this kind has to be done in Africa to exploit the considerable resource already existing in our society.

I have resisted the temptation in this paper to overemphasize the need for localization of science teaching equipment used in African schools. Although valuable work has been done in several countries, (notably Kenya, Nigeria, South Africa, and Zimbabwe, with a Primary Science Education Project starting in Malawi), Africa is still largely dependent upon imported school science apparati, chemicals, and other materials. Many valuable sources of alternative science teaching aids could be exploited, given suitable mechanisms for doing so (Whittle, 1991). There is also an increasing body of African expertise in areas such as land, agriculture, forestry, water, and mineral resources (Graves, 1987). Much collaborative work will need to be done by the curriculum developers to involve various experts and commercial interests. Local textbooks of varying quality are becoming quite common in Africa; there is a danger that these could enshrine conservative practices in science teaching, but the trend to more indigenous applications is commendable.

African Science Teacher Education

It is my view that the science teacher will always be the major resource in the classroom. Therefore, teacher education is the key stage at which reform can be effected in science education. Ware (1991) highlights the need for continuing in-service training, not only for teachers, but for teacher educators. In my experience, I would include university subject specialists in this category because their influence on intending teachers is considerable, and not always in sympathy with the modern pedagogical practice advocated by their education faculties. It is a sad reflection on our African ability to pursue an endeavor to its conclusion that excellent innovative science teacher education resource materials produced during the Harare Generator nearly 2 years ago have yet to see the light of day (Whittle, 1992). However, that conference, and developments such as FASE, PROTEC, SEP, SGSP, STAN's secretariat, Zambian JETS clubs, and ZimSci, all provide hope for development of resources for African science teaching in the future, if we can get our act together.

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Science, Mathematics, and Technology Education and the Dysfunctional Civilization

Ubiratan D'Ambrosio

A Look into Human Social Behavior

The last 100 years has shown enormous advances in our knowledge of nature and in developing new technologies. The boundaries between science fiction and reality have been reduced. Yet the same century has shown us a human behavior that goes beyond imagination. Unprecedented means of mass destruction, of insecurity, new terrible diseases, unjustified famine, drug abuse, and moral decay are matched only by an irreversible destruction of the environment.

When Al Gore (1992) reviews the cause of what he properly calls "dysfunctional civilization," he explicitly refers to

> *. . . unwritten rules that govern our relationship to the environment (that) have been passed down from one generation to the next since the time of Descartes, Bacon and the pioneers of scientific revolution some 375 years ago. We have absorbed these rules and lived by them for centuries without seriously questioning them.*

Indeed to take things as they are, with a character of inevitability, seems to plague humankind in all sectors, not the least in labor relations and, hence, in production. Questioning established rules seem to be rejected. In an important and probably one of earliest Post-World War II analyses of the course of civilization as a whole, Norbert Wiener wrote that

> *. . . the Labor unions and the Labor movement are in the hands of a highly limited personnel, thoroughly well trained in the specialized problems of shop stewarding and disputes concerning wages and conditions of work; and totally unprepared to enter into the larger political, technical, sociological, and economic questions which concern the very existence of labor.*
>
> (Wiener, 1948)

Those two absolutely related invitations to look anew in the foundations of what is called the modern world, suggests our inquiry into the essentials of science, mathematics and technology education.

Many of the both positive and negative characteristics of the new modern world have to do with science, mathematics and technology. Morality, or rather the lack of morality, intrinsic to the current rethorics of science, mathematics and technology education should be a major concern for all of us.

The Post-World War II Scenario

Since the end of World War II, which was a showcase of major achievements in science, mathematics, and technology and something like a marketing of the enormous potentials of scientific and technological progress, the route of development was marked by emphasis on science, mathematics, and technology. But the same World War II gave us at the same time a demonstration of the potential for the inhuman and destructive behavior of the species, for bestiality and genocide, exactly by those countries that have invested in and achieved most in science, mathematics, and technology. The supposedly good results overshadowed the horror associated with them and, without any inclusion of discussions referring to ethics and morality, lead the worlds' nations, particularly those ranked as "new" nations, to invest enormously in education. The emphasis was, in particular, on literacy and on science, mathematics, and technology education, mostly under the aegis of UNESCO. This major effort in developing curricula, new methodologies and materials, and training of human resources was performed without space for unbiased history, ethics, and for a critical view of both pre- and post-World War II society as a whole. Today it is clear that the objective was the reformulation of the world order, aimed at reestablishing the former imperial partition of the world and leading the former colonies to a misleading situation of independent nations subjected to the same relationship of economic, social, and political subservience to the former colonial powers. The United Nations, an ideal body created to pave the way to a fair structure for world governance, was perverted in these ideals through the establishment of a Security Council that was unable to produce security in the almost 50 years of its existence.

Education, particularly, was then seen as the most efficient and necessary way to the progress of individual countries and of world as a whole; the results have been less than satisfactory, indeed disappointing. Countries that were poor are even poorer, the gap between rich and poor has increased, and peace seems far more remote than 50 years ago. The level of planetary destruction is getting closer to irreversibility. What has gone wrong?

A Critical View on the Concept of Curriculum

My criticism focuses in the narrow interpretation of science, and consequently that of mathematics and technology that prevails in educational discourse. In particular, the concept of curriculum is equivocated. Clearly, when thinking about curriculum as the strategy for educational practice, three components are equally essential: objectives, content, and methods. Regrettably, curriculum has been identified with an arrangement of content. Science, mathematics, and technology education have been stressing techniques, formulae, and theories geared toward drills and exam-focused topics, without a real contextualized understanding of the subjects. To bring science, mathematics, and technology into context, we must first look into the place of education in modern societies.

Education, particularly science education, is a major social and economical enterprise. It is possible to estimate that in the U.S., science and mathematics education moves about 400 billion dollars, exclusive of publishing and media. Other countries of the developed world will have proportional budgets for science education. And although less in absolute values, the investment in science education in developing countries is, relative to the national budget, also high. Why should societies invest so much in education, particularly in science education?

In general, societies aim for every adult to be literate and to possess the knowledge and skills necessary to compete in a global economy and to exercise the rights and responsibilities of citizenship.

These very general goals can be achieved only through an educational system available to all children, where they find quality education in a disciplined environment conductive to learning and free of drugs and violence. This is a fundamental reason to keep educational systems running.

Among the identifiable ways to reach these general goals, we give special emphasis to strengthening mathematics and science education throughout the system, especially in the early grades. Of course, this can be achieved only if the number of teachers with substantive background in mathematics and science increases dramatically. And if we are looking for a society with equal opportunities for all, opportunities to complete undergraduate and graduate degrees in science, mathematics, and technology must come from all strata of society, particularly women and minorities.

A Multi-dimensional Concept of Teaching

Why such emphasis in science and mathematics, and why to relate science and mathematics education with the overall goals of society? I distinguish four main reasons. We teach science and mathematics for all because, through science and mathematics, individuals can be:

1. Wiser consumers, in particular as "users" of science and technology, such as in matters related to nutrition, health, waste, and so forth;

2. Wiser decision makers, or voters in the selection of decision makers, in issues relating to science and technology, such as environmental policies and production, economic and developmental decisions and security issues;

3. Motivated and prepared to change and embrace new careers in their professional lives, which increasingly depend on dominance of telecommunications and informatics, robotics, and other scientific and technological knowledge and abilities;

4. Prepared to make personal decisions that depend on ethical considerations, such as those related to termination of life, abortion, organ transplants, genetic modifications, elimination of species, and so forth.

It would be a mistake to try to rank these reasons in importance, as they are all equally necessary to achieve democracy in our home—which is the entire planet. In fact, the pursuit of all four reasons, which we might state as global aims of education, leads to global balance of production and consumption, hence better labor relations. This leads to security at home, in the cities, and to national security—in other words to social peace. To move away from the current intolerable discrepancies between rich and poor among our populations at home and among nations worldwide is a major factor in achieving military peace. Certainly an individuals' ability to choose the activity that best suits their own interests and personalities brings satisfaction in labor relations and, consequently, in private life, which has a major influence in generating self-esteem, higher productivity, and emotional equilibrium—that is, internal peace. This is a major fact in the will of individuals to join others in the preservation of the common good, our natural and cultural environment. Thus, the major goal of an educational system is the pursuit of *peace*, in its four dimensions: individual, social, military and environmental.

Education, Labor and Peace

All the issues that were discussed above have an effect in production and in its quality. Individuals performing a duty without pleasure can not feel internal peace and quality is hardly achieved. Contrary to the artisanal production, where quality is an essential factor, in industrial production we seen an increasing dissociation between the producer and the product. This pattern of work, of routine production, besides affecting the quality of the product itself, has consequences that may be even worse for the nation as a whole, which could be called a behavioral addiction, with implications for the mental health of the population. We always think about addiction in terms of drugs, cigarettes, and alcohol. But indeed, behavioral addiction—such as working obsessively without creativity; or gambling; or fanaticism in sports, as for example the soccer mania in Europe—may have serious consequences for the mental health of society and poses a threat to national equilibrium. It paves the way to fundamentalism and radical political behavior, a real threat to democracy.

This has much to do with science, mathematics, and technology education, because it may be the result of boredom, of the routine of a production system highly automated that reduces the individual to a mere observer of gauges and manipulator of control knobs. The scenarios of Fritz Lang's *Metropolis* and Charlie Chaplin's *Modern Times* are present in the modern production system. Of course, this kind of specialized work relies very much on training involving science, mathematics, and technology and, consequently, requires a broader and more critical view of education in these areas.

Creativity must be an important component in education, more than pure capability of reading and following instructions. Problems are solved and new situations are faced not as a function of learning methods and routines but only when aiming at creativity and preparing to face new situations in daily life.

The way to avoid this kind of passivity, this kind of behavioral addiction in science, mathematics, and technology, calls for a deeper look into history and philosophy. The Middle Ages paved the way to Cartesianism, with an implication that humans and nature are separate entities. Indeed, since then a conception that knowledge is the result of pure thought and theoretical knowledge has developed.

Misconceptions coming from this perception led to spoiling relations between human beings and the earth, reaching a situation in which these relations are leading to mutual destruction, instead of being the results of a same creative process. The view that mind and body are separate entities, which implies in a dichotomy between intellectual and physical world and consequently between humans and nature, has given origin to the abusive utilization of resources and to irresponsible consumption habits. A return to a balanced and saner relationship between humans and nature calls for the perception of an embodied mind as the essence of humankind. This calls for a deep rethinking of education, mainly education in science, mathematics, and technology as related to education in the arts and humanities. A closer connection must be sought. The closer the connection, the more intense and noticeable must be the presence of values, moral issues, and the recovery of spiritual life and shared responsibility. Where should the focus to begin be placed?

Education and the Forces of Society

Science, mathematics, and technology education, the same as education *tout court*, is an action. As with every action, we expect a result. Because it is a social action, there are expectations about the outcome of such an action by several sectors of society. Expectations come from society directly involved (student, parents, teachers) and from society at large (policy makers and the rest of the population). These expectations generate pressures on the educational action, whose results will eventually be different from those initially planned, thus generating progress. This operates as a cycle (Figure 1).

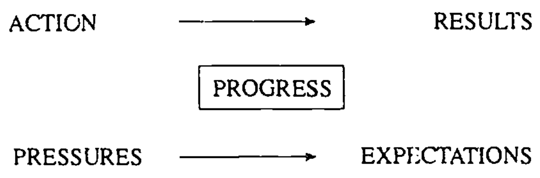

Figure 1. The Expectations-Pressures-Progress Cycle

Although it may sound strange, progress is identified with the unplanned, not with the routinely expected outcomes, which are the objectives of schools. Thus progress goes in the counter-flux of the cycle. The cycle tends to exert pressures to meet the expectations, as a rule conservation. In education, the cycle voices the conservative forces, but innovation and change are essential for progress. This contradiction is in the root of a hopeless malaise of education, particularly of science and mathematics education.

The scheme above synthesize the basic rules of cultural dynamics; in education we are caught in what we call the (vertical) cultural dynamics of generations. Although we agree that both traditions (which are transmitted from generation to generation) and cultural memory are to be preserved, progress is the result of overcoming some of the practices and theories associated with them, while preserving some of their basic values. This duality of objectives is the crux of education, and to play this duality is the mission of an educator.

Particularly important is the role of science and mathematics educators. This is particularly true for mathematics, which is seen as the imprint of modern science and advanced technology. These, in turn, are esteemed to be, and to a great extent are, the pillars of modern society. Thus, no one would be considered fully empowered for citizenship without a number of mathematical capabilities. The minimum of these capabilities, once called in mathematics education "mathematics for all" and at other times identified as "mathematics literacy," is still the subject of much controversy.

Pressures manifest themselves through various agents, each one of them loaded with cultural values and biases. These agents come from the most varied sectors of society and produce an impact on educational practices, schematically described in Figure 2.

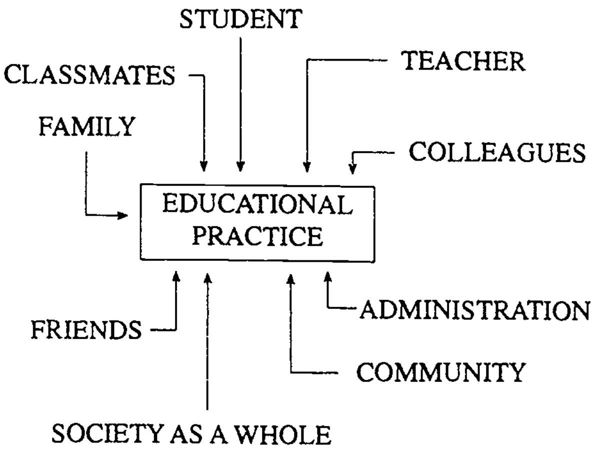

Figure 2. Impact of Social Agents of Educational Practice

Curriculum and the Four Myths Surrounding It

Science, mathematics, and technology education relies on several auxiliary sciences and on some supporting forces that have much to do with what we teach, how we teach, and why we teach—in other words, with the traditional components of curriculum contents, methods, and objectives.

Methods dealing with the processes of learning and teaching and its theoretical substratum are what is called, in modern days, cognition. Content that we are willing to transmit is the result of our perception of that content as something difficult and accessible only to a few and only if it is taught—in other words, if there is someone teaching it. Thus, it is based on a mystified vision of knowledge. Objectives, on the other hand, are based on the belief that the content we are willing to pass to the students is necessary in daily life, thus relating indiscriminately content and method with real societal participation. These perceptions of the components of the curriculum serve as the backbone of science, mathematics, and technology education and are by and large uncontested in the profession. From these pillars come most of the theories, decisions, practices, and supporting research in science, mathematics, and technology education. These attitudes lead to widespread myths.

First Myth: Universality of Science, Mathematics, and Technology and of Science, Mathematics, and Technology Education

Is it sustainable that the same scientific explanations, as well as mathematical practices and technology uses, serve everyone in this world and should be taught to everyone in the same way? There are no strong arguments supporting this widespread view. On the contrary, recent advances in cognition points to the socio-cultural influences in the process of building knowledge, in particular of mathematical knowledge (Saxe, 1991). This socio-cultural relativism in the history of ideas, in particular in the history of what became known as science, opens the way to the most recent aspects of learning that call for closer attention to the socio-cultural bases of science, mathematics, and technology education. As every product of creativity, science, mathematics, and technology are perceived at first, as produced by individuals as a response to stimuli from the environment and understood as natural as well as socio-cultural. Thus, scientified explanations, mathematical practices, and technological uses result from knowledge constructed and reconstructed in different ways from individual to individual, shared by culturally identified groups and obviously utilized in circumstances which vary according to the whys, whats and hows they are perceived.

This tells about the obsolescence of looking into the objectives and goals of mathematics education in the traditional way. It is opportune to recall my polemical approach to *Objectives of Mathematics Education* in ICME 3, in Karlsruhe, in 1976. This was followed 8 years later, by the also polemic views on the bases of mathematics education in the opening plenary address in ICME 5 in Adelaide, in 1986. Now another 8 years of research strongly support those views (Nunes, 1992). All this comes in support of my reaction against the popular myths on science, mathematics, and technology education and on science, mathematics, and technology themselves.

The old idea of defining objectives related to content leads to nothing. Indeed, if we look closely to the shifts of paradigms in the modern world, particularly in science, we see reflections in the means of production, obviously in the opportunities for work that displaces individuals claiming to be prepared because they have mastered such or such knowledge. What we expect today to say of people prepared to perform in society, both as producers (workers) or consumers (responsible citizens) is that they the capability of facing new situations, of systemic (or global or holistic) thinking, of abstraction and of collaboration with strangers towards a common action (Reich, 1992).

We have mentioned "why, what, and how" as questions that dominate the current scenario of science, mathematics, and technology education, although the technical terms objectives, content, and methods are more commonly used. If we accept the definition of curriculum as the strategy of educational action, and if we agree that in the curriculum the three components of objectives, content, and methods are solidary, as Cartesian coordinates of three-dimensional space, we are paving the way for the second myth.

Second Myth: Linearity in the Construction of Knowledge

Clearly, linearity is intrinsic to the definition of curriculum given above. The advances in cognitive theories, mainly when related to culture (Varela, Thompson & Rosch, 1991), lead to a non-Cartesian approach to the curriculum, which we have proposed elsewhere, and to the rejection of the myth of linearity (D'Ambrosio, 1991). In fact, linearity in doing science, mathematics, and technology leads to something similar to a style in the construction of knowledge that corresponds to what Pierre Samuel has labeled *ane qui trotte* in his critical view of some kind of mathematical research.

Another important issue refers to learning. This is a cultural action. The factors evolved in learning are of a varied nature and very difficult to predict. It results from inspiration, motivation, interests and, according to the metaphor used by Bernard Shaw, from perspiration! Learning clearly relies on previous experiences, on a process of lived memories and of cultural behavior understood, according to H. Maturana and F. Varela (1991) as "the transgenerational stability of behavioral patterns ontogentically acquired in the communicative dynamics of a social environment" (p. 201). Although the first factor—lived memories—has been increasingly recognized in educational discourse, and carries with it notions such as self-esteem, cultural behavior is as yet something hard to explain, and in some educational circles even rejected as a scientific issue.

The theoretical framework in which these reflections are based accepts a process in which previous experiences accumulated during a lifetime (and, according to some, through generations) are retrieved as a function of an action to be performed, a combination of routine and creativity, which are always present and never exclusively. Both are part of the dialectical process of construction and acquisition of knowledge, usually called learning. Time, as related to the successive actions that take place during this process, is part of the cultural component. Thus, we reach the third myth.

Third Myth: Equal Time for Different Individuals to Learn

This clearly affects current practices in teaching. It is difficult to make compatible different learning times with current practices in the classroom. Learning as an action is a dynamic process, and we have to allow each student the needed time to acquire that knowledge (some students never do) and to construct or reconstruct knowledge (it always happens). When we say "construction or reconstruction of knowledge always happens," and we say that "acquisition of 'that' knowledge may never happen for an individual," there is much uneasiness among educators. Isn't construction of knowledge more difficult (using this vague term—difficult—frequently used by educators) than mere acquisition of knowledge? I claim *no*. Construction of knowledge is a permanent process in human beings, a form of action associated with life. Many of the mistaken views on acquisition and construction of knowledge came from the fourth myth.

Fourth Myth: It Is Possible to Measure (to Quantify) Knowledge

This has impregnated current education, fathered by discriminatory designs. How much one knows is absolutely impossible to measure. Of course, "A" can verify "B" knows what "A" wants "B" to know, and "A" can give points to that and can even attribute weights for this "quantity of knowledge." These points are normally called "grades" in the school systems and are indeed filters used by society to select those whom societies feels are "fit," according to the expectations of the dominating power structure in society. Clearly, this has little to do with knowledge. At best would be what Cheik Antar Diop once called the "psittacistic knowledge" imposed by the colonial masters.

Conclusion

We now return to the issues discussed in the beginning of this pa . We can say that the expectations of society give rise to the four myths identified above. These myths shape the public image of science, mathematics, and technology in the following way: Science, mathematics, and technology are universal; thus, everybody must "master" them as the result of a linear presentation—teaching. This begins in the early grades of structured schools in which an individual spends a certain time at each stage of the process and at the end of each stage, the individuals are measured on how much they have learned. If we sustain these myths, progress in science, mathematics, and technology education, in the sense presented above, is hopeless.

The appeal for a planetary view of shared responsibility calls for a deep revolution in the educational systems, particularly affecting science, mathematics, and technology. It goes much beyond the search of better results, of a more productive, and qualitatively more efficient education in these areas. But is fundamental to achieve another qualitative level of education that will allow correction of the distortions for the generations to come. It is not simply to fix goals that will reflect good results in testing, the price of which may be an aggravation of dysfunctional civilization. It is the search of a new venue for the world, as new and more responsible style of leadership, oriented toward a preservation and, indeed, the improvement of civilization. We have the means to offer the future generations of the entire world well-being and dignity.

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Juggling the Variables in the Science Education—Policy Equation: Developing Country Perspectives

Michael Kahn and Sharon Levy

Context

South Africa is a somewhat atypical developing country—it is one of the few sub-Saharan countries with a positive balance of payments and a negative growth in GDP/capita; it is the largest consumer of power on the continent with one of the lowest rates of literacy. The technology of apartheid has involved mass deportation of people, the squandering of resources, and loss of life. Political settlement is a prerequisite for capital inflows, and the utilization of this finance is, in turn, predicated upon human capital investment. The last 40 years have seen little but wastage in this latter area.

Much of the political struggle against minority rule in South Africa has focused on the educational system. That conflict raged through the 1980s and was characterized by a strong sense of rejection of "apartheid gutter education." The battle finally culminated in the slogan "liberation before education." Eventually, a move toward defining a "Peoples' Education" was begun. This resulted in the establishment of the National Education Coordinating Committee (NECC), which sought to redefine the curricula for language, history, mathematics, and science. Particularly since the "Pretoria Spring" of 1990, widespread debate on education scope and provision has taken place outside State circles, especially through the National Education Policy Initiative (NEPI, 1992), an organ of the NECC, which commissioned studies on all aspects of the education system. NEPI work groups all subscribe to five basic principles concerning the policies they formulate. These are a commitment to: a unitary education system, democracy, non-racism, non-sexism, and redress. We consider, below, some of the issues and problems discussed in the work of the NEPI Science Curriculum Group.

Issues

International experience regarding the main determinants of educational quality is unequivocal: at primary level it is the availability of sound instructional materials, and at secondary level the quality of teachers, which matter most. The situation in South Africa is deficient on both counts. Moreover, in science education it is critical, with gross shortages of facilities and suitably qualified teachers.

In this climate of bureaucratic blunders and wastage, a large number of non-governmental organizations (NGOs) have sprung up to offer redress, to provide support to the field, and to initiate change. The initial funding for these came from the more enlightened sectors of industry who saw future personnel needs being satisfied by focusing on the Black community. The main emphasis of the science education NGOs has been on in-service education of teachers, which includes workshops, school classroom visits, and the supply of low-cost kits. The NGOs have generally been forced to work within the prescribed syllabi, but have tried to introduce learner-centered methods. Whether this has succeeded is uncertain, given the disabling context within which science teachers find themselves operating.

The outcome of more than a decade of such intervention is hard to quantify, because most projects lack external evaluation. Success is frequently measured in terms of longevity and popular appeal to teachers. The existence of the NGO sector has provided the State with an excuse gradually to withdraw the little education support service it has provided to the Black community. Such innovation as has been conducted by the State has been confined to the White departments; in the Black sector it has largely been left to the NGOs to fulfill this function. The present response to these shortages by donors is twofold: first, to throw resources at the problem; second, to identify certain NGO science projects and pump them up so that they expand to cover as large a clientele as possible. The inherent dangers in both these responses follows.

This view of the problem and the responses to it may be represented by an input/output model. The concern we wish to express is that the output may be more-of-the-same inadequate science, rather than a more appropriate, accessible, alternative science for all. This linear model ignores the complexities of the context in which science education is occurring, the vested interests which it has served, as well as other dimensions of the problem which are not reflected.

Variables

Human and Physical Resources

If a solution is so simple, how does one explain the following? In certain regions there are classes without teachers, equipment, or textbooks. Elsewhere departments are retrenching teachers. In some schools there are piles of brand-new textbooks, and the dust layer on the equipment indicates its lack of use. Much of this chaos may be placed at the door of current policy makers who are operating a corrupt administration. However, even if the administration were behaving in the best bureaucratic tradition, the following problems would remain:

1. The provision of resources without adequate support to utilize them;
2. Teacher qualification being unrelated to quality;
3. Personnel provision seen in isolation from staff development;
4. Finance provision without community accountability; and
5. Research unrelated to decision-making.

Each pair of these variables may be thought of as an axis in a multi-dimensional equation, located within boundary conditions such as world view, political legitimacy, coordination, and access to information that determine the limits of change.

Although NGOs have realized that equipment-based solutions must be backed up by field support, departments of education continue to dump science equipment on teachers who are either unable or unwilling to utilize the equipment. The second problem relating to qualifications is more subtle. While the number of teachers who have attained a school certificate plus 3 years of further study (so-called M+3 level) has risen as a result of ministerial edict, many science and mathematics teachers who have followed this path have not developed themselves in science or mathematics but study exotic subjects such as criminology or biblical studies. Teacher qualification is thus hardly related to quality. It is left to NGOs to determine the necessity for staff development. In the matter of finance, provision by the State is still racially lopsided. On the other hand, many projects find themselves accused of lacking community accountability and squandering scarce resources. Last is the question of research and its relationship to policy. Education research in South Africa has generally concentrated on opposition activity: the policy debate has been restricted, and research on the macro workings of the school system has hardly taken place.

Hidden Variables—Ideological

What about the implicit variables, those which form part of the "hidden curriculum"? Ideological constraints are present in the non-formal sector as well as the formal sector. It is crucial that these be examined, particularly because the country is in transition, and the hidden variables need to be discovered.

There is a belief that NGOs offer viable alternatives to the science education offered in the formal sector.

Yet it is possible that NGOs praxis may be the same ideological wolf dressed in sheep's clothing. This can only be avoided through careful self-reflection and self-understanding. In the work performed to produce the survey Projects Speak for Themselves (Levy, 1992), it was hoped that evidence would be found to show that there was an alternative and progressive ideological influence at play in the NGO sector. Instead, the survey revealed that no clear-cut distinction can be made at the ideological level between formal and non-formal projects. There are a number of aspects of this.

First, there is a tendency to forget, now that political changes are afoot, that, as Sharp puts it,"the political content of education is an absent presence" (Sharp, 1980, p. 125). At present, the direction of growth in the NGO sector is dominated by a number of large affirmative action trusts whose power may well be disproportionate to their judgment. Thus, an NGO project may be funded to expand according to the agenda of the funder, rather than for educational reasons.

Second, the science curriculum is in part set by the perceived social and economic needs of our country, and constant critical examination of these is demanded. There is a spate of projects in the country whose main appeal to donors is that they claim to have a direct bearing on future employment needs.

Third, a prevailing ideology affects the fabric of social relations in general, and the relationship between student and teacher in particular. After all, assisting teachers to break out of an authoritarian mode of teaching is not merely assisting changes to a didactically more effective mode, but is challenging the social relations that underpin the practice in the first place. Science education is not conducted in a social vacuum, but is a social activity itself.

Fourth, the content of a curriculum can be more or less critical of a prevailing social and economic ideology. Present authoritarian methods encourage students not to raise questions about the social and economic systems that they have inherited. Science in society programs frequently deal very superficially with the economic fabric of society.

Finally, a curriculum reflects a view of the world, and a view of the world is an ideology, in the very general sense of the word. Teaching science implies addressing students' beliefs about the world. Most science curriculum projects in South Africa are currently preoccupied with resource provision and immediate concerns of teacher motivation, confidence, and content knowledge; only a handful are aware of and consciously address the ideological aspects of the curriculum. It would be simplistic to locate these programs solely in the non-government or non-formal sector.

Responses and Solutions: So Where To?

Tragically, the response by the State to the situation of deprivation has been irrational, with the over-concentration of resources in White education been dispensed with, not by redeployment to areas of need, but by retrenchment and early retirement packages. Accordingly, the burden for redress still rests firmly on the shoulders of the NGO sector.

That there will be a continued role for NGO activity in the transitional period is a given: the form it will take is less clear. On the one side are voices advocating the elimination of NGOs as band-aids to a basic wound; on the other side, those who see the NGOs as the site for innovation that a cumbersome bureaucracy cannot provide, and for which the same bureaucracy should pay a market price. If the experience of neighboring countries is any judge, the NGOs will persist into the future, but their activity will become increasingly regulated.

Basing its position on experience with low-cost science education provision in Zimbabwe and Botswana, the NEPI science education proposals are geared toward providing Science for All throughout the school years. This is to be achieved through kit approaches at senior primary and junior secondary levels, with distance education and field support. Educational technology should be employed where appropriate. For instance resource centers could provide learners with opportunities to develop skills and enhance their learning. However, where such technology reinforces inequitable distribution and access, this should be resisted. An area of particular need for research is that of the influence of conflict between medium of instruction and mother tongue (Kotecha, Rutherford, & Starfield, 1990; Rollnick, 1988).

In contrast with the State's policy of vocational education (Ched, 1991), the report argues for science and technology education within general education, reasoning that it is citizens with flexibility, not inappropriately trained products, who should emerge from the school system. Given the general breakdown of the education system and the crisis of legitimacy, a radical change in the process of syllabus design and implementation is recommended. Instead of the syllabus determination being in the hands of a few, it is recommended that consultation with all interest groups is essential.

Because there are so few appropriately qualified science teachers ongoing in-service training of teachers is essential. New and emerging models of pre-service and in-service training that seek to shift the site of curriculum development to the school need to be replicated, particularly in Colleges of Education. Another possibility is the retraining of non-science teachers (Kahn, 1991). It is clear that the debate on an appropriate science education is just beginning. Although no-one should be deluded into thinking that good science education guarantees economic development, it is a necessary condition for it to be sustained. It is our hope that the science education policy options now being considered are part of the foundation for this.

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Critical Issues in the Design and Development of New Science Curricula: Why Teach Acids and Bases at Khetisa High School?

Wobbe de Vos

Introduction

In developed countries, science education has a long history. Most science subjects were taught in European and American secondary schools more than a century ago. In many developing countries, secondary education was introduced only relatively recently. It was seen as reasonable that students in developing countries should learn the same science as was taught in the developed world.

Nowadays, however, science education in the developed world is undergoing a process of radical change. It is generally realized that science is not being taught to future scientists in the first place (as was the case in the past), but that the large majority of students consists of future non-scientists. This does not make science education meaningless, because every citizen lives in a world that is full of science and technology, but it does affect the aim and, consequently, the content of the curriculum.

Should the developing countries follow this process, or should they focus on the traditional syllabus? Decisions about what science to teach should be made within the developing countries themselves. What follows are the results of an attempt to analyze the present situation, with a focus on chemistry because it is the only subject with which I have experience in learning, teaching, teacher training and educational research. I do not know to what extent my conclusions will be valid for physics or biology or general science, but my impression is that the situation in those subjects is not completely different. The starting point for the analysis is the question of legitimization: how can we account for the fact that we teach "school chemistry" to millions of children and not, for instance, psychology or law? What is the rationale behind chemistry, physics or biology, in secondary school?

If we accept that the content of the chemistry syllabus is not self-evident, we can look critically at "traditional" school chemistry from various points of view. In this paper the following viewpoints will be discussed: chemistry itself, technology, society, the teacher, and the student. Each of these viewpoints represents a "critical issue."

Chemistry

What is the relationship between school chemistry and the scientific discipline called chemistry? I am not sure that the links between school chemistry and modern chemical research are very strong. There is, for instance, the typical university professor who begins the first lecture to freshmen students by telling them to forget everything they ever learned in school. There are, on the other hand, research chemists who have children in secondary school and who are surprised about the peculiar chemistry their children learn. Research chemists do not recognize school chemistry. They do not bother about a distinction between chemical and physical change, as for instance Holderness and Lambert (1990) do. They don't worry about the correct definition of a molecule, and they usually identify a substance by its nmr, mass spectrometry, infra red or other spectrum, not by isolating it and then determining its density or its boiling point. Acids and bases, a classic school chemistry topic, is not in the mainstream of current chemical research.

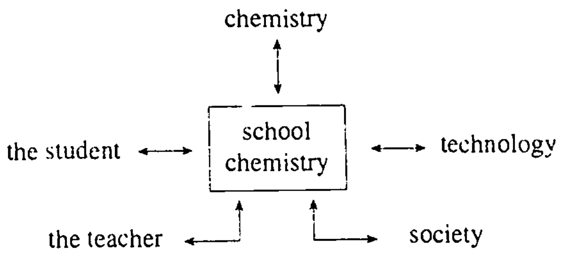

Figure 1. School Chemistry and Its Relationship to Other Variables

The link between traditional school chemistry and modern chemistry does not seem very strong. There is a much stronger link, however, between school chemistry and the chemistry from the past, especially from the nineteenth century. In some European countries, chemistry was introduced as a subject in secondary schools as early as 1860. The first syllabi reflected the state of the discipline in those days. What did chemistry look like in 1860? The periodic table had not yet been published but Lavoisier (1965), in his *Elements of Chemistry* had distinguished between metallic and non-metallic elements. Both form oxides but the oxides of metals, such as calcium oxide and iron oxides are related to bases, and non-metal oxides, such as carbon dioxide and sulfur dioxide, are related to acids. This situated the concepts of acids and bases right in the heart of chemical theory. Acids and bases had a prominent place in premendeleveian chemical thinking and, consequently, in early school chemistry. The concepts of acids and bases have been further developed through the years, for example, by Arrhenius, by Brønsted, and by Lewis, but they have never lost their prominent position in the school.

There is a theory on the evolution of the human brain that says that deep inside we have the brain of a reptile, and on top of that has grown a structure of the type that all mammals have, and the typical human part of the brain, the neocortex, has been superimposed on these older structures. According to this theory, each of these structures determines aspects of our behavior. In biological evolution the old is not replaced by the new, but the new grows on top of the old. It looks as if the chemistry syllabus has developed in the same way. My conclusion is that, although topics from modern chemistry have been included in the syllabus, the underlying conceptual structure reflects nineteenth century scientific thinking.

Technology

Let us now look at relationships between school chemistry and technology. I know a teacher who took his class to the local water company to see river water being purified. An information officer showed the students around the plant and pointed out that various substances were being added to purify the water. This created confusion among the students because they could not understand how one can make water pure by throwing things into it. The point is that tap water is "pure" in a *technological* context. The water is said to be pure when it complies with a list of very specific requirements laid down by law. These include taste, smell, color, sterility, pH, oxygen content, hardness, and so on. But the students had been taught that "pure" means the total absence of any other substance. This is a concept in a *theoretical* context, something like the ideal gas.

The excursion to the water company was an extension of the chapter on purification of substances. But the chapter itself aimed at developing a theoretical concept of purity that, in traditional school chemistry, is necessary for understanding the chemical substance and reaction concepts. The teacher made a brave attempt to make his teaching more relevant to the students, but he had not been aware of a change in meaning of "purification." It is often assumed that technology is applied science, and that learning science opens the door to understanding technology. But this ignores the fact that technology often has its own way of thinking, its own language, and its own history. In the eighteenth century the steam engine was invented, the nineteenth century produced thermodynamics, and in the twentieth century, we tend to believe that the steam engine is applied thermodynamics.

Even if the same words are used as in science and in technology, the context in which they are used is different, and, therefore, the word may have a completely different meaning. Teaching concepts in a scientific context may create confusion rather than understanding with respect to technology. (The problems associated with the technology-science relationship have been more fully analyzed by Gardner [1992]). My conclusion is that school chemistry does not seem to have strong links with technology.

Society

Society seems to offer an excellent justification for teaching chemistry to future citizens. We live in a world that is full of chemical processes and products, natural as well as synthetic. Everyone should understand at least some of the chemical aspects of our world. This is in the interest of both the individual citizen and society as a whole. Science should be taught in secondary schools not necessarily to future scientists, but to future bus drivers, farmers, cooks, policemen, nurses, lawyers, and so on.

An important example of science-society relationships is provided by the environment. Environmental issues, local as well as global ones, are now being included in science curricula all over the world. A lot of work is being done to make science education play its part in the attempts to protect our environment. It is interesting to note that the Brundtland Commission on Environment and Development concludes in its report *Our Common Future* (1987) that the environmental, the economic, and the educational challenge are in fact one and the same. If there ever was a societal justification for teaching science to everybody, here is a very explicit one.

We must, however, be aware of the fact that school chemistry was not originally designed for teaching chemistry to future citizens but for training future chemists, from laboratory assistants to chemical researchers. Textbooks from the nineteenth century show that chemistry was taught within a vocational setting. Students were addressed as future colleagues who were to be informed about facts and theories already accepted by scientists and about methods and procedures used to make new discoveries. This has been an aim for at least a century as is reflected in the preface of a book called *Basic Chemistry* (Dingle & Simpson, 1959), which tells students to "make a note of everything that happens," because "the development of a lucid descriptive style should be part of *the training of all scientists*." (my italics). This book was in use not in 1860, but in 1960. There is of course nothing wrong with making notes, but the link with the training of scientists does not apply any more for basic science courses. The aim of science education in secondary schools has changed, and this change has by now been generally accepted. What about adaptation of the content to this new aim?

When I suggested to chemistry teachers that the traditional chapter on acids and bases in the book might be a little outdated, most of them disagreed. They pointed to the sky and argued that acid rain is a problem that cannot be properly understood without some knowledge of acid base reactions. For many chemistry teachers, acid rain is a present from heaven—it provides a welcome justification for keeping the old chapter on the syllabus. And indeed, every modern chemistry textbook mentions acid rain somewhere in the chapter on acids and bases. But, like in biological evolution, the new is built on top of the old. Before acid rain became an issue, we introduced the Brønsted-Lowry definitions of acid and base in school chemistry. Why? Because they make the acid and base concepts applicable in non-aqueous solutions. This is interesting for chemists, but it is irrelevant for most other citizens. Nevertheless we are now teaching acid rain in terms of the Brønsted-Lowry definitions, according to which, water itself is an acid. Again, the link between what is actually taught in schools and the justification provided by society is not always very strong.

The Teacher

What is the position of teachers in relation to school chemistry? Their training varies from country to country. In some countries they are fully trained chemists who have obtained an additional teaching certificate. Elsewhere they have been trained as teachers from the start, learning the necessary chemistry as part of their teacher training. In either case, most teachers have never left the educational circuit: They went from school to university or teacher training college and then back to school. They may have been trained as chemists but they have not worked as chemists outside the university. They know a lot of chemistry but they know little about what chemists or chemical technologists actually do, for example, in chemical industry. If the syllabus gives inadequate information about chemical aspects of our society, most teachers will have difficulties in compensating for this. The same is true in principle for curriculum developers, textbook authors, chemical educators and the like, including myself, who began their career as teachers.

I have argued that school chemistry does not have strong links with modern chemistry, with technology, and with society in general. If this is correct, we can describe chemical education in secondary schools as a rather closed system, almost a ritual. The final examination that is based on the syllabus provides an *internal* justification for the content of the chemistry lessons. The external effect is not the student's expertise in chemistry but the registration of chemistry as one of the subjects on the student's certificate. A teacher who has never really left this closed system will find it difficult to look at it from a different angle. I remember encouraging my students to work hard for the exam, without feeling the necessity to refer to another possible reason why they should learn chemistry.

The Student

Listening to students I slowly became aware of a nineteenth century view on science and on education that is present somewhere at the root of our teaching. In this view students are put in the position of nineteenth century scientists, people who strictly distinguish between subject and object and who put themselves in the detached position of spectators, making careful observations and arriving by rational argumentation at some inescapable conclusion. An impressive but dispassionate process. The "science" in schoolbooks is a reconstruction that tends to leave out the emotional part of the process, the tension, the fascination, the frustration. This is not what science really is and it does not appeal to most students. If anything, it alienates them from science.

An example of the detached attitude of school chemistry is its approach to substances. A formula and a systematic name refer to a substance characterized by a set of substance properties, such as color, melting point, and density. They ignore the fact that the substance, in a less detached approach, also has a meaning to someone. Sodium chloride has properties, but salt means taste, and it may evoke associations of food with too much salt or without salt, or of swimming in the sea, or of relatives who are not allowed to eat salt because of high blood pressure. Salt is important in all human cultures, and sodium chloride is a very narrow way of looking at salt. In school chemistry salt is reduced to sodium chloride, and if we restrict our teaching to sodium chloride we do injustice to the student as well as to the salt. This is but one example, but school chemistry could become much more meaningful to students if we discussed the meaning of substances along with their properties. Water, ice, iron, gold, sand, stone, wood and air are other examples.

Conclusion

What is the result of this analysis? My conclusion is that we have to look very carefully and very critically at the traditional content of the curriculum. When the National Curriculum was about to be introduced in Great Britain, Francesca Garforth wrote:

> *It may well be that there is a corpus of knowledge without which no syllabus could be called chemistry and that the draft NC syllabus encapsu-*

> *ates this. Equally it may be that by our own schooling, subsequent training and teaching we cannot see anything different adequately filling the space called chemistry at this level.*
>
> (Garforth, 1983)

There is a challenge in these words, a challenge to design a new kind of curriculum that is not something new on top of the old, but a syllabus content that is based on what we know about society and about the student.

I think that, from the point of view of a chemist, we are sometimes misled by the word science. It forces us to put every chemical activity in a scientific context. The average chemistry textbook begins by announcing that chemistry is a science. I have nothing against science (I call myself a scientist), but I believe there is a lot of chemistry that is not science in the traditional sense but, for instance, technology, craft, or sheer magic and could be taught as such. Traditional science teaching is very much explanatory; maybe we should try to teach more questions and fewer answers. And, after all, is that less scientific?

Khetisa High School is in Lesotho, in Southern Africa. There may be very good reasons to teach acids, and maybe also bases, in Khetisa High School and, for that matter, in any other secondary school in developing countries. But it is worthwhile to consider breaking away from a tradition that in developed countries has been self-evident for over a century but that by now seems to have outlived its usefulness.

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Teacher Stress and Curriculum Innovations in Science Teaching

Miriam Ben-Peretz

Introduction

> *Stress is often accepted as an inescapable aspect of teaching.*
>
> (Smith & Bourke 1992, p.31)

Stress itself is not necessarily a negative factor in teachers' lives. Though, on one hand, teacher work-related stress may be linked with ill health, and reduced teacher commitment and effectiveness, it may coexist, as well, with high teacher satisfaction (Kyriacou, 1987).

Changes in education may be a major source of stress for teachers (Cole 1989). Kyriacou (1989) claims that

> *In the United Kingdom, for example, recent changes in the school curriculum (ranging from introducing more science in primary schools to new forms of assessment in the secondary schools) make it very likely that meeting the demands stemming from curriculum changes will emerge as a major area of stress in schools.*
>
> (p. 32)

Stress situations may stem from the introduction of innovative science curricula into schools. Innovative curricula in science are conceived as the appropriate response to the knowledge explosion and to the needs of individuals and society, but they often fail to accomplish their goals. Many reasons may account for this failure. The intensification of teacher stress may be one possible cause of failure. The creation of curriculum-linked teacher stress are examined in the light of the findings of Smith and Bourke (1992).

A conceptual framework is presented to account for both positive and negative aspects of stress caused by innovative science curricula. This framework is based on Schwab's (1964) notion of the four "commonplaces" of education, namely, subject matter, learner, teacher, and milieu. Some implications for research and for the implementation of innovative science curricula are discussed. A brief discussion of the "commonplaces" of education and stress induced by curricular innovation follows.

The Subject Matter Aspect

Innovative science curricula introduce new philosophies of science, such as a view of science as an ethical endeavor, or an integration-oriented approach to science teaching. The more innovative a curriculum is, the more updated the knowledge embedded in it. For instance, modern biology curricula may call for knowledge in physics and chemistry that teachers may not have mastered. Moreover, in innovative, inquiry-oriented science, teachers are expected to use complicated laboratory techniques and appropriate classroom management skills. The combination of such new demands may cause great difficulties for science teachers. Teachers may suffer from a sense of de-skilling, as their previous knowledge and skills are felt to be insufficient and even counter productive.

Conflicts and dilemmas may arise when new approaches contradict existing beliefs or are incompatible with previous expectations. Thus, a teachers' view of science may not be in accord with the views reflected in the new materials. Demands for open-ended problem solving experiences may cause classroom behavior that contradicts schools norms and expectations for classroom discipline. Teachers may find that they do not have enough time to fulfill the requirements of the new curricula and, thus, experience increased time pressure. On one hand, time allocation for the study of science may not allow teachers to implement the new ideas and learning activities. On the other hand, the amount of work required for teacher preparation may intrude on other commitments and on the home life of teachers. Still, innovative science curricula may be a source of stimulation to teachers who suffer from burnout and may raise their enthusiasm for new challenges.

The Learner Aspect

Innovative curricula make new demands on students. Therefore, teachers may find it difficult to motivate their students to become involved in the new learning situation. Students may lack pre-requisite knowledge and may resist the additional workload that is required to cope with the new materials. New learning strategies, such as discovery learning, may cause feelings of uncertainty and a sense of failure in many students who are unaccustomed to open-ended inquiry. Lack of ready-made answers and solutions to problems may frustrate students and make them unwilling to cooperate in the efforts required by the new curricula. Moreover, students may be critical of the new role played by their science teachers, not as holders of knowledge but as guides in independent inquiry, or as leaders of classroom discussions on ethical issues. New assessment modes of student achievement may be another source of students who resist becoming full partners in the new learning processes. The end result may be that instead of being enthusiastic about the learning opportunities provided by the innovation, students may reject the new curricula. Students' resistance, or students' enthusiasm, tend to create similar reactions of their teachers. It is extremely difficult for teachers to remain enthusiastic in the implementation of new curricula in the face of their students' negative stance towards the materials.

On the other hand, a powerful positive aspect of teacher stress, ensuing from the impact of innovative curricula on students, may be the new hope generated through opening new vistas of responding to students' needs and interests and providing opportunities for them to realize their learning potential.

The Milieu—Educational Authorities

Smith & Bourke (1992) define the relationship between stress and the environment as follows: "Stress arises where there is a 'lack of fit' between the needs and capacitates of individuals and the conditions existing in their environment" (p. 32).

External agents usually play a major role in curriculum change and determine, to a large extent, the nature of the teaching environment. Ministries of education, boards of education, superintendents, and other figures of authority may impose curricular innovation on the school system. The national curriculum in Britain is one example, but there exist many other examples of top-down curricular decisions imposed on teachers.

Capel (1989) claims that "at the present time there are so many reforms at all levels being introduced into schools that many teachers feel they have little or no control over their own actions" (p. 44). Many of these reforms concern science education because of the espoused need to improve the teaching of science at all age levels. These reforms are often accompanied by an elaborate system of evaluation, such as external testing, and detailed documentation of classroom interactions. The burden of accountability imposed on teachers takes on new and stressful dimensions. The felt threat to teacher autonomy may be grave, combined with an added sense of competition, caused by external testing. "I want my class to be on the top of the achievement scale," may become a common sentiment expressed by teachers implementing novel science curricula, thus diminishing any chance for fruitful collaboration and exacerbating the stress experienced by teachers. On the other hand, the public visibility of innovative programs in schools may stimulate hope for a higher professional status for teachers and may energize them in their daily endeavors.

Such positive results are to be expected only when the nature of the proposed changes is clear to teachers and when open channels of communications allow teachers to become full partners in the implementation process. Smith and Bourke (1992) claim that the system fails to communicate the ideals and the actuality of the changes in education "under these circumstances, regardless of the merits of the proposed changes, teachers were more likely to suffer anxiety because their needs for security and recognition of professional worth were unfulfilled" (p. 43).

The Milieu—Parents and Community

Parents are powerful stakeholders in education and in educational change. Cole (1989) claims that

> *. . . central control of the curriculum and examinations reinforced by parental power at the local level, will reduce teachers' control over exactly what they teach their pupils, how and when. The combination of greater demands and a sense of diminishing power to match up to them promises to make teaching even more stressful in the future.*
>
> (p. 164)

Lack of control over the demands made upon them is perceived to be an important factor concerning teacher stress. Kyriacou (1989) states that

> *. . . the degrees of control teachers feel they have over the demands made upon them is of crucial importance. Where teachers feel they have some control over the frequency and nature of the demands made upon them, and over the ability to deal successfully with these demands, stress is likely to be minimized.*
>
> (p. 28)

Innovations in science teaching, whether centrally determined or locally planned, demand a variety of skills and mastery over new knowledge. When the expectations of parents are raised and they become involved as active stakeholders, they constitute a powerful audience for teachers' accountability. Local innovations may be initiated on a school-based level or by concerned parents and community members. In such cases, parent involvement may be perceived as a threat to teachers' professionalism. However, the promise of new modes of interaction with parents, of creating meaningful partnership between school and home, though stressful, may become a source for teacher satisfaction. This may be one of the reasons for the apparent paradox reported by Kyriacou (1987), namely the coexistence of high stress and high satisfaction.

Discussion of the Conceptual Framework

The previous parts of this paper highlighted some of the possible outcomes of introducing innovative science curricula in schools, causing teacher stress. Figure 1 summarizes this analysis in the form of a conceptual framework for viewing the relationship between innovative science curricula and teacher stress.

Figure 1 is divided into an inner circle, representing the experiences of teachers and the possible impact of innovative science curricula from four different viewpoints, expressed through arrows pointing inwards. The outcomes of the interaction between external factors and teachers' experiences are expressed with the help of arrows pointing outwards. Potentially positive perceptions and emotions are noted by plus (+) signs, and potentially negative perceptions and emotions are noted by minus (-) signs. It is contended that all these perceptions are emotions, whether positive or negative, that put enormous stress on teachers.

Thus, in the subject matter domain, the combined impact of a new philosophy of science and teaching, with the uncertainties of new knowledge and new required skills, may be perceived by teachers as diminishing their expertise, on one hand, and creating new time pressures, on the other hand. According to Brown and McIntyre (1993), teachers aim at establishing and

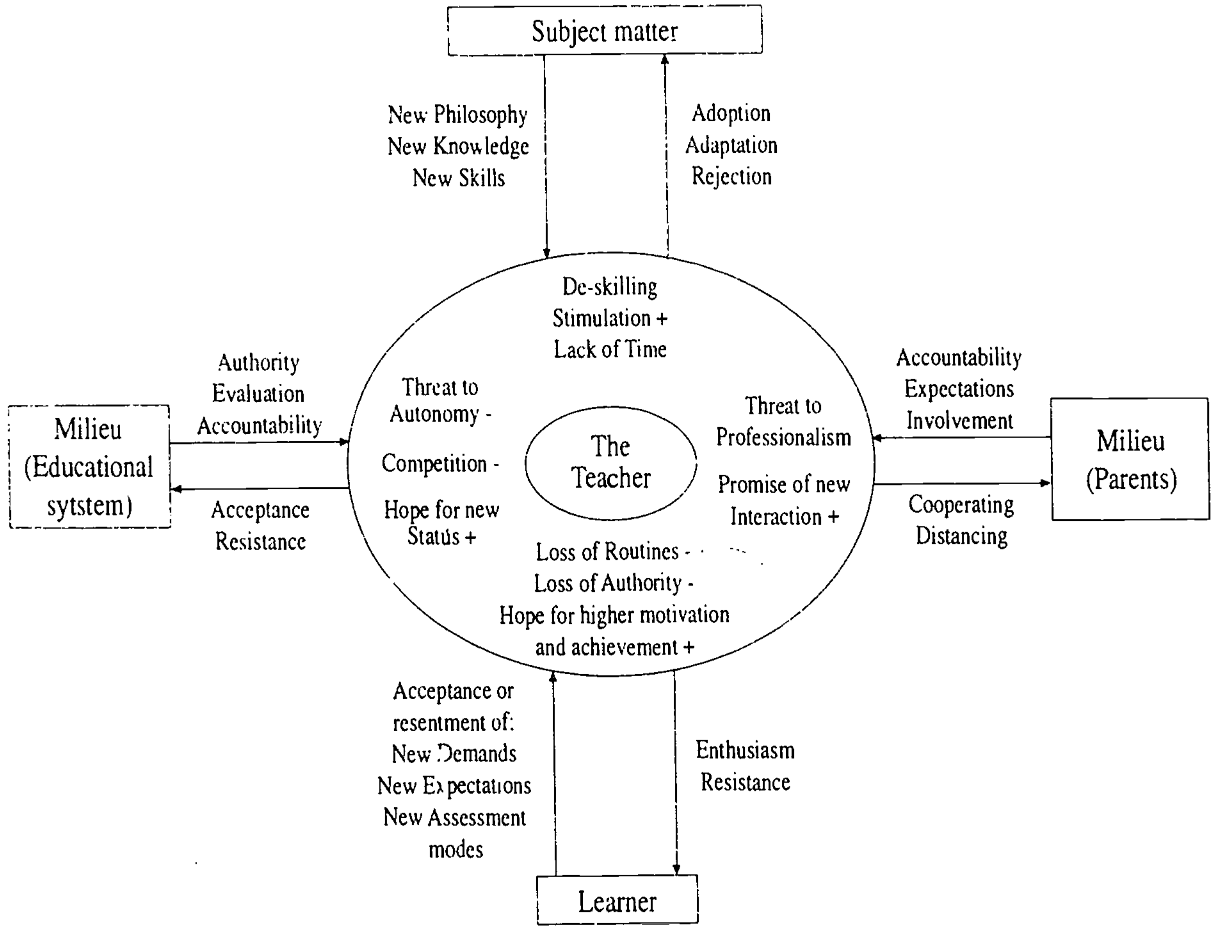

Figure 1. The Potential Impact of Curriculum Innovations on Teacher Stress: A Conceptual Framework

maintaining what they call a "Normal Desirable State of Pupil Activity" (NDS). "In other words, the lesson was seen as satisfactory so long as pupils continued to act in those ways which were seen by the teacher as routinely desirable" (Brown & McIntyre, 1993, p. 54). Feeling de-skilled, shakes teachers' confidence in their own perception of routinely desirable activities and may lead to growing dissatisfaction with their own lessons, thus contributing to teachers' stress. Moreover, time pressure was found to be closely linked to stress. Smith and Bourke (1992) argue that the level of stress arising from time pressure was the second highest recorded by teachers in their study. Their findings indicate that the largest direct effect on teacher stress stems from assessment workload and is related to time pressure. Innovative curricula tend to amplify the amount of time pressure experienced by teachers because of extended preparation needs and the growing time allocation for classroom explanations and for student assessment.

The combination of a sense of de-skilling with time pressure may be so stressful for teachers that they may tend to reject the new science curriculum or adapt it only partially. On the other hand, innovative science curricula may stimulate teachers to create what may be called positive stress and may lead to creative adoption of the new curriculum through its adaptation to teachers' specific classroom situations.

The student domain in the conceptual framework constitutes, in a sense, a mirror reflection of the subject matter domain. Unfamiliar teaching routines make new demands on students and change the nature of "normal desirable states of pupil activities" (Brown and McIntyre 1993), contributing to growing uncertainties and stress experienced by teachers and students. Students may fail to cooperate and to make the efforts required by the new curriculum, which is thus doomed to fail. Unaccustomed to new modes of assessment, students may not be able to perform according to their teachers' expectations or to the hopes of the developers. For instance, tests that focus on problem solving and laboratory skills may yield disappointing results when students have not had opportunities to become familiar with this testing mode. As noted above, students may accept or resent the demands of the innovation. Their responses are enormously important to teachers, whose own enthusiasm, or rejection, is viewed as being dependent on the ensuing classroom climate.

Smith and Bourke (1992) found that "the highest levels of teacher stress were found to be those arising from lack of rewards and recognition" (p. 42). Students' achievement is an important component of teachers' professional recognition. Diminished achievement levels may, therefore, lead to a raise in teachers' stress and may weaken their motivation to implement the new curriculum. The delicate balance between teachers' authority in their classrooms and the requirements of more innovative science curricula that tend to foster student autonomy may be difficult to sustain. In such situations, conflict-related stress (Smith and Bourke 1992) may be induced, coupled with a desire to return to more customary classroom routines that are less stress-raising. Even teachers who resist this reversion to the old and more comfortable teaching modes may find it difficult to succeed in implementing new curricula. Smith and Bourke (1992) claim that "teachers often deal with stresses in the workplace ineffectively, diverting time and energy away from their classes and effectively reducing their creativity, emotional concern, enthusiasm and flexibility" (p. 42). But those are exactly the qualities necessary for coping with the innovation, mastering its educational potential, and using it with appropriate creativity and flexibility, especially under severe limitations of time allocation.

The milieu domain plays a double role in the conceptual framework presented here, referring mainly to factors outside the school itself. The external factors related to are school authorities on one hand, and parents on the other hand.

Milieu

School authorities include external agencies such as Ministries of Education and superintendents, as well as school-based authorities, such as principals, or department heads. Both external and internal agents tend to impose their authority and to enforce accountability of teachers for the successful implementation of new curricula. Accountability to others may be perceived by teachers as a stressful threat to their professional autonomy. These feelings may be exacerbated by the failure of the educational system to communicate effectively to teachers the distinctive features and rationale of the proposed innovations. An additional stressful factor is the potential growth of competition among teachers who are confronted with unaccustomed demands. Collaboration and sharing of experiences and knowledge are deemed essential for teachers' ability to cope with innovations. Collaboration sets the stage for creative problem solving, which is necessary in non-routine situations (Meichenbaum et al., 1982), and may serve to counteract stressful competition among teachers.

Competition is not necessarily a negative component of professional lives, but it increases the stress experienced by teachers. On the positive side, teachers' involvement in curricular innovations in science may add to their professional status. They may perceive themselves, and may be perceived by the establishment and the community, as performing at the forefront of science, being up-to-date and in accord with relevant future orientations. This aspect of innovations in science teaching may act as a positive stress stimulant.

Milieu: Parents

Parents constitute another situational factor to consider from the point of view of stress-related educational innovations in school. New curricula create greater expectations and tend to strengthen parents' wish for greater involvement in the school. Parents' involvement may express itself by parents raising questions and doubts concerning the innovation, as well as through an increase in suggestions for support; parents' involvement may also be shown by attempts to help the students in learning the new materials. Though teachers may welcome this cooperation, the ensuing perceived threat to their professionalism may produce a sense of distancing, extending the gap between school and home, thus endangering the success of the new curriculum.

The conceptual framework presented above is an attempt to bring together a number of possible factors that may act jointly and separately to create a highly stressful situation for teachers implementing innovative curricula in science. The proposed conceptual framework presents a view of the inner world of teachers who are confronted with innovations in science teaching. The relationships among the impact of the different aspects discussed have to be explored systematically to gain a better understanding of why new curricula fail to be implemented. The framework is conceived as a source for research questions and for coping strategies.

Potential Uses of the Conceptual Framework

Learning the process of implementation of educational innovations is essential for school improvement. Investigating the nature of stress induced by curricula innovations may provide important insights into the practice of teaching and may yield possible strategies for coping with stress.

Research questions that may be generated from the framework are, for instance:

1. What are the possible conflicts and dilemmas experienced by teachers who try to cope with the new materials?
2. What are the causes for time pressure related to the new curriculum?
3. In what ways are parents involved in the innovations?
4. What rewards and recognition for teachers and students are part of the implementation process?
5. Do teachers differentiate among the possible source of stress?
6. What kinds of strategies are adapted by teachers to cope with stress related to the innovation?
7. What is the impact of coping deliberately with one, or more, of the stress situations?

Providing answers to these and other questions concerning the nature of stress related to curriculum innovations in science is conceived to be essential for the development and implementation of new modes of science teaching.

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Models and Examples of Science Curriculum Development and Implementation in the Caribbean

Winston King

Introduction

Over the years science education at the primary level in the Caribbean has used various strategies to produce curriculum materials that are useful to the various systems. By and large this production has been quite efficient, and it would be true to say that each island has available some written curriculum guide for teachers, and sometimes "readers" for pupils. Despite this fact, there is a clear indication that primary science teaching still needs a lot of improvement. The systems seem to be underachieving even at the level of production of scientifically literate citizens.

What has been sadly lacking is the allocation to curriculum implementation the importance it deserves. Well worked-out teaching/learning activities lie on principal's shelves or are gathering dust in a Ministry. What must be understood is that implementation involves much more than putting materials in the hands of teachers and leaving them to sink or swim.

This paper seeks to do four main things: to demonstrate how patterns or models of strategy in curriculum development and implementation have evolved and the reasons for the evolution; to show the critical importance of curriculum implementation in the whole process of curriculum innovation and change; to outline and describe examples of curriculum development and implementation in Caribbean science education at the primary level; and to identify the factors that influence curriculum development implementation.

Patterns of Curriculum Development Used—An Evolving Situation

Three patterns or models that depict how primary science curriculum development has taken place over the years are examined in this paper. Each is first described and then evaluated for effectiveness and efficiency. The development of the patterns over the years presents a movement toward overcoming problems of curriculum innovation, especially development and implementation. Each pattern shows quite an advance on the previous one. The advances have been in the form of a deliberate attempt to ensure that systems acquire the capacity to provide on-going and dynamic development and renewal of curriculum materials. Equally important, there has been an attempt to see the process of curriculum innovation as much more than just development of materials, emphasizing the critical role of teacher training and retraining.

This evolution toward an effective pattern has been helped in no small way by the development of a cadre of qualified Caribbean people, thus eliminating the total reliance on outside experts. This is not to say that such outside expertise is not useful and welcome, but it is now more as facilitator. The system and indigenous expertise identify and articulate problems, and help from outside assists in the search for solutions.

Examples of Science Curriculum Development at the Primary Level

The three patterns mentioned above have been used in the development of the primary science curriculum. For the purposes of this paper the two examples are specifically chosen to illustrate the operation of two different patterns: one used in an in-country development, the other used in a regional development.

As is to be expected, the two programs differed essentially on the scale of operations and the time taken for development to be completed. The regional program was part of a project funded by an external donor. As such, there was sufficient funding to impanel teachers and specialists from across the region on a regular basis. The in-country development was done much more on an ad hoc, voluntary basis, promoted by the local science teachers' association and the local Ministry of Education. The aims of the in-country development are:

1. To help pupils to report objectively and accurately;
2. To develop desirable values and attitudes towards each other, the environment, and the country;
3. To develop skills and attitudes that are flexible enough to provide adaptation to change;
4. To equip pupils to lead a full life in this modern scientific age;
5. To develop an appreciation of the order and beauty of the universe and the world in which we live;
6. To help pupils to think scientifically, to carry out simple experiments, to overcome fear of the unknown, and to reason from cause to effect; and
7. To help pupils learn a method of approach through which they can tackle and solve problems for themselves.

The regional program had similar aims, but these were stated in different words. Philosophically, the two programs are not too dissimilar, each emphasizing activity-oriented and child-centered approaches, the processes of science, and the desirable attitudes of and toward science that are important in developing the quality of life. The main difference in the materials is that the regional program produced both teachers' and learners' materials. This is most likely because of the point made earlier—availability of financial and other resources.

Table 1. Factors Influencing the Science Curriculum Development and Implementation

Categories	
Socio-historical	
Contextual	curriculum aims, school climate, facilities and equipment, communication of information
Internal/Personal	teachers' and pupils' concern e.g. teacher re-orientation; teacher's perception of aims, methods. and content; teaching style; age and ability of pupil

An Example of Curriculum Implementation in Barbados

This in-country program of implementation has been in operation ever since the development phase was completed in the early 1980s. Essentially, it was built on the vibrancy of an Education Officer, Ministry of Education, and two science education specialists from the Faculty of Education at the local campus, and teachers from the development team.

These resource people participate in three strategically-located zones in the country. From each zone, other resource teachers emerged after the period of involvement of the Project Implementation Team. These joined the PIT and have been involved in both their own zone and other zones. Thus, a network of resource people has been built to generally look after curriculum implementation, and renewal where necessary. Periodically there are sessions when all resource people meet to update information on the process and to plan future directions.

Constraints on Effective Science Curriculum Development and Implementation

Research in the Caribbean has shown that there are many factors that influence science curriculum development and implementation. It was found that these factors may be classified into three categories (See Table 1).

This paper has attempted to show how, over time, Caribbean countries have striven to produce strategies that would make curriculum development and implementation in primary science education more effective and efficient. This evolution of strategies has been fueled by the underlying problem of providing quality materials for the classroom situation. The thesis is that no matter how well prepared curriculum materials are, they fail if they do not bring about desirable changes in the learners. Examples of the operation of models of strategies for curriculum development and implementation are presented, and their strengths and weaknesses examined carefully. Chief among constraints faced in the Caribbean region in the science curriculum innovation process is the insufficiency of upgrading and re-orientation activities so necessary for an essentially unqualified and untrained teaching force.

Science Education in Developing Countries: Grassroots Elementary Science

Howard Fearn-Wannan

Introduction

A recent symposium conducted by the Australian and New Zealand Association for the Advancement of Science concluded that elementary science teaching in Australia is "not up to scratch." There appear to be fundamental structural problems that are preventing interest in science among elementary school children. Enthusiasm for science, the basis for making a decision for a career in science and technology, appears to be lacking among many able young Australians. As Pennington (1989) put it: "Today's young people are seeing security in those professions which regulate rather than those that are creative and entrepreneurial."

A study of the international literature suggests that Australia is not unique in this respect and, as Schoenberger and Russell (1986) reported, the problem is compounded by the low expectations of parents with respect to science in elementary school curriculums. Nor is there much support from federal and state governments. Gardner (1989) criticized the Australian federal government for basing its science policy upon the assumption that the nation's best intellectual stock was already in the science education system. He expressed the view that young people need to be encouraged early by means of a "stimulating and interest-generating science program at the primary school level where the foundations of children's interest in science are established."

Endemic Problems

The first fundamental problem is that very little science is taught in the great majority of Australian elementary schools. Although there are no reported surveys relating to this issue, one has only to speak with elementary school teachers to realize the truth of this claim. As a consequence, a great many Australian children are completing the elementary school years with neutral or even negative attitudes toward science. There are at least two reasons for this state of affairs: inadequate pre-service education and misconceptions about science.

Inadequate Pre-service Education

Many young teachers graduate with apprehension and with a marked sense of inadequacy with respect to science. Referring to a recent government survey of science teachers' qualifications. Chipman (1992) wrote that "It is a case of the blind leading the blind. Alexanders Pope's dictum that a little knowledge is a dangerous thing fits perfectly the present state of science education in Australian schools."

Martin's (1992) view was that "the change from a content-oriented textbook-dependent way of teaching elementary science to a hands-on problem-solving approach is particularly difficult for many teachers." It induces an apprehension toward science that, as Tilgner (1990) claimed, leaves many teachers feeling "totally unprepared to do an adequate job." Similarly, Duschl (1983) found that the knowledge component is threatening to elementary science student teachers and expressed the view that "many science methods courses are breeding grounds for an apprehension towards science."

Misconceptions About Science

Science in Australia is generally not perceived as a culture-friendly enterprise. Those who practice it are seen to be remote, white-coated individuals who pursue their dubious practices in sterile laboratories. Science is also seen, although to a diminishing extent, as a male-oriented discipline. Gold (1990) commented that "Women, particularly young women, have been identified as a rich source of scientific recruitment. At every level of education, to doctorate and beyond, women now comprise one third or more of total numbers. But not in science."

Regrettably, for many of our elementary teachers science is perceived as essentially harmful. Chipman (1992) wrote: "Australia's scientifically-uneducated science teachers today serve as a major conduit for the greenhouse gasbags and environmental doom sayers who peddle conjecture as conclusion, and possibility as probability."

The second fundamental problem relates to weaknesses in the curriculum: (a) lack of a theoretical base and (b) little emphasis on process learning'

Lack of a Theoretical Base

Much of the science that is taught consists of unpopular ideas without a system and without consideration of a psychological and conceptual rationale. This approach to science teaching to children was criticized by Kamic and De Vries (1978) who claimed that "science topics or processes that are developed randomly and in isolation do little to assist later learning."

A great deal has been written about the merits and flaws of Piaget's developmental theories. Although it is acknowledged by most Piagetian protagonists that flaws can be found in his methodology and his propensity to generalize widely from limited samples, the neo-Piagetian view is that his broad principles of cognitive development have credibily provided, as Mackay (1973) put it, "that Piaget's theory relates to the development of the idealized average." Uncertainty arising from debate amongst the theorists has led to a devaluation of the importance of developmental learning theory in curriculum development.

Another question of interest is the manner in which children learn science. Ausubel (1963) expressed the view that the science curriculum should "give the student a feeling for science as a selectively and sequentially organized structure. This is no less important than imparting the view that science is a method of inquiry."

Little Emphasis on Process Learning

Where curriculums for science education are formalized, it is usual to find a reference to the development of scientific thinking and mental discipline. In practice, however, process learning tends to occur as an incidental outcome, little attention being given to the deliberate planning of process-developing activities. As Edward De Bono (1980) put it, "Information is easy to teach. Process skills like thinking are much more difficult to teach and to test, we tend to ignore them."

A New Curriculum

Theory-based

This new curriculum has been conceived in both Piagetian and Ausubelian terms. An attempt has been made to match the curricular content with the abilities and experiences of the majority of each age group in the light of modern psychological research. An emphasis on visual, aural, and tactile observation in years 1 and 2, comprehension and inductive reasoning in years 3 and 4, and prediction and hypotheses-making in years 5 and 6, typify the mental processes fostered at each level of development.

The Ausubelian emphasis can be seen in the progressive differentiation of concepts associated with each scientific topic (Figure 1).

"Hands-on"

Every child is involved in as much "hands-on" activity as possible. Lab sheets are used for children to record their work verbally and pictorially and to rein-

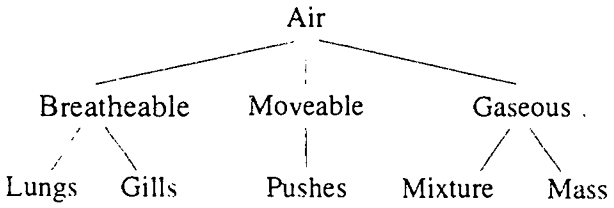

Figure 1. Concepts Associated With Scientific Topics

force their learning with science-based puzzles. The materials used for these "hands-on" activities are very simple, and in most cases, consist of discarded materials from the home.

Interactive

This curriculum is presented as a series of books for children in years 1 to 6 of elementary school. It is centered around the research activities of test-tube cartoon characters who talk with the children from the page and encourage the children to perform the science activities and think about them. It is written in such a way as to be used independently by a child or by a class of children with a teacher.

Recent research (Romance and Vitalke, 1992) has strengthened the author's commitment to the use of reading materials in conjunction with "hands-on" science activities. In a study of the interaction between science-based reading and in-depth practical science, grade 4 children demonstrated significantly enhanced achievement, attitude, and self-confidence in both science and reading. This work was based on a study by Crocker et al. (1986), who confirmed that there is a considerable overlap between science process skills and applied reading skills.

Teacher-supportive

As Tilgner (1990) noted, many elementary teachers have negative attitudes toward science and have a great sense of inadequacy with respect to teaching the subject. This curriculum includes detailed notes for teachers and parents on the concepts, the processes and the equipment for each scientific topic. Teachers can simply follow the logic of the text that covers the essential science content. There is no need for original lesson preparation.

Phased Introduction of Problem-Solving

Many teachers find the use of problem-solving methods too daunting, and many children "play aimlessly" unless given careful guidance and introduced to problem-solving science gradually. This curriculum is designed to introduce young children to the idea of doing simple science activities themselves. This is consolidated with older children doing more complex activities, eventually attempting undirected projects in science and technology. The most senior children in the elementary school are introduced to the notion of controlling variables in experimentation, and are given open-ended "design, evaluate and build" exercises. Such activities introduce the application of scientific principles to the needs of society.

Gender Bias-free

The author has attempted to counter the traditional socialization of girls with respect to science and mathematics. It includes an emphasis on spatial and practical skills and relies heavily upon concrete "hands-on" activities. The science content relates, where possible, to children's common everyday experiences.

In the classroom situation, the learning takes place in a very socially supportive setting. The children are encouraged to talk among themselves and with the teacher. Their lab sheets require verbal and pictorial responses. According to the literature, such a learning context is conducive to quality learning among girls as well as boys.

Balance of Content and Process

The long-standing debate about the relative merits of content and process in science education seems to have settled upon a sensible balance between the two emphases. Harlen (1978) suggested that content objectives should be treated in the same way as process and affective objectives. Rumelhardt (1984) strengthened the argument by insisting that "new concepts need to be clearly related to schemata deliberately laid down." If erroneous schemata have been set in place then, as Howard (1989) put it, "much instruction may simply be a waste of time unless such naive schemata are deliberately replaced by contemporary scientific ones." This is an argument in favor of the early study of science. The new curriculum addresses these issues.

Balance of Verbal and Pictorial Learning

The learning styles of elementary school children are quite variable. For some, particularly girls, verbal learning is highly appropriate. Others seem to respond better when verbal learning is supplemented by pictorial illustration. Children in years 1 and 3 benefit most from the pictorial approach. At this age, children are just beginning to read, and an over-emphasis on verbal learning may be counterproductive. These new curricular materials are colorfully illustrated at all levels. The verbal component, however, is minimal and age-appropriate for years 1 and 2. It increases in proportion and difficulty as the children move through the school.

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Science Education Reform for All Students

Susan Arbuckle and Steven Schneider

Introduction

The need for drastic improvement in American students' achievement in mathematics and science has been well documented. Disinterest and poor performance is acute among ethnic and racial minorities and girls, all currently under-represented in the math and science fields, yet who constitute an increasing percentage of the student body and future workforce. In addition to undermining a nation's ability to be economically competitive in an increasingly technological world market, these deficiencies threaten the very fabric of society insofar as the society is producing citizens who cannot make responsible decisions based on at least a rudimentary understanding of scientific principles and methodology. Furthermore, a lack of scientific knowledge perpetuates a two-tiered society composed on a wealthy, technically adept elite and a poor, underemployed, scientifically illiterate underclass (predominantly ethnic and racial minorities and women).

California Context

California has 15% of all U.S. students, some of the nation's larger urban centers, and some of the country's most isolated rural and mountain towns. The state's cultural pluralism and demographic mix will require implementing a variety of approaches and harnessing many resources to make the necessary improvements in mathematics and science education. Success in addressing these issues will require a systemic approach rather than piecemeal efforts.

California is the third largest state of the U.S. in area and has about 29 million people, or 11% of the country's population. In California there are more than 5 million public school children in grades K-12 and an additional one half million children in private schools. More than half of California's public school students are ethnic minorities: Hispanic Americans (35.3%), African Americans (8.6%), Asian Americans 18.0%), Filipino (2.3%), Native Americans (.08%), and Pacific Islanders (0.6%). Moreover, the non-white (particularly the Hispanic) population is growing. At least 178 different languages (including dialects) are spoken by the state's school children. The public school system is ultimately responsible to the state governor, superintendent, and board of education. The state's schools are divided into 1400 school districts, comprised of more than 200,000 public school teachers, of whom a majority are teachers of science.

In 1989 the California Department of Education (CDE) received a grant from the U.S. Department of Education to pilot the National Science Teachers Association's Scope, Sequence, and Coordination (SSC) project (Aldridge, 1989). The original grant was supplemented in 1990 by the National Science Foundation to support further planning and implementation of the project. Now in its third year, the project is still in a developmental stage, implemented in at least 120 schools in grades 7 to 11, involving more than 300 teachers. SSC is evolving amidst a climate of widespread reform in California (as well as nationally), supported by the pedagogical approaches espoused in such influential documents as Science for All Americans (Rutherford & Ahlgren, 1990) and the California Science Framework (CDE; a 1990 document clarifying the state's conviction that modern science instruction should be nondogmatic and thematic and must actively engage students).

SSC is a response to the fact that over half of U.S.

students do not take science past the tenth grade. Students have very little exposure to science until sixth or seventh grade, at which time the traditional progression through science is life, physical, and then chemistry. Most students take only what is required to graduate from high school or required to enter college. Science is perceived by the majority of American students as boring, difficult, and irrelevant to daily life. Conventional instruction, with its reliance on role learning, memorization of facts, and an emphasis on dense textbooks and worksheets has, for the most part, failed to stimulate children's curiosity and creativity. Activities are few, and rather than challenging students to ask questions and propose their own theories, laboratory exercises are built around predetermined steps and answers.

Philosophy of the Scope, Sequence, and Coordination Project

SSC addresses this dilemma by offering every science, every year, to every student in an effort to engage and retain the children's interest and to encourage success in science throughout their schooling. Starting in the seventh grade, schools are redesigning their instructional program to integrate or coordinate the different disciplines of biology, chemistry, physics, and earth/space science. This coordinated model borrows from practice in Israel, Britain, and other European countries.

Scope refers to the range and depth of science concepts and processes that students study and is guided by the aphorism "less is more" (California State Department of Education, 1990). Sequence refers to the spiraling and articulation of science content and processes through the fourth to seventh years of middle and high school. Concepts are introduced, reviewed, and enriched over time, moving from concrete (descriptive and phenomenological science learning) in the early grades to abstract (semi-empirical and more quantitative and theoretical work) in grades eleven and twelve. Coordination is the degree to which the four disciplines are interconnected and taught concurrently (see note below). SSC classes differ from traditional science classes in the following dimensions:

1. Exposure to more than one science discipline,
2. Covering fewer concepts but in greater depth,
3. Moving from concrete to abstract,
4. Revisiting concepts over time,
5. More hands-on activities,
6. More group activities, and
7. Heterogeneous grouping of students at various ability levels.

Teachers strive to make curriculum relevant to what the children see in their daily lives. They utilize local resources, such as a bay, river, or wetlands, utility plants, science and technology museums, and industrial plants. Textbooks are too often encyclopedic and unrelated to local conditions, so carefully chosen textbooks (e.g., Salter science, Balanced Science) are used sparingly, and supplemented with lessons and laboratory activities assembled by teachers from their own repertoires to meet the criteria of the SSC philosophy. SSC incorporates the California Science Framework's emphasis on unifying themes or "Big Ideas" (such as Energy, Evolution, Patterns of Change, Scale and Structure, Stability, and Systems and Interactions), under which concepts and facts are organized and made manageable. Scientific literacy lies beyond the ingesting of facts in an understanding of the larger ideas that "link the theoretical structures of the various scientific disciplines and show how they are logically parallel and cohesive" (California State Department of Education, 1990).

An example of weaving several disciplines under one rubric is a unit on water, in which students learn about the water molecule (chemistry), the cell (biology), hydroelectric energy (physics), and the hydrological cycle (earth science). Another example would be a discussion of muscles in biology class while covering pulleys in a physical science class. Revisiting concepts over time gives students a chance to understand an idea from several angles and to build confidence to go on to the next level. "Through repetition and doing different kinds of activities on the same concept, students who in the past found themselves just barely able to scratch by with a passing grade, have been able to learn it with a good deal higher grade." (Aldridge, 1989) The ideal of constructivistic learning is realized in large part through hands-on activities, which may comprise up to 80% of classroom time (the California Science Framework mandates teachers spend at least 40% of classroom time engaged in active learning). As one teacher reports, "We've gone to a completely hands-on, manipulative, critically analytical kind of program. We don't do a lot of reading, we don't do a lot of text book work . . . Instead the kids are asking questions, analyzing things, making observations" (Aldridge, 1989).

Organization and Implementation of the *Scope, Sequence and Coordination* Project

SSC is a grassroots approach designed to achieve widespread and persistent change in public school science education. An organizational challenge because of California's large geographic size and economic and cultural diversity, the project managers divided the state into three geographic regions and then "hubs," each comprised of at least 10 schools (there were originally 110 schools involved as pilot sites). Teachers act as hub coordinators, and a teacher at each school is the site coordinator. Teachers from each hub meet on a regular basis to exchange ideas, plan, and perform in-service activities. Hub leaders meet less frequently but on a regular basis with the three regional coordinators and project manager and staff from the California State Department of Education. The CDE role is to facilitate the organization and management of the project, to provide support, to negotiate state level policies and obstacles to the reform movement, and to channel funds to the pilot sites.

The importance of the grassroots model, in contrast to previous state efforts to implement top-down reform by decree, lies in the expression of faith in teachers' ability to design a program in which they are empowered and for which they can claim ownership. As each group of four to eight teachers in each science department of each high school propose their plan of action, a wide variety of approaches, all within the overall domain of SSC, come into being. Now after 3 years, some trial and error, and levels of refinement, the individual schools are moving toward greater commonalities. The process has not been without obstacles and idiosyncrasies, several of which continue to hinder the project's progress.

Among the problematic implementation issues have been:

1. Time—teachers are hard pressed to find time outside of their classroom duties to meet together, to plan, to create and combine new curriculum materials. Devising and carrying out more lab activities requires more preparation and organization.

2. Funds have not always been steady, and are never enough to meet the needs of release time for teachers, the purchasing of laboratory equipment and other curriculum materials, and so forth.

3. Scheduling and space logistics are difficult for team teaching and for alternating students and specific-discipline teachers through 6-week units.

4. Integration of natural science disciplines is difficult for teachers who have discipline-specific expertise and when instructional materials resources are historically segregated by discipline.

5. Team teachers sometimes find they are not as compatible in their styles as they had imagined.

6. State credentialling requirements have had to be modified to recognize the value of enabling science teachers to teach across disciplines.

7. Some parents and students are resistant to the elimination of tracking by ability groups.

8. Even teachers who are philosophically committed to the reform may experience difficulty letting go of established behavior (the traditional lecture mode, wanting to cover as much material as possible in each semester) and replacing them with more effective, open ended tructional techniques.

9. Although teachers and project staff know what type of changes they want to effect in instructional practice, there are few role models available to train teachers in new behaviors.

10. Evaluation of student achievement is moving toward authentic performance assessment, and teachers find devising fair and accurate assessments is a complex task.

Despite these hurdles, the SSC project is supported by continuous funding (approximately $2-4,000/school/year) and by an enthusiasm among the state's science teachers that this is a reform whose time is long overdue. Although resentful of the inordinate and often uncompensated amounts of time and effort required by the project, the majority of teachers and administrators are committed advocates and promoters of the reform.

Science for All: The Case of Santa-Ana High School

Basic to the thrust of SSC, the California Education code, and the California Science Framework is a belief in equity and access to educational opportunity for all people, regardless of gender, ethnicity, or race. The SSC Task Force on Historically Underrepresented Groups (Hispanic Americans, African Americans, Native Americans, Southeast Asians, Pacific Islanders, women, the disabled, and language minority and special needs students), declares in its mission statement that:

- All students have the ability to learn and succeed in a strong and engaging science curricula,
- All teachers accept the professional responsibility to prepare all students to be scientifically literate and to participate in a technological society; and
- All students should be engaged in curriculum that integrates current technology and equipment in the teaching of science.

Santa Ana High School, located in Southern California near Disneyland (Los Angeles, California) has the highest population of non-whites of any school participating in SSC. Out of a total student population of 2,727 in 1992-93 in grades 9 through 12, 94% are Hispanic, 3% are Caucasian, 2% are Asian American and 1% are African American or other (Indian, Samoan, Filipino, etc.).

Santa Ana is the oldest high school in the county, having celebrated its 100th year in 1989. Once agricultural, the surrounding region has become part of the urban sprawl of Orange county. Although more affluent neighborhoods and technology and business parks have grown up nearby, the neighborhood immediately surrounding Santa Ana High School is characterized by shopping centers in need of renewal, run-down houses and apartment buildings marked with graffiti, motels, and mobile home parks. Santa Ana is the point of arrival for many Mexican immigrants, and in fact the high school has a reputation in Mexico as the best place for immigrant families to get a good start in the American public school system. The school climate suffers more from the image of the surrounding community (primarily immigrants, high unemployment, low income) and nonmatriculated mischief makers (drug dealers, gang members) than from the demeanor or comportment of students on campus. A strict dress code prohibits inappropriate garments and any colors or insignia that could be construed as gang related. The campus is patrolled, and the faculty park in a fenced lot, but teachers report they are not fearful for their safety while at work. Although community members from different ethnic backgrounds may clash outside of school, within school there is no significant inter-racial problem.

More than 1700 of the school's students are not fluent in English, which is more than the total population in most high schools. This poses a formidable professional challenge to the faculty, who have responded with resiliency and a progressive program of language acquisition assistance. There are eight levels of Limited English Proficiency (LEP), ranging from a literacy program for students who are non-readers in their native language to classes for gifted and talented children who have not yet mastered English. The faculty is careful not to inhibit children's advancement by tracking them on the basis of limited language skills. Bilingual classes are offered in English, math, and social studies. Sheltered English classes are offered in science, and there are plans for future bilingual science classes to reach a greater number of non-English speakers at an earlier phase in their cultural acclamation.

Five of the thirteen science department teachers spent the first grant year of the SSC project planning its design and implementation. They garnered support from fellow faculty, the administration, and finally the school board. Board members had felt science was of low priority for LEP students compared with verbal and language skills, and their idea of academic support in science was to teach biology vocabulary terms to LEP kids during the summer. The science department now offers 37 sections of SSC in ninth and tenth grade. Class size is 35-41. LEP science classes have an aide who circulates to assist the teacher in communicating to all students, to help keep all students on task, and ensure that students are equipped with pencils, and so forth. Students usually speak their native language among themselves in the classrooms, but they speak English to the teacher.

The SSC course is organized into 6-week units—students rotate to a different teacher of a different science discipline every 6 weeks. Teachers coordinate their instruction thematically. Although the record keeping of grades and attendance is more complicated, the benefits to both students and teachers are many.

1. Several teachers come to know the same individual students and can confer about students' progress and academic needs among themselves.
2. Students have the advantage of exposure to different instructional styles and teaching personalities; one style may succeed where another fails to reach the child.
3. Teachers stay in their own classroom while students move, so that each group of students is exposed to classrooms where higher level physics or chemistry is taught, and the upper levels are made less formidable and more accessible through simple physical contact. (In traditional science departments the advanced science teachers usually do not teach or mix with beginning level students, which further alienates the beginners from the advanced learners and instructors.
4. Teachers find that the swapping of students keeps them more disciplined because they know the next teacher will see with what sort of preparation the students arrive. It is an inducement and a matter of pride to do a better job when the outcome will be immediately (at the close of 6 weeks) scrutinized by one's colleague.

The SSC program, combined with the school's sensitivity to the educational needs of LEP students, has made a significant difference in the number of students progressing through the science curriculum. Five years ago LEP students didn't continue in science because by the time they had finished the minimal science requirements for graduation, they were too old or too far along to take advanced science, and thereby shut out of pursuing science beyond the secondary level. This year more than 20 students are taking college level chemistry, and 170 students want to take physiology. Teachers find that science laboratory activities reinforce language skills; students often do more writing in science than in other subjects. They can see what they're doing in a concrete way and can write about it on worksheets and from the board. Also, they derive mutual support and encouragement in writing skills by working in groups on science questions.

The vast majority of students are first generation immigrants from Mexico. It will taken them 7 to 9 years to become fluent in English. They are from families where there are several young children, often only one parent, and a high rate of unemployment among adult relatives. These students must deal with domestic violence, inadequate health care, parents who are struggling to survive, as well as threats to safety on the street after dark. Parents are generally not able to be supportive or encouraging of a student's academic efforts; the parents don't know the material themselves, they rely on the child to assist in the family's survival, and they are unaccustomed to interacting with school personnel. Santa Ana High School has bilingual outreach counselors for almost 3,000 students, and as one teacher quipped, they are too busy filling in transcripts to actually advise students. There is also bilingual Spanish Parent Teacher Association (*Padres y Maestros Unidos*), and parenting classes are offered through the Human Relations Commission, in which an increasing number of parents participate each year. Several administrators and a few of the science teachers are bilingual. Teachers receive training in cultural sensitivity to help them understand what sort of traditions compel student's behavior. Teachers report that it is not unusual for parents to pull kids out of school so that they can help the parent (whose English proficiency is even more limited) go to the bank, interview for a job, or to babysit younger siblings or care for older relatives while the parent works. Furthermore, the student population is transient; some families may come to California for a few months and then return to Mexico or move on to another community, drawn by work or kinship ties.

Students experience no push to excel from home, and most are not even encouraged to finish high school. Consequently, their aspirations and self-esteem are quite low. Encouragement to do well in school may come only from a good-hearted teacher, or a teacher concerned that we will not have an electorate capable of informed decision making. When asked what they might do after they finish school, a common answer on the part of students is "I'll work at McDonalds just like my Dad." College is often viewed as out of the question—who would pay for it? Families are unaware of scholarship programs.

In addition to an outreach counselor and bilingual classroom instructional aides, the Santa Ana science faculty has the advantage of a laboratory equipment manager. A college student works part-time for the science department setting up lab equipment and keeping it organized and in working order. This frees the teachers to devote their time to planning and teaching rather than maintenance, and prolongs the life of valuable equipment. An additional way in which teachers are freed to reach more students is the involvement of university students, both Hispanic and female, as mentors in the classroom. Further role modeling is provided by a cadre of "gray haired engineers," a group of retired engineers who volunteer to work with interested students are schooled on long-term research projects and experiments. Santa Ana participates in a grant program in which 25 students work for local businesses in industrial laboratory settings each summer in an effort to prepare them for university entrance. These are all examples of how Santa Ana High School utilizes community resources to cope with the needs of their science students.

What do the SSC teachers encounter on a daily basis in their classrooms, and what instructional techniques are employed to reach these students? Incoming students must be taught basic skills: classroom etiquette, the expectation that they will have paper and pencil, and fundamental study skills. Their morale level is high. As one Ph.D. teacher says, "These kids are the survivors" (i.e., the ones who made it out of poorer living conditions in Mexico, who managed to get to the school and into the classroom). Teachers believe in educating the whole person, and some instruction is as significant in its cultural content as its science content. In once instance, when a teacher posed a question only boys' hands went up in the air. He encouraged girls to answer, and called on one 16 year old who very tentatively and timidly ventured her response. "Now if this were a job interview and a boy answered by question in a strong voice, and a girl applicant answered me in a shy little voice, who would get the job?" An understanding of cultural norms of the society in which these children find themselves is important to their survival in the system and to increasing the chances they will stay in school long enough to succeed in science subjects.

Teachers use a multiplicity of formats to get ideas across: writing and drawing on the board or overhead, verbal exchange, asking questions, demonstrating, and performing any manner of theatrics. There is a great deal of "show and tell" and visual presentation in an SSC LEP classroom. "Most kids don't learn unless they do it, so lab activities take up more than half of classroom time, and that helps with understanding and retention" one 25-year veteran chemistry teacher relates. Students are quiet during instruction, but are encouraged to talk during group activities. The untraced nature of the SSC course boosts their self-esteem; no one is relegated to a "dummy" class, and everyone is learning the same material. Some teachers see a way to capitalize on the notion of "gangs" by letting the students group themselves to work on assignments in class. In cooperative groups, students are made to feel more responsible for their own learning through interaction and initiative. While girls who come from Hispanic cultural norms may at first suffer from timidity, teachers have seen that those who stay in school are likely to do very well. The boys are tougher to motivate because of a stigma of being a "school boy"—doing well academically is not consistent with the male idea of *machismo*.

Wherever possible, instruction is open-ended so that students can construct meaning for themselves instead of being fed something they don't fully comprehend or experience. Teachers may introduce discrepant data so students will think through the problem, and then teachers will ask how the investigation might be done differently. The negativity of a lack of continuity of having one teacher for a full year is outweighed by the positive benefits of changing teachers with every 6-week unit. As mentioned above, with each teacher, students experience different personalities, instructional styles, and approaches, so there are more opportunities for students to connect with a teacher whose instructional style is compatible with the individual student's learning style.

In terms of assessing the impact of SSC and this school's laudable language acquisition assistance efforts, there have not yet been enough years of the new science course to declare definitive results. It is clear that enrollment is up and a greater number of children are entering more comprehensive science courses earlier and staying in science longer. More students emerge eligible for entry into industry employment or university-level work. Performance assessment instruments are being developed at Santa Ana, as well as statewide in the SSC project, to more fairly and accurately measure students' knowledge and progress in the natural science disciplines. The difference at Santa Ana High School is that teachers recognize that in most of our high school science departments we've created an elitist program in which only those who come prepared with the appropriate credentials, background, and motivation levels can succeed. The result, as the demographics of school age children shifts dramatically, has been that fewer and fewer students do succeed, and the ranks of graduates from both the secondary and university level who are prepared to pursue science academically and professionally are dwindling. In the case of Santa Ana High School, teachers believe they must take a good look at who their students are and do whatever is within their means—pedagogically, organizationally, and with a great deal of resourcefulness—to give all students access.

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Third World Solutions to Third World Problems in Science Education

Paul Webb

Introduction

The science unit of the Center for Continuing Education (CENCE) was established in 1984 to promote science education in the Eastern Cape, South Africa, at both primary and secondary levels. Some of the problems encountered by teachers when teaching science in the Eastern Cape schools are:

1. Lack of training in science education;
2. Lack of apparatus and supporting materials;
3. Overcrowded classes;
4. Teaching science in a second language;
5. Lack of support mechanisms, for example, science societies, groups, committees, and so forth; and
6. Lack of facilities in general: some farm schools do not even have access to water, not to mention electricity.

Cooperation with the Urban Foundation Primary Science Programme and Shell Education Service has resulted in a synergistic and coordinated effort that has allowed the development of strategies to alleviate the situation that could not have been achieved individually by any one of these groups.

The Primary Science Programme in the Eastern Cape (PSP)

The PSP is a national program, funded by the private sector, aimed at upgrading primary science education in South Africa. Although the program is national, there are five geographic regions that operate fairly independently of one another and that have developed according to the needs and strengths in each area.

In the Eastern Cape the program provides in-service training courses for teachers, follow-up in-service workshops, and apparatus and materials for teaching science.

The materials provided to teachers during 1992 were written and distributed by CENCE, tested and disseminated via PSP workshops, and sponsored and printed by the Shell Education Service. PSP practical work apparatus is provided to schools in the form of a kit that handles all the prescribed experiments for years 5, 6, and 7. Enough apparatus is usually supplied in each kit for 10 groups of pupils, but smaller, 5-group kits are also provided to farm schools. These kits are assembled at the Center and distributed to schools via PSP in-service training workshops.

Geographical Extent of the Program

Primary Science Programme activities in the Eastern Cape currently stretch from Mossel Bay in the west to the Transkei border in the east. This region of activity covers an area greater than that of European countries such as Austria or Bulgaria, and approaches the size of Czechoslovakia or England. In African terms it approximates the size of Malawi or half the size of countries such as Ghana or Uganda.

History of the Program in the Eastern Cape

The Primary Science Programme (PSP) in the Eastern

Cape was launched in 1984 and from this initial contact, has grown more than 20-fold during 8 years from 58 teachers at 32 schools, to the 1992 figure of 1,067 teachers in 657 schools. The Urban Foundation has supplied science kits to 513 schools. Reduced numbers of teachers participating during 1986 and 1987 reflect the climate of political unrest that existed during this period.

Methods

The Eastern Cape has been divided into six regions for the purposes of the program and a number of part time lecturers and coordinators operate in each area. The regions are centered on Port Elizabeth, Grahamstown, Cradock, Queenstown, and East London, but numerous venues in the surrounding districts are used for contact sessions. The Port Elizabeth area has been divided into two regions to cater to teachers serving in both Department of Education and Training (DET) and Department of Education and Culture (DEC) schools in an area stretching from the Sundays River in the east to Mossel Bay in the west.

Implementors are drawn from local communities and include lecturers from universities and colleges, science project workers, science advisors, school teachers within and without the program, principals, farm school managers, and "household managers" in cities and on remote farms. The program brings a variety of people together, and this contact often results in attempts to solve social as well as educational problems. A great deal of bi-directional learning has taken place and the program has an important sensitizing effect on many individuals who would not normally come into direct contact with pressing social issues in their immediate environment.

The reality of the teaching context and the needs of teachers have determined the type of materials and in service training offered. Currently, most teachers attend a quarterly, 1 day workshop in each region. The content covered is timed according to the requirements of the syllabus and the materials provided attempt to take into account current findings in science education research.

In new areas, and areas where the natural turnover of staff provides groups of teachers large enough to warrant a special course, an intensive initial training course is held for new participants. These teachers then enter an ongoing, quarterly system of workshops. Workshop sessions focus on teacher activity with special emphasis on practical work and methodology. Materials such as worksheets and posters are supplied to participants and appropriate new texts are made available to teachers for purchase through an order system. An opportunity is also afforded during the workshops for teachers to replace apparatus and consumables such as glassware and chemicals.

Staff development is promoted wherever possible by quarterly seminars for implementors. During these sessions the content, philosophy, and methodology of the program is discussed and implementors' experiences shared. These seminars also allowed for coordination and uniformity of administration.

Materials

In-service training focuses on teacher development. This can be evaluated in a number of ways but a current weak link in the process is evaluating how this development is transmitted to pupils in the classroom. This apparent deficiency prompted the development of "user-friendly" pupil material that could provide an immediate reflection of what was happening in the classroom. These worksheets, which include numerous cartoons and illustrations to stimulate interest and promote understanding, were tested on teachers during workshops and by teachers in the classroom. In this way teachers became part of the development process through editing and putting forward new ideas.

Another classroom problem is the authoritarian methodology used by Eastern Cape teachers. This probably reflects their own training and experiences as pupils. This authoritarian, "telling" approach remains a problem despite strenuous remedial efforts in workshop sessions. A series of "prompt posters" were therefore developed to promote teachers questioning skills and to change both attitudes and methods through successful use in the classroom. The prompt posters are designed for immediate use in the classroom. A poster is draped over a portable lectern that doubles as protective storage space when the posters are not in use. The lesson "prompts," mainly in the form of questions, are printed on the back of the posters for teachers to read.

After testing year 7, worksheets (more than 250,000 individual sheets of paper) and posters with teachers and pupils, workbooks and posters were made available to schools on the Urban Foundation Primary Science Programme at a price considerably less than that of the cost of production. More than 25,000 workbooks were purchased and 80% of the schools on the program bought lecterns and sets of prompt posters.

Rationale Behind the Development of the Materials

The posters are meant to be fairly self explanatory, with all that needs to be said and done written on the back. There are also small versions of the illustration on the reverse side of the poster for teacher use. The prompt posters are not designed to be used as a single lesson plan, but may be used in part and brought out again when they are needed. They can then be stored safely in the lectern after use.

The teacher's guide is written to help teachers teach the syllabus topics using prompt posters and worksheets. These guides remind teachers to make lots of references to key words, to summarize, and to get the pupils to record what they have learned. Teachers are also encouraged to allow the pupils to do the worksheets when they come up in the lesson prompts on the posters. The apparatus needed for experiments is noted at the beginning of each activity in the worksheet, allowing teachers to make sure they hand out whatever is needed before the pupils start their practical work. Teachers are also reminded that the worksheets are not designed to test the children's knowledge, but to allow them to learn, and so they should allow pupils enough time to discuss their ideas. The series of posters, worksheets, and teachers' guides for year 7 science teachers are complementary to and, where relevant, promote the use of the Urban Foundation Primary Science kit.

The content covered by the posters and the worksheets is based on the syllabus, but does not cover everything pupils have to do. It is pointed out that the posters are merely a guide to be used along with the prescribed text book and lesson plan. Teachers are encouraged to improvise whenever they feel the need and to give their pupils the best learning experience possible.

The underlying rationale that directed the production of the materials can be summarized at follows. Development was shaped by the belief that the materials should:

1. Allow concepts to be built in a logical way;
2. Be pleasurable, challenging, and interactive;
3. Present concepts as visually and concretely as possible;
4. Enable users to easily grasp what is intended through pictorial aids and verbal prompts;
5. Allow mastery of small steps with opportunity for demonstrable achievement, leading to more complex skills and confidence building;
6. Emphasize oral, written, and other communicative skills;
7. Allow pupils with restricted language competency to demonstrate their skills and understandings;

8. Create a change in attitude from valuing content to valuing skills and concepts;

9. Make explicit the intent underlying the lesson as this leads the teacher to security and focus;

10. Be able to be put into immediate practice in the classroom;

11. Allow users to become part of the development process—adjustment and change can then be made through teacher and pupil input via open ended testing and trials;

12. Be able to be used at a range of levels, for example, both for the introduction of concepts and adult learning; and

13. Be transferable to other subjects and be used as a model by teachers to develop the same type of materials for themselves.

The cartoons on the worksheets are meant to make the activities fun and reading more pleasant. They also help make sense of new words and provide visual stimulation for concept formation. The layout gives pupils experience of a number of different ways of presenting and recording information.

Cost Efficiency

The cost of poster production, that is, developing, printing, distribution, and so forth, was approximately R4,20 (US $1.40) per poster. Each 72-page workbook cost R1,50 (US $0.50). These were provided to schools at R2,00 (US $0.66) per poster and 20c (US $0.07) per workbook.

There are an average of 50 seventh year pupils per PSP school in the Eastern Cape. The total cost of equipping an "average" school with a full set of posters plus a workbook for each pupil was as indicated in Table 1.

Table 1. Cost Efficiency

		RAND	US $
26 posters @ R2,00 (US $0,66) each	=	52,00	17,16
50 books @ R0,20 (US $0,07) each	=	10.00	3.33
		62.00	20.66
Actual cost of supplies			
26 posters @ R4,20 (US $1,40)	=	109,20	36,40
50 books @ R1,50 (US $0,50)	=	75.00	25.00
		184,20	61,40
Less recoupments		-62.00	-20.66
		R122.20	$40.73

Cost per pupil = R2,44

Evaluation

A question which could be asked is "Was it worth spending the equivalent of a bottle of beer on each pupil?" What has been achieved in the classroom? Some feedback was obtained when the material was tested on teachers before printing, and teachers showed great enthusiasm for the project. Attempts were made to obtain further evaluatory feedback from the following sources: 20 implementors in the field, a sample of 55 teachers using the materials, and a sample of 173 pupils of the above teachers.

A 2-hour report back and discussion session during a quarterly seminar was held in June 1992 for the lecturers implementing the program. All reported positively and felt that, at least, the materials were improving the teachers knowledge during workshops.

A sample of 55 teachers who had purchased a full set of poster and workbooks were approached for written comment and were asked: (a) Which of the posters have you used in the classroom? and (b) Which of the posters did you find most useful? All indicated that they had used all of the posters and, although asked explicitly to do so, would not select any poster as the most useful, unanimously preferring to state that they had found all the posters useful.

A total of 173 pupils in 6 schools selected from teachers who said they had used the materials were visited to determine:(a) whether the pupils had been exposed to the materials, and (b) students' reactions to the materials.

All of the pupils recognized the materials and could comment on the posters and workbooks. This suggests that the materials have been used in the classrooms sampled, but no measure has been made as to the effect on learning.

Feedback was positive and examples of the pupils written comments included: "We thank the association which sent us these posters, they make us very happy," "They keep us curious in lessons," "Simple English is used," and "We like the pictures very well."

Conclusion

Cooperation among the PSP, Shell Education Service, and CENCE has allowed what appears to be a very cost-effective method for developing and producing classroom materials for science teaching. Although subjective pointers suggest that the materials are being used, at least to some measure in the manner intended, a reliable judgment of cost efficiency can only be made in terms of the materials achieving their objective—improved science teaching and learning in the classroom. Research into the effect of the materials in the classroom therefore remains a vital component of the overall process, and therefore should receive priority attention.

Design and Development of an Integrated Science and Language Curriculum for Academically Disadvantaged Students

Diane Grayson

Introduction

In 1990, the Science Faculty at the University of Natal in Pietermaritzburg committed itself to trying to increase the abysmally small number of Black African science graduates by launching the Science Foundation Programme (SFP). The purpose of the SFP is to identify academically talented but underprepared African students and help them develop the skills and resources needed to succeed in degree studies in science or applied science. Because of the challenging and difficult nature of the brief of the SFP, a year was spent in curriculum development prior to accepting the first group of students in February 1991. On-going curriculum development has taken place during the 2 years since the program began. In this paper I focus on the *process* of curriculum development rather than the end product in the hopes that it may be useful to others who wish to engage in a similar process.

The initial curriculum design process took the form of one afternoon-long meeting a month for a year. On-going curriculum development has occurred informally during the weekly staff meetings that have been held since the program began and more formally at quarterly curriculum development meetings.

An important aspect of the curriculum development process is the interdisciplinary nature of the development "team." The team comprises representatives from each component of the program (biology, chemistry, physics, mathematics, and English-language development) as well as a counseling psychologist. Both the original design meetings and the on-going development meetings are attended by the subject lecturers and by science subject "advisers," that is, mainstream lecturers from each of the science departments involved in the SFP.

Before the SFP began, none of the staff (myself excluded) had much familiarity with the research literature in science education. As Coordinator of the SFP, I felt that if we were to be as effective as possible it was crucial for the SFP to be based on sound science education principles. To this end, staff read selected papers from the literature in science education and cognitive science prior to each curriculum development meeting. These papers provided a focus for discussion at the meetings, as well as helped staff gain some background knowledge in the field. Another benefit of having everyone read a set of papers is that we acquired a common language with which to communicate with one another about the whole educational endeavor.

I believe the order in which we performed various aspects of the curriculum development process is important. For us, the selection of specific content areas came last rather than first. Our first step was to generate a set of educational principles and instructional guidelines to form the supporting structure, or skeleton, of the curriculum. The next step was to put muscle on the bones by identifying cognitive and practical skills that we felt were specific to each of our disciplines. Last, we put the skin on the structure by selecting particular content areas. Each of these aspects of the development process is described below, with special mention of the role of the English-language development and counseling components.

The Skeleton

The first part of the curriculum that we generated was a set of educational principles and instructional guidelines to provide the skeleton, or underlying supporting structure, for the program. These principles and guidelines reflect our thinking about the role of the learner and the teacher, our understanding of how learning occurs, and what and how we think we should teach. The initial set of principles was generated during a brain-storming session and refined over the course of the year. This section contains these principles and guidelines, some of the motivation behind them, and how they have been implemented.

Active Participation Should Be Required of Students

Although the dominant mode of instruction for all high school students in South Africa requires pupils to receive knowledge rather than to generate it, this problem is particularly acute in Black schools, where classes are often inordinately large, and teachers are frequently underqualified. One of our educational goals is to help students become willing and able to relinquish the role of passive recipient and become active constructors of knowledge.

Learning and Teaching are Interactive

The role of the instructor should be to facilitate or mediate the learning process. In most university courses, and even more so at high school, the instructor teaches, and the student learns. The goal of instruction is commonly seen as the transference of a body of knowledge from instructor to student. We felt that both instructor and student should be learners and that the curriculum should be influenced by the interaction between them. We see our role as being less about "teaching" in the sense of conveying information and more about helping students learn to learn.

Students Must Take Responsibility for Their Own Learning and Share Responsibility for Their Peers' Learning

Students from Black schools tend to have an unhealthily high dependence upon the authority figure. We thus felt it was crucial for them to see that learning is their responsibility, and the instructor is merely a facilitator in the process. In addition, students need to be introduced to the concept of working cooperatively toward a common goal, a concept that is not only of value pedagogically but is also important to prospective employers.

Several of our instructional guidelines are directly related to the principles above:

1. Lectures are ineffective and should be minimized,

2. Learning should be experiential as far as possible, and

3. Peer interaction should be encouraged.

To implement these principles and guidelines we structured the SFP so that there are no lectures in the first semester. The biology, chemistry, and physics courses all take place in the laboratory. The experiments are of the guided-discovery type rather than the verification type and provide the medium through which students acquire knowledge. The mathematics and language courses comprise tutorial style classes, discussions, and small group work in the first semester. An important reason for adopting this mode of instruction is to try to break students out of the rote learning mold familiar to them by placing them in a learning environment in which there is nothing to learn by rote.

Although we would prefer to maintain the same instructional mode all year long, we recognized that we must help the students learn to cope with the mode they will experience in first year. Thus in the second semester the style of instruction switches to the lecture/tutorial/practical format. However, we hope that by then students will bring reflective and critical thinking skills to bear on what they are learning, even if the mode of delivery is a lecture.

Peer interaction is an important component of the learning environment. Apart from giving students a sense of responsibility for one another, peer interaction also provides the opportunity for students to formulate and express their understandings and misunderstandings, that is, to articulate their ideas. In the laboratories, students work in pairs, in tutorials students are encouraged to work together, and in one of the language sessions each week they work in pre-assigned peer groups of eight students each. In addition, students are encouraged to form study groups at night in the residences.

An important reason for including these first three principles, apart from the pedagogical value, is that the school system in South Africa, and in Black schools especially, is very authoritarian. Students are expected to be quiet and listen to the teacher. Questioning is often perceived as impertinent and is definitely not encouraged. Working together is seen as "cheating." The only sources of knowledge are the teacher and the book. It is thus important for SFP students to learn that they can and must construct their own knowledge, and that both they themselves and their peers can be sources of knowledge.

Start Where the Students Are

The corollary to this principle is that we must end the year where the students need to be so they can cope with degree-level courses. Thus, rather than pitching the SFP at a level intermediate between high school and first year, we designed the program so that there is a phased transition during the course of the year. Because the students are underprepared, sometimes the level of work near the beginning of the year is way below high school. In addition the pace is very slow. As the year progresses both the level and the pace of work pick up, until by the end of the year the work is at first year level and almost at first year pace. This structure allows students to build up their stamina and speed over the course of a year. It also provides for good "impedance matching" at both ends of the year.

Learning Must be Rooted in Specific Content

We do not try to teach generalized, context-independent skills, but rather root the teaching of skills in specific content. This is in contrast to the way many support programmes have been run in the past, in which students were taught "study skills" separately from their specific subjects.

Disciplines Should Be Broadly Integrated

We wanted the students to see that there is a unity to science, a common underlying way of thinking and approaching problems, rather than placing each subject in a box, isolated from all the other subjects.

A related instructional guideline we identified is the need to teach for transfer. Although there is debate about how readily students transfer learning from one context to another, we had all had the experience of assuming that students had learned something in one course but could not use that learning in the context of another subject. Thus, we decided to deliberately build in opportunities for transfer of learning among courses. We wanted to encourage transfer of three kinds of learning: cognitive skills, practical skills, and content. For example, we designed the courses so that in biology, students learn the practical skill of controlling variables; the students then use this skill in physics a week later. In Physics they learn the reasoning skill of proportional reasoning, and then use it in mathematics. The process of transfer is further encouraged by structuring opportunities for students to reflect on the transfers they make. In particular, each semester they are required to write a short paper as part of the English-language development course in which they give examples of how learning from one subject has helped them in another subject.

Both Conceptual Understanding and Problem-Solving Skills Need to Be Developed

At university there is often a concentration on the latter with little attention paid to the former. Thus, one sometimes gets the situation where students can solve textbook problems but do not "understand" the material.

Two related instructional guidelines that we adopted are: (a) students' explanations in their own words must be emphasized; and (b) students must be assessed frequently, including delivering assignments often. Implementation of the first guideline not only leads to better conceptual understanding but it also provides students with opportunities to get practice in written English. The second guideline was introduced because colleagues working elsewhere in the country had found that Black students were often poor at assessing how well they were performing in a course and understanding the material. The result was that there were many disappointed and amazed Black students when the exam results were given. We hoped that by providing the students with regular feedback they would become experienced and adept at self-assessment.

Cognitive and Practical Skills Must be Taught Explicitly, Not Assumed to Be Picked Up "Along The Way"

Most science instructors say they want students to learn to be critical, independent thinkers who can reason logically; however, these same instructors tend to concentrate on teaching content. The assumption is generally made that students will "pick up" the reasoning skills "along the way" if one teaches the content. This assumption is unfounded for all but very strong students. We felt that if we are serious that thinking, reasoning, and practical skills are at least as important as content then we should teach these things explicitly. Moreover, with students who are underprepared, the learning process must be as efficient as possible, so we must specifically teach all of the things we feel are important for students to learn. The problem that we immediately encountered was that many of us could not articulate the specific skills required by our disciplines. We therefore added another principle:

Thinking and reasoning skills needed for each discipline must be identified and explicated by instructors. This is described in more detail in the next section.

The Muscles

Once the skeleton of educational principles and instructional guidelines was constructed, we put the "muscles" onto the bones. We assigned ourselves the task of trying to explicate the skills, both practical and cognitive, that we believed students ought to develop in each of our disciplines. We had a month to think and then brought a list of skills to the next meeting.

Many of the skills that were identified in the context of one science were applicable to one or more of the other sciences. A number of the reasoning skills pertained to both mathematics and the sciences. This overlap made it easier for us to teach for transfer of skills, one of our instructional guidelines. We divided our list of skills into practical and thinking/reasoning (cognitive). Some of the practical skills identified are: manipulate simple apparatus; take accurate measurements; make correct and careful observations; represent observations accurately (e.g., biology drawings); record data honestly and with appropriate level of precision (not too many significant figures); analyze and display data appropriately; control variables; recognize experimental limitations (uncertainties); and appreciate validity of experimental results (believe what you see).

Our list of cognitive skills was much longer. A number of these have been identified elsewhere (Arons, 1990; Redish, 1988). The main skills for the sciences were: formulate and test hypotheses; recognize limits of applicability of concepts/methods/models/theories; make appropriate approximations; use limiting cases; estimate; have a sense of orders of magnitude; distinguish primary effects from secondary effects; give phenomenological (qualitative) explanations, interpret abstract representations, for example, diagrams or equations; translate between representations, for example, graphs to equations; translate between physical phenomena and abstract representations; distinguish an influence from a determining factor; distinguish inferences from observations; perform hypothetico-deductive reasoning; reason by analogy; and perform proportional reasoning.

Some of these skills were also seen as relevant to mathematics, especially the reasoning skills and the translation between representations, such as graphs and equations or verbal and algebraic representations. In addition, a skill that was identified as being vital in mathematics is the confidence to create a variable where the need for one is not made explicit in a problem statement. The language instructor identified the following skills: make explicit the demands of a reading/writing task (topic analysis); read critically; write effectively; reflect on process used to fulfill demands of task (metacognition); evaluate the effectiveness of a communicative strategy with the purpose of modifying future behavior; link present task to theoretical base of the discipline; be able to generalize and make predictions; be able to generate other examples.

Clearly the skills identified by the language instructor are of central importance if the students are to be able to do almost any of the tasks required of them in the science and math courses. Thus, in many ways the language course is the cornerstone of the whole program. Implicit in our use of the term "skill" rather than "ability" is the notion that it is something that can be learned by the student and be improved with practice, rather than something a student either has or does not have. This point is particularly important when one is concerned with underprepared students who may, at first sight, appear less "able" than well-prepared students. The "skills" paradigm allows for the possibility of growth and development.

The Skin

We used several criteria to decide how to flesh out the program, that is, what content to teach. The material had to be amenable to the method of teaching we endorsed. It had to be a good vehicle for the teaching of cognitive and practical skills along with the content. It had to be foundational in the discipline, that is, material that helps provide a good grounding in the particular discipline. Last, it should, where possible, include opportunities for transfer to other subjects.

To illustrate the last criterion, in the second term the physics course includes a study of heat and heat transfer processes; in the third term the biology course includes a section on thermal regulation in mammals; in the fourth term the chemistry course includes a study of endothermic and exothermic reactions. The following quotation is taken from one of the papers the students wrote reflecting on transfer of learnings they made:

> *At the beginning of the year we dealt with some concepts relating to heat transfer in physics, i.e. things like how heat is transferred, direction, etc. We have also dealt with heat transfer in chemistry. In fact in chemistry it was a matter of identifying if ever the reaction is exothermic or endothermic, but even then it's either heat is transferred to the surroundings or transferred by the surroundings. We have also dealt with heat transfer in biology. Although in biology we dealt with it under the topic homeothermy but the concept is still more or less the same as in physics and chemistry.*

In addition to building in opportunities for transfer, some topics in the mathematics and language courses were chosen partially because they would be needed in other courses. For example, all of the sciences require students to plot and interpret graphs. Thus one of the first topics to be taught in the mathematics course is graphs. In the language course students learn how to write an academic essay and a report of an investigation.

In keeping with the aim of the SFP, namely to equip students with underlying skills and resources needed to succeed in further studies in science, we decided not to "pre-teach" first year material, but we did decide to end the year by laying the groundwork for the topics students would encounter at the beginning of their first year of degree studies.

English-Language Development

Bcause all of the students in the SFP are, at best, second-language speakers of English, we decided that English language development needed to form an integral part of the SFP. The students are thus enrolled in a special section of a credit-bearing course called Learning, Language and Logic (3L), which has been developed over a number of years for second-language speakers, most of whom are also disadvantaged. For six periods a week, SFP students follow the same curriculum as the mainstream students. However, the SFP 3L course has an additional 2 periods (1 double period) a week which is a "language and science" session. All science instructors have several language sessions allocated to them during the year. The science teachers work together with language instructors to devise tasks that address the language demands of the particular science discipline. Language instructors work with the students on the form of the task rather than the content, and the assignments are finally handed in to the science instructors. Thus, students improve their competence in English, and scientific English in particular, while doing real science tasks.

Counseling

An important part of the SFP is the counseling component. Given the social circumstances from which most SFP students come (poverty, violence, etc.) it would be unrealistic to imagine that the students will cope academically if only their cognitive needs are addressed. We thus decided to incorporate a counseling component into the structure of the SFP. The counseling component is designed to address the emotional, psychological, vocational, and social needs of the students. Clearly, problems in these areas can prevent students from performing well academically.

The counseling component is run by a registered counseling psychologist and contains several elements. Students participate in workshops and small groups to develop self-awareness and important life skills, such as stress management and time management. They work throughout the year on a project relating some aspect of science to the community. They research various career options in science and applied science, receive talks from scientists from various fields (which helps them plan their degree structure) and go on field trips to see first-hand the type of work scientists do. Students also receive individual counseling. Last, the counselor facilitates a weekly feedback session where students can air their concerns (which are relayed back to the staff where appropriate) and hear concerns from the staff.

Conclusion

The most important aspects of the process of curriculum development for the Science Foundation Programme are that the development team is inter-disciplinary and that the process involved deciding on educational principles and instructional guidelines, cognitive and practical skills, and content *in that order*. By adding two non-science components, namely English-language development and counseling, we sought to address certain areas that, if ignored, may seriously hinder students' ability to learn science. The process has been stimulating for the instructors and has, we believe, produced a program that is well-matched to the needs of the students, both academic and non-academic. The end result is a program that is integrated and holistic.

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Chemistry Curriculum Development in Israel Based on the Diagnosis of Students' Learning Difficulties

Ruth Ben-Zvi and Avi Hofstein

Introduction

The inadequacy of students' knowledge and the resulting learning difficulties have been a central theme of research in the last decade. The initial phases focused on the description of students' difficulties. Numerous studies in the area of concept learning show that students frequently hold ideas that are different from the accepted scientific views (McDermott, 1984; Driver, 1987; Duit et al., 1985). In some cases, these ideas are consistent and make sense from the students' point of view; in others, students have a confused, inconsistent way of thinking. So far, however, research findings in this area have had only limited influence and impact on the practice of science education in the classroom or (school) laboratory, let alone on the design of curricula and teaching programs.

This is is not difficult to understand, for some of the following reasons:

1. Researchers themselves have frequently failed to make explicit the implications of their research findings for educational practice and for curriculum design.
2. Investigations into students' learning difficulties are often conducted under conditions that are remote from the reality of actual teaching. Although findings from such investigations are usually interesting in themselves, the artificiality of the setting in which they were obtained can represent a barrier to their practical application.
3. Educational practitioners (i.e., teachers, teacher educators, and curriculum developers) tend to be reluctant to accept and act on the basis of research findings, either because they conflict with the personal beliefs and convictions held by the practitioners or because the changes for which they call are difficult to implement in practice.
4. Teachers are frequently unaware of the fact that learning difficulties and misconceptions do exist among their students.

Definition of Learning Difficulties

Learning difficulty may be said to exist in any situation where a student fails to grasp a concept or idea as the result of one or more of the following factors:

1. The nature of the ideas/knowledge system already possessed by the student, or the inadequacy of such knowledge in relation to the concept to be acquired (Hewson & Hewson, 1984). There is an expanding literature concerning the role of prior knowledge on learning. Much of it is based on the constructivist point of view (Driver, 1987);
2. The demand and complexity of a learning task in terms of information processing, compared with the student's information-handling capacity; and/or
3. Communication problems arising from language use (e.g., in relation to technical terms or to general terms with context-specific specialized meanings) or the complexity of sentence structure and syntax used by the

teacher (compared with the student's own language).

To bring the work on learning difficulties to the stage that it will be useful in practice, several steps are necessary (Kempa, 1988):

1. Identification of learning difficulties and how they are manifested in students' behavior;
2. Interpretation of the difficulties with a focus on their source; and
3. Treatments (remedies) that lead to avoidance, bypass, or remediation of a certain difficulty.

It is suggested that the implementation of one's knowledge concerning a learning difficulty in a curriculum context should proceed as described in the following scheme (Figure 1).

To accomplish these steps, there is a need to build a cooperation between the three predominant components of the framework of curriculum development and implementation, namely researchers, curriculum developers, and the science teacher in school. This model was adapted in Israel and is used in the Amos de Shalit Israel Science Teaching Center. Examples pertaining to chemistry curriculum are presented.

Chemistry Curriculum Development in Israel: Background

In Israel, the academic senior high school consists of 3 years. The age range is 15-18. The educational system in Israel is centralized, and thus, the same chemistry syllabus is taught in all the academic high schools in the country. This also means that many teachers use the same curriculum materials, that is, textbooks, teachers' guides, teaching aids, and various teaching and learning tools. These materials are developed by the "Chemistry Group," a curriculum development team in the Department of Science Teaching Weizmann Institute of Science.

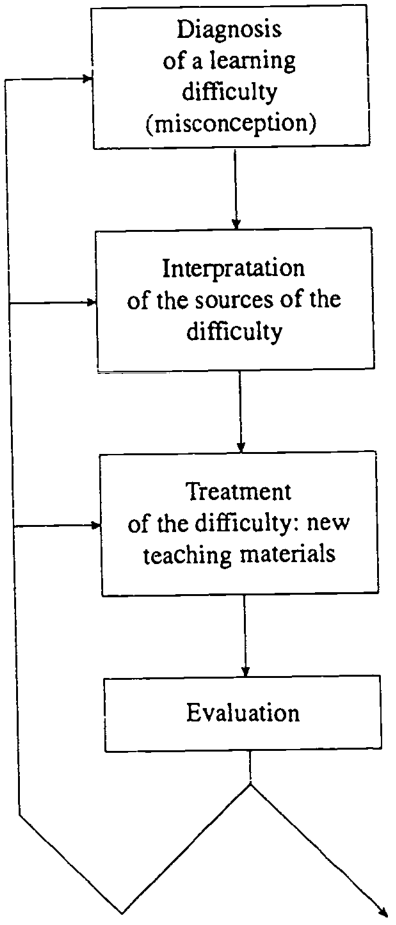

Figure 1. Curricular Interpretation of Learning Difficulties

Stages in the Development of a Chemistry Curriculum in Israel

Diagnosis of a Learning Difficulty

The following is a description of the model used to develop a chapter in the Chemistry curriculum: *Chemistry—A Challenge* (Ben Zvi & Silberstine, 1984). For the purpose of a study, a sample of 337 students from 11 tenth-grade classes was used. After studying chemistry for 8 months , the students were given a set of formulae and were asked to describe these by represented drawings of a model. Students were presented with a set formula (e.g., O_2, $O_{2(g)}$, N_2O_4, NO_2, etc.). When student views about structure were studied, it was found that most of the students, who were at an advanced stage of the introductory course in chemistry, knew how to represent one molecule of an element. However, many of them had difficulty representing correctly one molecule of a compound or an element in the gaseous or solid state. A third of our sample incorrectly represented the structure of a molecule of a compound. The most prevalent error was representation of the molecule N_2O_4, for example, as two connected or disconnected fragments—one denoting N_2 and the other O_4. About a third of the sample represented incorrectly an element in the gaseous state. For example, in the description of $O_3(g)$ most of the wrong answers represented the gas by one molecule or by three disconnected atoms. The performance dropped even more when students were asked to represent a compound in the gaseous state—about 70% of the students gave an incorrect representation.

Interpretation of the Sources of the Difficulty

The examples presented in part a are a selection from a more comprehensive study that led us to assume the following as the main reasons for students' misconceptions regarding structure.

1. An incorrect understanding of the atomic model: If students feel that the atom is a small piece of an element, then an additive view of the structure of a compound (i.e., one small piece of one element being near a small piece of another element) is a natural outcome.

2. Misleading use of models: In textbooks, the use of models is usually confined to single units. For example, the representation of a chemical reaction, such as synthesis of HCl, is presented by one molecule of hydrogen, one molecule of chlorine, and two molecules of hydrogen chloride.

3. Misunderstanding of chemical equations: The chemical equation is read by students as representing single units and not many units.

4. Information overload: As was mentioned before, our results showed that when students had to represent a compound in the gaseous state their performance dropped noticeably. To perform correctly, students had to control two variables simultaneously, each of which caused difficulties on its own, one—the transition from an element to a compound and the other—the transition from one molecule to many molecules. The demands of the task apparently overloaded students' working memory, and they regressed to simpler, incorrect models by neglecting one aspect or another (Eylon et al., 1987).

Treatment of Difficulty: Development of New Teaching Materials

An Incorrect Understanding of the Atomic Model

An analysis of students' answers concerning the atomic model led us to assume that the intuitive models that students have (i.e., that an atom is a piece of substance carrying all the properties of this substance) places them in the Greek period. Because we felt that many of the other difficulties are caused by this view, the objective of the developers of the new program was to show students how and why the atomic model was changed. The atom is therefore presented as an ever-developing model, the characteristics of which change in accordance with new facts that have to be explained. Figure 2 serves to illustrate this approach. After an introduction to scientific theories and models, a brief historical review is presented, leading to a model of the atom that was devised in the beginning of the 19th century to explain some quantitative aspects of chemistry known at that time. This model, the Daltonian Atom, could explain the laws of constant composition and multiple proportions but could not be applied to explain other properties of matter such as electrical conductivity. Dalton's ideas had, therefore, to be changed to include additional features. This interplay of facts -> model -> new facts -> new model is carried on during some months of study and with a summary of the stages of the development of the atomic model as it currently exists.

Misleading Use of Models and Misunderstanding of Chemical Equations

In the new textbook, stress is placed on presenting many particles whenever possible (using models of solids, liquids, and gases). Whenever the representation of many particles tends to obscure the point under discussion, the student is specifically told that for reasons of clarity, only one set of particles was presented. Almost every chapter is followed by a unit called "the chemists' language," where the meaning of symbols and equations is taught, and here again the need to think simultaneously of many particles is stressed.

Information Overload

It is our belief that if students get used to thinking of many units and of the structure of each unit as well, they will have fewer problems with a true understanding of aspects of structure. This treatment, it is suggested, will help reduce the overload on students short-term memory.

Evaluation

An intensive evaluation project aimed at learning about the productivity of the remedy was conducted. The sample consisted of 1,078 students from 35 classes. Half of this population studied a currently used book (a control group) and the rest studied the new course "Chemistry—A Challenge" (1984) (experimental group). The students were given three sets of questionnaires, each consisting of both achievement tests and diagnostic questions, to which they had to respond by drawings models. One set of

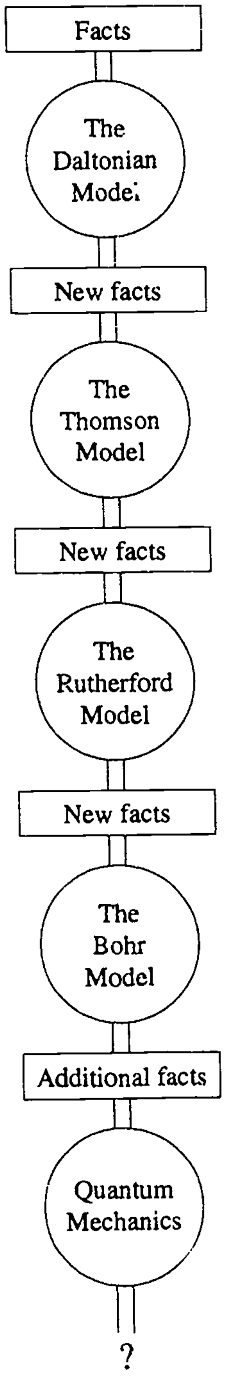

Figure 2. Development of the Atomic Model

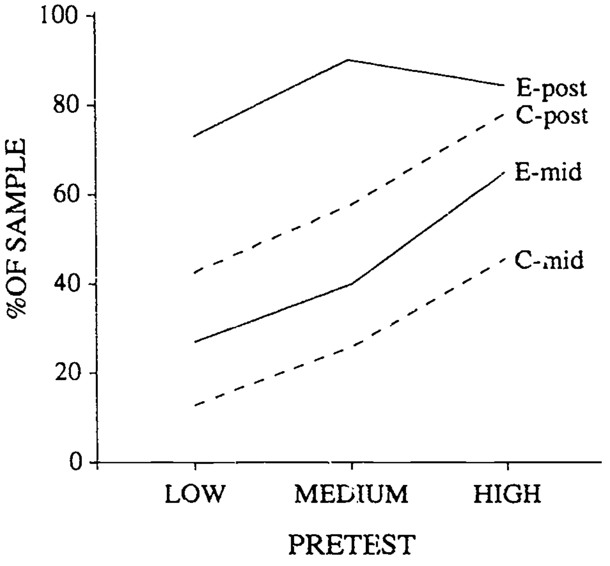

Figure 3. Students' Achievements in the Concept of Structure

questionnaires was given prior to the beginning of their study; the questionnaires tested students' understanding and knowledge of their prior studies. The second set was submitted in the middle of the year and the third served as a post-test.

Figure 3 summarizes the results of the evaluation concerning the aspect of structure. As can be seen, by the end of the year the high achievers succeeded in the tasks no matter which learning method was used. The new program, however, had a pronounced effect on the mid and low achievers, that is, those who seemed to have developed misconceptions unless specifically treated.

Concluding Remarks

The results of the four stage study concerning students' understanding of aspects of structure show that if those responsible for the teaching process, that is, curriculum developers and teachers, are conscious of problems faced by the students, quite a lot can be done to prevent students from developing misconceptions.

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Modes of Assessment in Science Education

Senta Raizen

Testing—Why?

Why worry about assessment in science education? One important reason is the general link among tests, the curriculum, and what students are motivated to learn. It is a truism that what gets tested gets taught. If there is a prescribed national or school curriculum, teachers will use it as a basis for their own tests; if there are national or regional tests, teachers will adjust the curriculum they teach so that students will do well on such external tests. And students will attend to whatever they believe they will have to know to get good grades.

A second reason is that we use assessments to assign grades and rankings to individual students (Assessment Purpose 1) and thereby to distribute educational goods and, at the higher levels, career opportunities (Assessment Purpose 2). Third, some educational authorities at the national or regional levels use assessments of student achievement to monitor the performance of the educational systems (and sometimes teachers) under their jurisdictions (Assessment Purpose 3). Yet another reason is the role of assessment in current efforts to reform science education. Past reform efforts tended to concentrate on curriculum development and teacher training; though such efforts continue, many countries now also are engaged in the setting of standards and development of related tests to achieve improved student learning in science (Assessment Purpose 4).

Testing—by Whom?

Generally, the purpose of an assessment determines who designs it and controls its administration, that is, whether the tests are controlled by the classroom teacher or whether they are mandated by external authorities. Tests controlled by the classroom teacher might be constructed either by the teacher or by specialists outside the classroom, but the scheduling, use, and scoring of the test are up to the teacher. Teacher-controlled tests most often are used for grading students (Purpose 1) and making decisions about their further study of science (Purpose 2), although the latter use often includes externally mandated test as well,. constructed by university or central education bodies. In principle, teachers also could and should use their own or other suitable tests to evaluate and improve the effectiveness of their own instruction (Purpose 4), but in actuality teachers make little use of testing for this purpose.

External authorities interested in monitoring the overall science achievement of students and the performance of schools under their jurisdiction (Purpose 3) generally control the tests used for this purpose and their scoring, even though classroom teachers may be involved in the administration. These sorts of tests either are administered to all students in the jurisdiction(s) involved or require large samples so that results will be generalizable to the whole student population or education systems in question. As a consequence, testing strategies must be limited to those that generate responses scorable with reliability and at a reasonable cost for thousands of students. In those countries where current efforts to reform science education emphasize the use of assessments to improve student achievement (Purpose 4), the tests also generally are mandated and often constructed by authorities external to the classroom.

Testing—What ?

But what is it that students should know and be able to do in science? Assessment for any of the four purposes must be grounded in a clear understanding of the goals of science education. The general populace may still believe that science education is of little consequence except for students destined to enter scientific careers. More and more, however, industry leaders, scientists, and educators are recognizing the importance of scientific literacy for all. Economic considerations—the competence needed to perform effectively in the modern workplace—are foremost in the perceived need for scientific literacy for all; also significant is the need to equip all young people to cope successfully with individual, family, and community responsibilities (Champagne et al., 1989). Indeed, it has been argued that providing a sound science education to meet the needs of all students would also establish a sound foundation for individuals who may wish to go into science- and technology-related occupations.

Whether a country accepts this argument and the difficult challenge of providing an adequate science background and understanding for all its students, or whether it tests students largely to determine who is eligible for advanced education in the sciences (Purpose 2), assessments need to probe the knowledge and skills deemed integral to a given level of proficiency in science. The challenge is to probe students achievement in science in several different dimensions.

Knowledge of the Various Aspects of Science

This includes an understanding of a network of key scientific facts and concepts in each of the several disciplines, as well as key themes that cross disciplinary boundaries—the notion of systems, models, scale, form and function, and cause and effect, for example. Also, students should gain an understanding of the historical development of science, that science is part of human culture and holds certain values integral to the quest for understanding the natural world.

Competence in Science Laboratory Skills and Related Procedures

This is necessary for students to gain an understanding of how evidence is collected in science, even if they do not practice science in later life (Hein, 1990). By the end of the primary grades, for example, students should know how to read a real thermometer (not a temperature scale reproduced on paper), connect a wire to a terminal, focus a microscope, observe and record the behavior of an animal, and measure the amount of rainfall and its acidity.

Even more important are the science-thinking and reasoning skills involved in answering questions that arise in the course of an investigation. More broadly, by the end of the elementary years, children should have acquired some facility in generating a hypothesis regarding some observed phenomena, designing an experiment that is a valid test of the hypothesis, and collecting, analyzing, and presenting data through the use of their laboratory skills. Again, these abilities are part of acquiring an understanding of how scientists ask questions of nature and obtain information relevant to deepening their knowledge.

Ability and Willingness to Integrate the Knowledge and Competencies Acquired in the Study of Science and to Apply Them to New Situations

This implies that students have internalized some of the values and habits of mind that characterize the doing of science—desire for knowledge, relying on data, willingness to modify explanations, accepting ambiguity, respecting reason, and being honest in their work (American Association for the Advancement of Science, 1989).

As pointed out in the National Center's assessment reports (Raizen et al., 1989; 1990), these dimensions of science proficiency are progressively more difficult to assess and responses to test questions more difficult to interpret. Consider the goal of applying science knowledge and reasoning to new problems. This involves being able to deal with several alternative approaches; solutions (and therefore right answers) generally are not evident in advance; judgments may have to account for multiple, and sometimes conflicting, pieces of evidence; interpretations may involve considerable uncertainty; and mid-course corrections will likely be necessary (Resnick, 1987). Thomas (1983) puts the essence of what it means to think and perform as a scientist more succinctly:

> *In real life, research is dependent on the human capacity for making predictions that go wrong, and on the even more human gift for bouncing back to try again. This is the way the work goes . . . Error is the mode.*
>
> (p. 82)

To what extent does any science test permit the exercise of this kind of thinking and behavior? Yet, if a science assessment does not reflect the nature of science and the goals of science education, it is not valid. Moreover, if students have been engaged in the authentic study of science, a test that does not reflect their study will be misleading about the knowledge and competencies of the students. In the worst case, a test mismatched to a reform curriculum will distort its goals and may narrow instruction to such an extent that what goes on in the classroom loses any semblance of fidelity to what science is all about.

In recent years, the notion of test validity has been expanded to include not only content validity but also educational and social validity. For example, Cronbach (1988) exhorts developers and users of tests ." . . to review whether a [testing] practice has appropriate consequences for individuals and institutions, and especially to guard against adverse consequences" (p. 3). Hence, as Messick (1989) argues, how test scores are interpreted and used in the formulation and implementation of educational policy ought to be part of considering the test's validity . . ." because the import of scores for action depends on the validity of their meaning and their value implications" (p. 11). Some assessment experts go even further and argue that tests should be explicitly designed to drive instruction in a positive way, so that teaching to the test would support rather than undermine educational objectives (Frederikson and Collins, 1989).

Testing —How ?

Current tests, particularly those used for large-scale assessments, tend to concentrate on knowledge of science facts and concepts and their rote application. The justification for testing procedures that emphasize memorization and single right answers is efficiency and reliability: being able to administer tests to large numbers of students and obtaining from each individual an unequivocal set of responses that yields an "objective," numerical score. Probing for understanding, testing for competence in hands-on performance, or assessing inductive reasoning and divergent thinking is uncommon in large-scale tests. Obviously, knowledge of factual information is important; even more important, however, is the organization of information and the ability to apply it. If their science instruction involved genuine investigations, students should also have become more skilled at the type of problem-solving described by Resnick. Unfortunately, most of these science and generic thinking skills cannot be assessed with much validity through multiple-choice or other short-answer paper-and-pencil tests of the kind used in large assessments.

Large-scale tests also suffer from inference problems. What do scores on such tests mean? All sorts of assumptions go into interpreting student scores when these are reported as reflecting science knowledge and understanding, let alone the ability and willingness of students to apply their knowledge outside of the testing situation. The first assumption is that a student's response to an item or question represents the same thought process or performance as that envisioned by the item writer. This may be a valid assumption for the memorization of factual knowledge or simple application of a rote algorithm, although in the case of a multiple-choice item, some students might have made lucky guesses. In the case of reasoning items with science content, however, remembered science knowledge or experience may be confounded with reasoning competence. If students get the right answer, did they know it from experience or reason it out? If they get the wrong answer, which was at fault, the science reasoning or lack of science knowledge? Another inference problem is presented by items or questions that attempt to test laboratory skills with paper-and-pencil questions and responses. Students' ability to pick out the highs and lows on a temperature chart yield little evidence of how well they can design and perform procedures for measuring, recording, and reporting daily and weekly temperature variations, let alone interpreting them. In brief, complex knowledge or performance is difficult to assess from student responses in short-answer form. Such responses are easy to score reliably, but inferences about students' thought processes or procedural abilities cannot be made.

A second assumption is that a set of test items probing a limited domain within the goals of science education actually mirrors the totality of these goals. Although factual knowledge is obviously necessary to science reasoning and problem-solving, there is little evidence to show that testing for factual knowledge yields information appropriate to making judgments about students with respect to their science thinking and reasoning abilities. A student's competence in responding to items probing for recall of factual information or logically correct deductions does not necessarily represent an understanding of a scientific principle or the ability to formulate a hypothesis and design a valid test for it.

Also, tests given at a specified time in the school year are snapshots; additional information is needed about students to appraise their growth in science learning or potential for further growth. If judgments on eligibility and placement are made on the basis of a single test (Assessment Purpose 2), and particularly if these judgments are made in the early school years, they may eliminate from further science study or relegate to lower tracks those students whose potential is not reflected in the test (Oakes, 1990). Regardless whether their goal is the scientific literacy of all citizens or the development of human resources for technical and scientific careers, countries need to examine how testing affects who is excluded from participating in the study of science or assigned to low-level courses.

When schools and school systems are evaluated on the basis of achievement test scores (Assessment Purpose 3), the content of the test ought to match the curricular objectives of the school or system. This often is not true in decentralized educational systems. For example, there surely will be a mismatch between a school that uses a project-oriented approach to the teaching of science, say, studying the effects of a dam on a nearby river and its surrounding ecosystem, and an externally mandated test designed to assess the amount of factual knowledge acquired by students in geology. There are likely to be factual questions on the test that the students will not be able to answer; yet, they will have little opportunity to demonstrate the science laboratory and thinking skills they have learned. Ought the test to be used to judge, and perhaps condemn, the school's science curriculum? Will those decrying the students' performance on the test understand that the school's objectives were radically different from the objectives embodied in the test, and that, in fact, the students may know more science than students elsewhere who may have performed better on the test?

Although large-scale assessments must be improved, they are not the most important vehicle for the reform of science education, even in the testing arena. Much more important is what the teacher does in the classroom. This is particularly true in elementary and middle school, where students form their attitudes toward any further involvement with science. The tests given by teachers for their own purposes play a much greater instructional role, certainly in science, than do standardized, large-scale tests. Sadly, at least in the U.S., teachers tend to imitate the practices of large-scale assessments (Dorr-Bremme & Herman, 1986), even though they have other assessment strategies open to hem. Tests and quizzes given by many teachers to assign grades to individual students (Assessment Purpose 1) focus largely on recall of vocabulary words and isolated facts, restatement of concepts out of context, and rote solving of the repetitive problem sets found at the end of units in the textbooks. The possibility that there might be more than one "right" answer hardly arises. Unless teachers take the results from such tests to be but one piece of evidence about what students know and can do in science, they not only shortchange their students, they also send very pointed messages about what really matters in science. No wonder many students turn away from the study of science as soon as they can, seeing science as an arcane collection of preordained facts, increasingly difficult and boring to learn, making little sense, and unconnected to their lives.

Some Reform Suggestions

What needs to be done? New curricula are being developed in many countries that will give children the opportunity to study important science topics in depth, involve them in hands-on and laboratory experiences, and allow them to develop thinking skills. Good curriculum by itself, however, is not sufficient. Also required are teachers who are secure in their science knowledge as well as in their ability to teach science, and who are given a context that makes good science teaching possible. And good curricula and good science teaching require teachers who understand and know how to use the many forms of assessment available to them. Where externally controlled tests are part of the educational process, these tests must be made consonant with the goals of science education, with the reform curricula, with the teachers' instruction, and with the assessment methods used in the classroom as part of the teachers' instruction.

Several different modes of assessment have a legitimate place in documenting what students know and can do in science; these different forms need to be used in concert, and each of them warrants considerable investment to develop more valid forms. The different modes and what needs to be done to improve them are discussed below in order of complexity and effort involved to bring about improvement.

Tests using multiple-choice and other short-answer formats are appropriate for probing science knowledge, some reasoning abilities and, within limits, conceptual understanding of scientific principles and of the nature of scientific investigation, for example, the need to control variables in a series of experiments. Such questions could be much improved by asking students to explain their answers or in other ways elaborate their short-answer responses. This sort of augmentation would provide at least some insight on students' thinking processes.

Essay questions, in addition to probing science knowledge and reasoning skills, allow students to display their ability to analyze a situation, to develop alternative approaches and present rationales for each, and to communicate effectively. There is some evidence, however, that a student's interest in the question posed in the test affects performance. Thus, optimally, essay questions would deal with problems that are known to have engaged students on a sustained basis. This is relatively easy to accomplish for the classroom teacher constructing a test and is more difficult in the case of large-scale assessments. Other factors likely to influence essay quality are the time allowed for the response and the student's facility with language and the type of writing called for in the essay (Applebee et al., 1989). A difficulty, especially in the case of large-scale assessments, is to develop scoring protocols that adequately reflect student performance along the several dimensions of interest.

Writing about doing science is not the same as doing science. Students must be given opportunity to demonstrate how well they can do lab work or perform scientific investigations appropriate to their level of development and schooling (Driver, 1990). For large-scale tests, this will require extensive—and expensive—development of meaningful performance tasks for individuals and for groups. The parallel development of scoring protocols is essential, including teachers' observations of performance, students' self-ratings, and students' evaluation of group performance where applicable. Work records kept by students also could be assessed by teachers and outsiders.

Some countries may be in a position to experiment with using computers and related information technology in large-scale assessments. For example, computers could be used to tailor assessments to the curriculum of a school, to pursue questions in depth, to present situations and tasks impossible to present in real time or concrete form in the classroom, and to provide assistance so that students can proceed despite specific knowledge gaps (Office of Technology Assessment, 1988). Computers can also record the intermediate steps taken by a student in arriving at the final response. Not only can such information be factored into a student's test score, more importantly, it can provide invaluable information for guiding instruction (Assessment Purpose 4).

Teachers must be educated to understand the range of assessment methods they have available and to use these in combination in a systematic and credible manner. Short-answer tests are an appropriate form of assessment, but teachers need to probe how a student arrives at an answer as well the answer itself. In addition, teachers should collect and evaluate tangible records of students' performance: homework, oral and written reports, laboratory notebooks, and descriptions of investigations. Teachers also should systematically observe students at work in science class, keeping their own records of each child's development in laboratory skills, collecting and interpreting information, and making appropriate deductions and inferences. Furthermore, teachers should appraise group performance and the contributions to group work made by individual children. As the year proceeds, information from each of these types of appraisal can be used to shape instruction and make it more effective. At the end of the year, a teacher should be able to construct a comprehensive profile of each student's science competence based on all three sources: test performance, records of the student's work, and teacher observation. Only when teachers become skilled in this type of assessment will good curricula be used effectively in the classroom. Pre-service and in-service science education for teachers must integrate knowledge of appropriate assessment strategies with knowledge of appropriate teaching strategies.

Secrecy has no place in an assessment system. First, secrecy robs testing of its role in conveying what is to be taught and learned. Second, test items and tests should be open to inspection by teachers, science educators, and scientists who can weed out poor items and appraise how well the tests match curricular goals. Third, teaching to tests and assessment exercises that mirror science knowledge and the nature of science with fidelity has the potential of bringing about major improvements in science instruction in the classroom. And finally, only through an open assessment systems can goals, classroom practice, and assessment in science education be brought into alignment.

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Assessment as Curriculum in Science Education

David Schuster

Introduction

Through the tasks and tests we set students, we reveal the real curricula of our science courses with respect to both content and process, regardless of any stated syllabi and course objectives. What we test and how we test sends a message to students and influence what and how students learn. What we do *not* test similarly influences what is *not* learned. To quote Alan Bell, "WYTIWYG—What You Test Is What You Get." Thus, in assessment we have a powerful lever with which to influence teaching and learning—for good or for ill. Eric Rogers (1969) stated this many years ago, but the mainstream has not followed through on this idea.

There generally tends to be considerable discussion about the aspects of education that we can call Curriculum, Teaching, and Learning, but Assessment often gets relegated to the status of the neglected "tail" of the system. Yet it is the tail that can wag the dog. The relative "afterthought" status may be accorded to assessment because it is often viewed purely as a *summative* instrument, used at the end of a course for ranking of students. Ideally, however, assessment should form an integral *formative* component of the educational environment, where it can provide a vehicle for shaping learning and teaching and, indeed, for interpreting the curriculum.

Cognitive Processes and Science Curricula

The cognitive processes and underlying knowledge involved in science are far more complex than may be apparent on the surface. The task facing a learner is correspondingly more demanding than is commonly realized. For example, some of the multiple facets of cognition might involve conceptual understanding, qualitative reasoning, visualization, multiple representations (diagrams, graphs, equations, words), problem-solving skills, problem re-description, formalism, algebraic manipulation, quantitative calculations, interpretation of results, and so forth, as well as metacognition and epistemic knowledge about science and its methods. Conventional texts and problems offer only a limited cognitive fare, mostly of facts and formulae, leaving students to somehow "pick up" the other important insights and modes of thinking, or fall by the wayside.

Conventional science syllabi are basically content listings—lists of topics to be covered. Sometimes educators attempt to extend this to the process area by devising specific "behavioral objectives," but although the intentions may be good, all but the best of such listings resemble rephrased content with verbs attached. It is nevertheless important to analyze and specify in some explicit way the process part of a curriculum. Process abilities prove difficult to define and specify separately in a meaningful way at the appropriate levels of both generality and detail. If process abilities are broad enough to apply across topics, these abilities may be so general as to be of little practical use in specific situations or have a need for interpretation. If process abilities are detailed and specific, they become unwieldy and repetitive, and, in any case, the way they are to be understood is with implicit reference to particular subject-matter items, rather than in the abstract.

A more effective alternative is to explicitly embed the important cognitive processes in the learning materials themselves—in the content, the problems, and crucially, in the assessment. In that way, the process aspect manifests itself throughout, flexibly, and in context—and, moreover, it is assessed! We thus suggest that both the content and process aspects of the curriculum can effectively be addressed via problem-oriented, learner-centered materials and can serve both as formative and summative assessment. For this approach to succeed, considerable thought and effort needs to go into assessment—at least as much as is usually devoted to writing texts and teaching the subject matter. Assessment seen in this light is far more than just a matter of selecting problems for the final examination.

Current Science Assessment

Many examination questions in conventional assessment in physics tend to resemble the end-of-chapter exercises in textbooks, focusing mainly on facts and formula-based numerical problems, while neglecting other aspects, such as qualitative conceptual understanding. It is thus not surprising that many students view physics as finding the right formula and plugging in numbers. They know that this often gets them through the examinations. The best efforts of teachers who try to go beyond this in their teaching may be thwarted unless the nature of the assessment also changes.

One reason for the rather limited and unbalanced nature of much conventional assessment may be a natural tendency to test that which is easiest to test rather than that which is important. It is easy to set a formula-based kinematics problem by selecting from the many end-of-chapter exercises available, but it is harder to devise questions testing a full range of conceptual understanding, and fewer such questions are available. It is interesting that materials for the lower levels often seem better designed in this regard than materials for upper-secondary and tertiary studies.

Nevertheless, over the years some good learner-centered materials and test problems have been produced, where the tasks and tests match a range of objectives. Arnold Arons, for example, has long advocated the use of qualitative questions; worksheet-type curriculum materials in university physics are being produced by the groups of L. C. McDermott, A. van Heuvelen, and W. Gerace, among many others. However, these approaches and materials are not yet in the mainstream.

Assessment as a Vehicle for Teaching and Learning

We put forward the proposition that it is possible to create multi-faceted problems structured to address a wide range of cognitive issues in a domain, even those that are normally considered elusive or hard to test, and that furthermore, such problems can be a primary vehicle for teaching and learning. To devise such problems one undertakes a task analysis of a prototypical example, identifying the underlying knowledge, procedures, and thought processes involved in a comprehensive understanding of the entire situation. The cognitive issues can be researched in a number of ways, for example, by probing of the thinking of experts and learners, together with introspective analysis and discussion. The task analysis is followed by "problem-creation," where the original example is expanded into a comprehensive "problem-situation." A sequence of carefully structured questions is produced, each of which explicitly addresses a particular aspect, such as qualitative reasoning, graphical representation, formalism, dependencies, calculation, special cases, interpretation, and so forth. A student working through this sequence will thus encounter a structured learning activity that embodies many facets of understanding and that helps guide the learner along effective-thinking routes.

Structured problems of this kind can serve the purposes of both formative learning and summative assessment—and serve them both more comprehensively than usual. A basic tenet of the approach advocated is that "the critical content of any learning experience is the method or process through which the learning occurs" (Postman & Weingartner, 1969). Through the things that we have students do, via such tasks and tests, we create curriculum.

Contrasting Examples

Two contrasting versions of a prototypical physics problem may help to illustrate these issues. First, a conventional examination problem in dynamics is presented, together with a typical solution. The same basic problem will then be formulated differently, that is, expanded into a structured teaching question. The implicit curricula defined by the two versions of the problem can then be contrasted by the reader.

Example 1

Version A. Conventional problem

A person of mass 60 kg stands on a bathroom scale, calibrated in kilograms, in an elevator. Find the scale reading when the elevator is accelerating upwards at 2 $m.s^{-2}$.

Solution and marking memorandum.

Let the force by the scale be S and the person's weight be W.
Using $F = ma$, we have $S - W = ma$, so $S = W + ma = mg + ma = m(g+a) = 60(10+2) = 60 \times 12 = 720$ N.
The scale reading is thus $720/10 = 72$ kg.

Comment: The above is a fairly common brief form of problem presentation in physics textbooks and examinations. The trouble is that it apparently focuses on only a limited aspect of understanding, namely formula-based calculation of a numerical answer. Students who have been drilled in this type of exercise may be able, if they are lucky, to get the right answer without any real conceptual understanding of what is happening in the situation. Furthermore, the bare–bones solution given above only compounds the problem because any underlying conceptual understanding required to actually generate the solution procedure is omitted, leaving only the formulae and results. The outcome of this, seen in national examination scripts, is that students try to commit to memory the particular result,that is, the "final formula" $S = mg + ma$, instead of applying general underlying principles. In fact, the adverse effects extend further than the students, contaminating even teachers and examiners: for a recent national physics paper the examiner's marking memorandum actually started by writing down the specific result "$S = mg+ma = m(g+a)$" without giving any indication of how it was obtained. Students began saying things like: "now do we add 'a' to 'g' when the elevator is going up, or subtract it, or is it the other way round?" Thus, through exposure to only this style of problem and solution, both students and teachers acquire a limited and skewed notion of what it means to do and understand science. Assessment of this nature provides an unfortunate monochromatic interpretation of the dynamics curriculum. The same example can however form the basis of a much more comprehensive and beneficial question, if it is expanded and recast as on the following page, in example 2.

Discussion: Because this is a specific physics example, one would need to have taught physics to fully appreciate all the issues involved. For the general reader we do discuss the problem in detail here or go into the details of the solution, but instead provide some general observations about the features of the example.

First, the presentation is made more interesting by relating it to a real situation with a reasonable purpose, instead of leaving it as an abstract exercise with the implicit purpose of "getting the answer." A diagram is included, though not strictly essential. In the structured formulation the student is "guided through" a desirable sequence of reasoning for problems of this type. Various important facets of understanding are addressed through explicit sub-questions. A qualitative conceptual understanding of the situation is em-

Example 2

Version B. Expanded formulation as a structured problem

Problem-situation

Physics student Anna, wishing to investigate for herself some physics ideas of force and motion, stands on a bathroom scale in an elevator. Anna has a mass of 60 kg and the scale is calibrated in newtons. She observes the scale reading for three different types of motion of the elevator:

1. while it is stationary
2. while it is moving steadily upward at a speed of 3 $m.s^{-1}$
3. while it is accelerating upwards at 2 $m.s^{-1}$

a) For EACH of these three situations, answer the following:

i. Characterize the motion of the person.

ii. Draw a 'free-body' force diagram showing all the forces acting ON the person. Name the objects that exert these forces.

iii. Say how these forces compare to each other, and explain why. Is there a net (resultant) force on the person or not?

iv. Determine the reading on the scale in newtons.

b) Fred, another student, feels that the reading on the scale should always be the same, independent of the type of motion of the elevator, and argues as follows: "A scale, by the way it works, always measures the *weight* of the person standing on it. The weight of the person, being the force of gravity on her, is the same irrespective of her motion. Therefore the scale should always read the same, no matter how the system moves." How would you respond to Fred? Is his line of argument correct ? If not, which parts are incorrect and why?

c) Fred is thoughtful about another issue, saying: " This scale is marked in newtons but I know that bathroom scales are normally marked in kilograms. Can a scale's kilogram reading vary depending on motion? And if it does, wouldn't it signify that the person's mass in kilograms is changing? How can this be? There seem to be ambiguities here." How would you reply?

phasized first, in physical terms rather than mathematical. The situation of accelerated motion is deliberately contrasted with that of steady motion and no motion to raise the essential differences. Representation of a seemingly complex situation in terms of simple force diagrams is explicitly promoted as an aid to conceptualizing and solving such problems. The problem is seen as "reduced" to its essence in terms of physical principles—a resultant force accelerating a single mass—and the lift is seen as extraneous, only serving to inform us that the mass is accelerating. The actual numerical calculation of the scale reading, dominant in the conventional formulation of the problem, is now relegated to a place after the conceptual basis is established. Finally, peoples' intuitive conceptions about the situation, involving the scale and what it measures, which may be at variance with the scientific view, are addressed explicitly, rather than being ignored.

The purpose of this comprehensive style of question should be evident to both students and teachers, that is, to promote complete understanding of the entire situation in both qualitative physical terms and quantitative mathematical terms, in contrast to just "finding the scale reading." Furthermore, the structured question sequence serves to "model" for the students the desirable modes of thinking and proceeding in problem-solving in a particular domain, in this case dynamics. Note that it is important to have a scheme that *requires* learners to go through all the stages and to think in all the important ways. Otherwise, learners tend to resort to those methods that the learners find easiest and to neglect harder aspects with which the learners are less familiar or don't understand.

However, once the modeled approach is assimilated by students through practice with several structured examples, some unstructured problems should follow. Students are encouraged to continue using the same approach for other problems in the domain, even when the problems are not presented in structured form. Thus, for example, we hope that students will continue drawing force diagrams to solve dynamics problems, even when such diagrams are not explicitly requested, because the diagrams have become a valued part of the student's repertoire. Similarly, we hope that students will start to ask qualitative questions themselves to satisfy their own need for proper conceptual understanding.

The structured example above is clearly much more "complete" than the original exercise from which it was developed. Nevertheless for any situation other aspects will always remain that can be included. The structured problem above could be further extended, for example, by asking students to contrast the following cases: where the lift is starting to move upwards, starting to move downwards, slowing to a stop at the top, or slowing to a stop at the bottom. Alternatively, these variations may be reserved for a summative examination after using the version above for formative teaching.

Note that although this structured example may seem fairly straightforward, the choice of exactly what to ask and how to ask it requires considerable insight into both the essence of the physics and the task facing the learner. The creation of such structured questions is not a one-way or once-off process: questions are modified and improved in the light of what actually happens when the students engage with the questions. The availability of structured problems of this nature should benefit science education. Beyond producing compilations of such problems however, a further aim would be to encourage teachers to create their own structured questions on an ongoing basis during teaching and learning.

From these two contrasting examples it should be clear how different problems can serve to *interpret* the same content syllabus differently. Further, one could argue that the more comprehensive version of the problem is actually *creating* curriculum.

Situating the Curriculum and Assessment

To the extent that we define curriculum by the tasks and tests we set, as much as by the syllabus topics, we can "angle" or "situate" the course for specific purposes or target groups. We can tailor examples and problems to reflect the context at hand and the background and needs of the learners. For example, where a physics course is a requirement for another discipline such as medicine, one can teach the basic principles through examples relevant to the life sciences. For a developing country, one could create problems around examples relevant to learners' experiences and interests or modify existing problems to fit the situation. Thus, for a country where elevators are uncommon one may readily change the "elevator and scale" example above to a situation within the everyday experience of students, for example, a load of bricks being raised or lowered at the end of a rope, with questions about the rope tension for various types of motion. The problem-type and underlying principles are essentially the same, so that similar question structuring can be used. The assumption here is that the example is being used primarily to teach basic dynamics principles, and where this can be combined with a relevant application so much the better. On the other hand, one may decide that this particular class of problem per se is not appropriate to particular needs and concentrate on other areas.

Note also that for developing countries an approach that balances abstract formalism with conceptual and experiential aspects should be particularly appropriate, though in fact the approach is desirable for all learners.

Conclusion

The idea of defining curriculum via problem-oriented tasks fits a constructivist view of learning: if students construct their own understanding through active processing, rather than simply "receiving" it from books or teachers, students can best do so through engagement with appropriate problems, carefully crafted with the learner in mind. The type and range of problems set will determine the student working and thinking activities, and hence define the action curriculum of a course. It is of course crucial that the character of the final examinations, as summative assessment, should match that of the formative assignments and tests.

The influence of problem-based learning resources extends beyond the cognitive level—on the metacognitive level such materials can promote students' awareness and management of their own thought processes; on the epistemic level these materials can help shape student perceptions of what science is all about and of the richness of real knowledge in science. Similarly, on the *affective* level, the approach can influence attitudes and motivation; students seem to enjoy the subject more, find the topics interesting, and ask conceptual questions rather than simply learning formulas.

The consistent use of problems of this type in a first-year physics course at the University of Natal in both teaching and assessment has had a significant effect on students' learning behavior, range of abilities, notions of understanding, and perceptions of the nature of science. The syllabus topics and textbook have remained the same, but the de-facto curriculum is interpreted through the types of problems assigned, and assessed accordingly.

> *It is not what you SAY to people that counts, it is what you have them DO.*
>
> (Postman & Weingartner 1969)

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Can We Control the Pattern of Students' Achievement by Designing Learning Material?

Itzhak Milgrorn and Eli Dori

Preparing the textbook *Into the Core of Matter* took 4 years; 5 supervisors, 27 teachers, 6 instructors, and 2 scientific advisors participated, with the professional Curriculum Team. The main objective was to provide teachers and students with a textbook for heterogeneous, mixed-ability classes. We intended the book as a tool that would allow weak learners adequate opportunities to learn and succeed and that would also provide an adequate challenge for good learners.

The professional team adopted a new didactical strategy, a concentric structure. Each of the five subjects in the book was designed to include "Core Content," intended for the entire student population. In each subject, the core was expanded into graded "optional tasks." It was hoped that the new structure would enable more teachers and learners to better realize their potential for success.

Designing the Trial Edition

The process included interconnected phases and simultaneous decisions. As much as they can be defined, the stages, schematically, were as follows.

1. Analyzing the specific content: mapping of concepts, differentiating "main concepts" and their conditions from secondary and peripheral concepts
2. Defining "Core Content" intended for all students and "Optional Tasks," enabling a variety of teacher-student choices, taking into account the number of lessons allotted by the curriculum

    a. The "Core Content" constitutes an independent, scientifically meaningful body of knowledge. The "Optional Tasks" either relate the concept to other relevant concepts, thus widening its incidence, or supply graded, deeper applications, thus deepening the concept's incidence.

3. Determining the depth of processing: deciding the intra-conceptual proportions, fitting the appropriate didactical technique for the learner to organize, elaborate, transform, or apply the rule of concept; choosing means of representation, for example, reading passages, leading questions, graphical representation, and so on.

Evaluation Process

The trial edition was tried during a period of 1 year in 57 classes, a planned sample across the country. Feedback from teachers' and learners' reactions to the trial edition was accumulated mainly by observation of teachers and learners variability of usage, recording misconceptions, misinterpretations, and difficulties.

In the former traditional structure, the learner's chances of success decreased as the lessons became more and more complex and difficult. The concentric structure, its "Core," determined by trial in classes, has the potential to change the pattern of teacher-learner anticipation. It presents the teacher and the learner with new hope and success with every new subject. Difficulties in the "Optional" recede at every new "Core." While ensuring success of the "Core Content" of every subject, it provides, in the "Options," varieties of choices adequate to teachers' developing experience and the learners' ability levels.

Comparing Patterns of Achievement

The "old" seventh grade textbook, *Structure of Matter*, and the new one, *Into the Core of Matter*, deal with the same body of knowledge—macro and micro aspects of the structure of matter. This provided the opportunity to try and evaluate the contribution of the new didactical strategy and its influence on the pattern of learners' achievement.

The comparison is between data from two different diagnostic tests and two different random samples of students and teachers. One is the "national science survey" conducted in 1980 when students used the book *Structure of Matter*. The second is a "Central District Test" conducted in 1990, when students used the new *Into the Core of Matter* as a textbook. Bearing in mind these reservations, the findings follow.

Achievements in Main Concepts

Tables 1 and 2 show the achievement in Main Concepts.

In the absence of this data in 1980, we can compare the 1990 achievements to the 1980 average in Table 1. The strong pupils increased by 29% over the 1980 average, medium level pupils by 23%, and weak pupils by 5%.

Table 1. Achievement of Pupils in Main Concepts 1990/1980 (%)

The Test	No. of Items	Sample (n)	General Average	S.D.
1990	14	964	81	20
1980	11	3420	60	25
Difference			+21	-5

Legend: In 1990, the achievements in Main Concepts is 21% higher than in 1980.
The smaller standard deviation denotes the decrease in the dispersion of the scores around the average.

Table 2. Achievement of Pupils According to the Levels* in "Main Concepts" 1990 (%)

Average Strong n = 310	S.D.	Average Medium n=439	S.D.	Average Weak n=215	S.D.
89	14	83	17	65	23

Legend: *Classification into ability levels was determined by a standard general test.

The standard deviations in the different groups should be noted. Relatively, the strong pupils are more homogenous than the other groups. The large standard deviation among the weak pupils shows the great heterogeneity of this group where there are pupils averaging 88% of the main concepts.

Achievement in Core Content

Tables 3 and 4 relate to achievement in Core Content including the Main Concepts.

In 1990, the achievement in Core Content had risen by 11% as compared with 1980. The lower standard deviation shows a tendency for the dispersion around the average to decrease. The gap between pupils' achievement is reduced.

The achievement of the strong pupils in the Core Content rose in 1990 by 3%, of the medium level pupils by 11%, and of the weak pupils by 10%. The gap between the group of medium level pupils and the group of strong pupils is reduced. The gap that was 15% in 1980 was reduced to only 7% in 1991. The group of medium level pupils constitutes 45% of the pupils tested in 1990 (439 pupils out of 964). The standard deviation among the weak pupils shows that there are pupils in this group whose achievement in the core content can reach up to 77%.

Table 3. Achievement of Pupils in Core Content 1990/1980 (%)

The Test	No. of Items	Sample (n)	General Average	S.D.
1990	23	964	72	19
1980	24	3420	61	22
Difference			+11	-3

Table 4. Achievement of Pupils According to their Levels* in the Core Content 1990/1980 (%)

The Test	No of Items	Av. Strong	S.D.	Av. Medium	S.D.	Av. Weak	S.D.
1990	23	80	15	73	17	57	20
1980	24	77	16	62	19	47	19
Difference		+3	-1	+11	-2	+10	+1

*Classification into ability levels was determined by a standard general test.

Table 5. Achievement of the Pupils According to Their Levels in all the Material in the Book Including the Optional Tasks

The Test	No. of Items	Gen. Av. n=964	S.D.	Av. Strong n=310	S.D	Av. Med. n=439	S.D.	Av. Weak n=215	S.D.
1990	38	70	18	78	14	72	16	55	29

Table 6. Comparative Achievement 1980/1990 in Anchor Items (%)

Anchor Items	Average General	Average Strong	Average Weak
1990 Test (new)	77	95	53
1980 Test (old)	63	96	42
Difference	+14*	-1	+11

*t-test significance .01

The gap is reduced between the group of medium level pupils and the group of strong pupils, 72 and 78, respectively. It seems that the change in the achievement patterns of medium level and weak pupils is not to the detriment of the strong pupils. The average achievement of the strong, 78, shows that the material is not just "easier to learn"; it provides adequate challenge for strong pupils. The average of weak pupils, 55, together with the large standard deviation of this group, shows that even when Optional Tasks are included in the test, the achievement of some of the group is good, reaching up to 74%. This data, and the score dispersion on which it is based, indicate a change in the achievement and success patterns of the pupils. In this light, the labels of "weak," "medium," and "strong" are questionable. While giving a good statistical picture, the data also conceal the potential of tens of thousands of pupils in each of the groups. This potential is partially realized when the book, the tool in the hands of the teacher and the pupil, is better adapted.

Finally, with the existing data, we sought a way to examine the validity of these comparisons. We found nine groups of items that can serve as anchor items, because each pair examined the same concept in 1980 and 1990. The comparison is presented in Table 6.

The anchor items do not represent all the material studied. These are nine concepts that appeared in both books, were studied, and the achievement measured in 1980 and 1990. In this comparison, too, when the same concept was tested once in 1980 and again in 1990, there is a general improvement of 14%. The main improvement seems to be among weak and medium-level pupils.

The difference between 1990 and 1980 achievement is significant at the .01 level, and this reinforces the hypothesis that the improvement is not a chance one, but derives, apparently, from the didactic adaptation effected following trial of the material in classrooms, feedback, and formative evaluation.

The comparison of contents and the scientific comparison of different curricula and of different textbooks would require content analysis. Here we attempted to investigate the contribution of the didactic adaptation to pupil achievement. In light of the findings presented above, the investment in didactic adaptation and evaluation seems worthwhile. A cardinal change in study materials, which are the instruments of the teacher, may change the achievement of patterns of pupils at all ability levels.

Implementing a Science Curriculum for the Middle Grades: Progress, Problems, and Prospects

Susan Loucks-Horsley and Harold Pratt

Introduction

There is no doubt that the middle grades pose an enormous challenge to educators: witness the many reports that have decried the "wasteland" that characterizes the traditional junior high and the continued inability to create environments where middle level students can thrive, no less learn. For those concerned about content learning, the challenge is even greater, for the vast majority of the effort being expended on changing middle level education has focused on issues of school structure, student psychological and physical well-being, and thematic teaching. Relatively little effort is focused on questions of what and how students should be taught in particular disciplines. Even less effort is placed on how curricula developed in line with what is known about the needs of early adolescents can best be implemented.

This article reports on a new science curriculum that attends to these questions. With support from the National Science Foundation, the Jefferson County (Colorado) Public Schools designed, developed, implemented, and tested a life-science curriculum that is inquiry- and activity-based, focuses on the human body (a topic of high interest to young adolescents), and incorporates a "depth rather than breath" approach emphasizing the learning of concepts over facts and vocabulary. With the assistance of NETWORK, Inc., an organization experienced in facilitating and evaluating change efforts, the Jeffco schools designed an implementation plan that incorporated research on change, adult learning, staff development, and teacher-support systems, and assessed the results of implementation. The purpose of this paper is to describe the curriculum development and implementation effort, report results of the implementation assessment, and discuss issues related to implementing new curricula in the middle grades.

Science Curriculum for Middle Grades

Although Jeffco is a large (75,000 students) suburban district west of Denver, the situation is one typical in many districts across the United States. The District was aware that no nationally developed, modern, hands-on science curriculum materials for middle-level life science existed. That the National Science Foundation had never funded a similar program for middle school/junior high school Life Science was apparent to the District curriculum developers and teachers when they looked for resources to support their locally developed curriculum syllabus.

Jeffco was in a situation in which most districts in the country find themselves—depending on textbooks available from the publishing companies as the major source of teaching materials. Unfortunately, these materials do not meet the instructional and curriculum recommendations of a number of major groups, including Project Synthesis (Harms & Yager, 1981), NSTA (1982), and the National Center for Improving Science Education (1991); the materials also do not fit needs of the middle level student as described earlier.

A study of the tables of contents found that any one textbook varied very little from the others. A closer examination of the discussion of any one particular topic revealed that virtually the same vocabulary words, types of illustration, and amount of text were used in all the textbooks. Furthermore, the general pattern of learning expected of the students was to memorize a large number of glossary-type definitions. Often laboratory activities were included in the text at the end of each section, but they were not an expected part of the learning process and the cognitive flow of the textbook could proceed very nicely without them.

A study by BSCS (Hurd, 1981) found that "the content in the three most widely used life science books can best be described as encyclopedic." The most widely used life science text in this country included 100 new and/or unfamiliar technical terms in each chapter. Because the book contained 25 chapters, students were exposed to a minimum of 2,500 new and/or unfamiliar technical terms in the course, as compared to a typical middle-level foreign language course with a goal of mastering about 1,250 words. The significance of this science vocabulary load becomes even more dramatic when one considers the accompanying conceptual load found in a science course. The new words in science are not simply a new representation of already familiar concepts as they are in a foreign language course, but instead represent new, often abstract, ideas.

This discrepancy was apparent to a group of teachers, administrators, and scientists who audited the Jeffco District science program in 1984. They noted the need for an updated set of life science materials and included a recommendation that District science teachers develop a new life science program.

Developing the Curriculum

Fortunately, Jeffco has had a long and rich experience in curriculum development, both within the District and in conjunction with a number of national curriculum development projects. Several of the recent curriculum development efforts had been under the direction of Judy Capra, a genetics associate at the Health Sciences Center of the University of Colorado Medical School. She had directed District teachers in previous years in the development of human genetics unit for 7th grade Life Science and high school biology.

Under the direction of Judy Capra and Harold Pratt, the district science coordinator, a number of life-science teachers met for an extended period in the summer of 1986 to begin creating the philosophy, framework, and content selection for the new Life Science program. In the subsequent months during the 1986-87 school year, the writing team met with virtually all life-science teachers to begin selecting the content and approach that would be most successful with middle-level, seventh grade students.

The process was not without conflict and controversy about what material to include and what to exclude so as to find a limited set of topics that could be treated in depth and with an extensive laboratory base. However, attention was always focused on the needs, abilities, and interests of the 12- to 13-year-old students. This meant that many of the standard topics such as taxonomy, evolution, much of the dissection and plant structure that were often included because "they had always been there" or were an important part of the standard biology discipline, were eliminated in favor of selecting topics more important to seventh graders.

The choice of content and development of the curriculum were guided by an underlying assumption that middle-level students are interested in learning more about their bodies and that they learn best through laboratory activities with an opportunity for application to their own lives. The Carnegie Council on Adolescent Development (1989) recommended that middle schools "improve the academic performance through fostering the health and fitness of young adolescents." A number of researchers, including Yager (1982) and Hurd (1989), have demonstrated that the attitudes of early adolescents toward science improve if students are provided with a relevant science curriculum that contains more personal and social issues that give meaning to their studies.

As the content selection, goal setting, and early writing of the curriculum materials progressed, it became clear that a number of features would distinguish this set of materials from the standard textbook materials currently being used in the District.

1. Fewer topics are covered in more depth; 75%

of the content focuses on the human body, emphasizing health and wellness behaviors and 25% on how we as humans fit in our ecosystem.

2. Laboratory activities are an integral part of the text; students do science and apply it to their daily lives instead of just reading about it.
3. Concepts are emphasized; less time is taken to memorize facts and vocabulary.
4. Activities are varied to accommodate different learning styles and to provide opportunities for higher levels of thinking.
5. Cooperative learning is encouraged; appropriate strategies are built into many activities.
6. The learning cycle is used to organize the activities and readings in the program. Students are first provided with exploration activities, then concepts are developed, and finally application opportunities are included.
7. Inquiry learning is enhanced by the use of discussions, analysis questions, and assessing student progress in ways that are consistent with the teaching strategies used.
8. A decision-making progress is taught directly and applied to such topics as reproduction, drug use, and environmental issues.
9. Activities can be integrated with other disciplines such as social studies, language arts, and math, which are often taught as a core in the middle level curriculum.

Implementation of the Curriculum Through Staff Development

One of the major issues relating to the development of significantly new curriculum is how much and what kind of in-service training and other support are necessary to successfully implement the new materials. To some degree, this is difficult to sort out in the developer district because for some teachers the implementation process begins early with the process of setting goals, selecting content, and developing approach of philosophy of the new course. There are approximately 60 middle-level life-science teachers in the Jeffco District. Approximately 85% of these teachers were involved to some degree in the development effort through writing or trail teaching. The other 15% remained on the "outside" until the course materials were completely developed and then participated in the last round of in-service training as the teachers implemented the materials in their classrooms.

Although the in-service program evolved to some degree over the 5 years of development and early implementation, it basically consisted of about 45 contact hours spread over the entire year. Early in the development process, seven life-science teachers were selected as the in-service cadre. In the first 2 years of in-service training, while the materials were still being developed and before the cadre had extensive experience with the new units in their own classrooms, the in-service sessions were taught jointly by Judy Capra and one of the cadre members. Later, the cadre members assumed almost the entire responsibility for the presentation of the in-service workshops.

Considerable time was spent in helping the cadre understand and grow in their leadership skills and abilities. They attended several all-day sessions of "formal" training in adult learning, the nature of the change process, the development of in-service teaching plans, and presentation techniques. Each time an in-service day or session was planned, the "lesson plans" were developed by the cadre and submitted to the project leaders. The next time around these plans were modified, updated, and resubmitted to the project leaders. Through this process of evolution, a series of well designed in-service plans were developed for the use by the cadre.

Implementation of the curriculum was guided by the Concerns-Based Adoption Model (CBAM), a model for how individuals progress as they learn about and use a new program or process (Hall & Loucks, 1978). The CBAM has seven Stages of Concern (Awareness, Information, Personal, Management, Consequence, Collaboration, and Refocussing) that help curriculum planners know what questions teachers will be asking as a new curriculum is implemented.

The content of the in-service sessions focused mainly on lower stages of concern (information, personal, management)—the "what is it" and "how to" questions about the new content and activities. Typically, teachers would do several of the activities and then discuss the approach they would take with students. Some activities were only discussed as a preview for teachers when time was not available to do the entire activity. At each session, there was usually time devoted to discussing broader teaching issues that guided much of the development of the course materials. These included cooperative learning, the use of the learning cycle, the teacher discussion techniques, evaluation procedures, content background, and general rationale for the course materials. This presentation of theory within the context of the curriculum materials seemed to provide the right balance and timing.

At each session, particularly the all-day ones, time was also allotted for participants to ask questions, share "war stories," and generally participate in problem-solving situations around their use of the materials. These were usually very rich and animated discussions that could have gone on much longer. In retrospect, it would have been advantageous to have had the luxury to spend much more time in these problem-solving situations. Those discussions come as close to coaching as an in-service leader can provide without spending time in the participant's classroom.

A major activity of the in-service cadre was the development of the Component Checklist, discussed in detail in the next section. The Checklist defined the components of the curriculum, with detailed descriptions of how teachers would be using it.

Assessing Implementation

There were two reasons to assess implementation of the Jeffco Life Science curriculum. First, by monitoring what teachers were doing with the curriculum, in-service sessions and other kinds of support could be adjusted to focus on areas where problems existed. The information also allowed us to reformulate the implementation design for use in the future.

The second reason to assess implementation was to support an evaluation of the effectiveness of the program being conducted in a number of the classrooms to determine whether students being taught the new curriculum learned more than those being taught the former curriculum. We know that, no matter what the results of the impact evaluation, we would not know *why* they occurred if we didn't know what was happening in classrooms. For example, if there were no significant differences between experimental classrooms and regular classrooms, we would need to know whether experiemental teachers were actually using the curriculum. If there were differences, it would be good to know to which components to attribute the differences.

Developing an Instrument to Assess Implementation

The primary question was: To what extent are teachers implementing the components of the Jeffco Life Science curriculum? To address this question we needed a clear definition of the curriculum's components and a methodology to determine individual teachers' extent of implementation. We chose to develop a Component Checklist, one part of a Practice Profile, a tool for defining innovations that was developed collaboratively by the NETWORK, Inc. and the Texas Research and Development Center for Teacher Education (Loucks & Crandall, 1982). The Profile was originally developed to define and assess

Table 1. Excerpt From Jeffco Life Science Component Checklist

Ideal sequence	Acceptable sequence	Unacceptable sequence
A. Teacher uses the prelab time to (1) begin with students experiences, a story, or other motivating device, (2) define purpose or objective of the activity, (3) review procedures, and (4) outline safety precautions	A. Teacher uses prelab for three of the four components including safety precautions.	A. Teacher uses prelab time for two of the four components and/or defines the concepts & outcomes first, so activity is done to confirm concepts.
B. Teacher uses postlab time to (1) discuss students' experience and data, (2) draw conclusions, (3) develop main concepts from the results, and (4) define terms as needed.	B. Teacher uses postlab for all four components but with only limited connections and discussions.	B. Teacher does not use all components.
C. Vocabulary is an aid to attaining & demonstrating application of concepts and is used\explained as needed.	C. Vocabulary is used for clarification and identification during prelab.	C. Memorisation of a large amount of additional vocabulary is the learning objective.

implementation of 61 innovations examined in the Study of Dissemination Efforts Supporting School Improvement (Crandall & Loucks, 1983) and has since been used in a large number of evaluation and research studies and technical assistance efforts.

A Component Checklist provides a standardized format for defining the components of an innovation that stand alone and can be described behaviorally. Typically the Checklist is defined from the developer's point of view and describes variations in use of each component in terms of ideal, acceptable, and unacceptable behaviors.

Table 1 shows two of the six components of the Jeffco Life Science program; the other components are use of the curriculum materials, student grading, teacher/student interaction, and grouping. Its development followed standard procedure. First, the developers of the curriculum were interviewed by the evaluator. Beginning with open-ended questions, they were asked to describe the program, to describe what one might see a teacher doing who was using the program and what might be doing on in the classroom. As some program components emerged, each was discussed in terms of how it might look if a teacher were using it in a ideal way, in a way that was unacceptable, and in a way that was not ideal but still acceptable. A Checklist was drafted that represented the discussion to the extent possible and was revised based on an additional discussion among developers and evaluator.

To pilot test the Checklist and learn what was missing, the evaluator visited with several teachers who were nominated to represent a range of implementation. Through interviews and classroom observations, the evaluator was able to question the current version of the checklist, discovering several places that needed revision. These included a component that needed to be divided into two components, some variations in teacher behavior that had not been anticipated by the developers but that needed to be added, and some clarification of terms describing particular teacher behaviors. The Checklist was finalized by the developers after several rounds of review and input by several groups of pilot teachers and the cadre.

Data Collection

To monitor implementation, data were collected three times, each time from a different set of teachers who were selected to represent (1) a range of experience with the curriculum; (2) different backgrounds with respect to training and experience with inquiry-based programs; and (3) different dispositions toward the new curriculum as judged by the developers (e.g., enthusiastic vs. reluctant users). In the second and third rounds of data collection, the teachers were those involved in the field test evaluation, giving pre- and post-tests to their students, including control group teachers who had not been given the curriculum materials.

Whenever possible, each teacher was interviewed for 30-60 minutes and observed for an entire science class. The interviews were initially open-ended, asking teachers to describe how they taught the curriculum and to describe a "typical" activity, from pre-lab to post-lab. Teachers were then asked questions about each component if their descriptions to that point did not provide sufficient information. Classroom activities were scripted, with special attention to the use of the curriculum's components.

As noted earlier, this procedure cannot be represented as adequate measurement of teacher implementation. Although an effort was made to cross-validate teachers' representations of their classroom behavior with their actual classroom behavior, we were not always able to observe teachers. Nor could we have great confidence that the observations made were typical of classroom behavior because one observation is never an adequate sample. Further, because a single activity from the curriculum typically takes more than one class period, we saw pre-labs for some, post-labs for others, students working on activities for others, and so forth. What we had was a snapshot of what the teacher was doing with the curriculum.

We determined, nevertheless, that the snapshots we acquired were better than nothing at all and were far better than some implementation data that are collected with paper-and-pencil teacher surveys. We also have some confidence that teachers were not behaving in atypical ways just for the observation. First, the kind of behaviors called for by the curriculum,, for example, cooperative learning and inquiry teaching, are not ones teachers easily turn on and off at will. They are difficult to master and, when they are being done well, it is difficult to believe they are not part of the teacher's repertoire. Second, enough teachers were not using the components so that we believed them when they said they did not feel compelled to do so. Some teachers readily admitted, for example, that they were not using all the priority activities, that cooperative learning groups did not work for them, or that all they used for grading were tests. Some introduced long vocabulary lists before a lesson, used demonstrations instead of student activities, and had students working alone on activities. There did not seem to be any "socially desirable" response, that is, no reason for them to pretend to teach in ways they normally did not.

Results of Implementation Assessment

For each teacher, information from the observations and interviews was used to characterize the teacher's behavior with respect to each component. The evaluator determined whether the behavior represented ideal, acceptable, or unacceptable variations. Data from the three data collection periods are shown in Tables 2, 3, and 4.

For Tables 2 and 3, ratings are designated by the appropriate letter. When the teacher demonstrated behaviors that were largely of one rating (e.g., accept-

Table 2. Component Checklist Summary (November 1987)

Teacher	Use Materials	Learning Sequence	Grading	Class Time	Interaction: Discussion	Interaction: Grouping
A	A/u	A/u	A	A/u	-	A
B	A/u	A/u	I/a	I	U	A
C	A/u	U?	A	U?	U?	A
D	A/u	A	I	A	I/a	I
E	A/u	A/u	I/a	I	-	A
F	I	A	I?	I	A?	I
G*	A/u	A/u	I/a	I	-	A
H*	A	U?	A?	-	-	-
I	U	U	A/U	U/i	U	U
J**	U	U	-	U	U	U
K	U	A/I	I	U/?	A?	A
L**	U	U	-	U	U	A U

able) but some minor behaviors were of another rating (e.g., unacceptable), then a double rating was given. For example, Teacher A in November 1987 used all the priority activities, but assigned all of the Analysis Questions to the students (whereas they were supposed to use Analysis Questions selectively). This resulted in an A/u rating.

For the final round of data collection, we experimented with a numerical rating system as in Table 4. Here we were able to sum ratings across components and obtain a rough score for extent of implementation. When we were missing data, as for Teachers F and L, we took an average of the teacher's score on the other components and substituted it for the missing score. As we noted earlier, several teachers who were not supposed to be using the curriculum were included in each round of data collection. These were teachers who constituted the control group for the outcomes evaluation. On Table 2 these are Teachers I-L, Table 3, G-L, Table 4, J-M.

Several observations can be made from these tables. First, there is a wide range of implementation of the Jeffco curriculum. Although rather obvious, some educators, particularly those who are not close to the classroom, still have the unrealistic expectation that, when trained well in a good curriculum, teachers will use the curriculum in the same way. Here, once again, is evidence that teachers adapt components on a curriculum to suit their own situations. For each round of data collection there were teachers who were using all or nearly all components in an ideal way, and, at the other extreme, teachers using more than one component in a way unacceptable to the developer.

We also noted that there is generally a difference between teachers who have been trained in the curriculum and who are expected to use it, and those for whom neither is the case. It is almost unnecessary to point out which are the control group teachers in the figures. This indicates that the Jeffco curriculum materials have helped teachers to use a type of instruction that is different in significant and important ways from the traditional curriculum. They are using a learning cycle (rather than lecturing and having

Table 3. Component Checklist Summary (April 1988)

Teacher	Use Materials	Learning Sequence	Grading	Class Time	Interaction: Discussion	Interaction: Grouping
A	I/u	I/a	A/u	A	A	A
B	A/u	A/u	A/u	U	U	A
C	A	A/u	A/u	A?	A/u	A
D	A/u	I/a	A/u	A	A	A
E	I/u	I?	I/u	I	I/a	I
F	A/u	A	A/u	I	A	A
G	u	u	I/a	U	U	A
H	u	A/u	I/a	I	A	A
I	u	I/u	I/a	I	I/a	A
J	u	A	A/u	A/u	u	A
K	u	A/u	A?	A/u	A/u	A
L	U	A/u	A/u	I/u	A	I/A

I,i = Ideal variation
A,a = acceptable variation
U,u = unacceptable variation
\- = no information
* = no observation
** = No interview
? = uncertain given limited information

infrequent, confirmatory labs), encouraging students to work in groups, and emphasizing higher-order learning more so than traditional teaching.

There are, however, teachers who have been trained in the curriculum who demonstrate low levels of implementation, and teachers in the control group who might almost be considered "users." This observation underlines once again the need to know what teachers are actually doing who are supposedly part of a control group or a treatment group. Figure 4 provides the most graphic evidence. Teacher M was not using Jeffco curriculum materials, yet her teaching followed a learning sequence, she used cooperative learning and promoted continuous interaction, and her grades were derived from a variety of sources with both fact and higher order learnings considered—in short, she was using nearly all the Jeffco curriculum components in an ideal way. Contrast this to Teachers A and B in Figure 4, who had been trained and were using the Jeffco materials, but with much less attention to the important components, especially the use of class time and encouragement of interaction.

A final general observation is that some components are much more readily implemented than others. Generally, it appears that teachers found it easier to manage class time and grade in appropriate ways than they did to support the right kinds of interactions through discussions and grouping strategies. When examined closely, the unacceptable behaviors in use of materials and the learning sequence also indicate

Table 4. Implementation Summary (November 1988)

Teacher	1 Curriculum	2 Sequence	3 Grading	4 Class Time	5 Interaction	6 Grouping	Total Scores
A	1	1	1	0	0	1	4
B	1	1	1	0	0	1	4
C	1	2	2	2	2	2	11
D	2	2	2	2	2	2	12
E	1	2	2	2	1	1	9
F	1	1	2	2	NI(1)	1	8
G	2	1	2	2	1	1	9
H	2	2	2	2	1	1	10
I	2	2	2	1	1	3	10
J	0	0	2	0	0	0	2
K	0	0	2	0	0	1	3
L	0	0	1	NI(5)	0	2	3/5
M	0	2	2	1	2	2	9

that teachers do not emphasize questions that require higher-level thinking and often do not extend discussions far enough to ensure the students understand important concepts.

Discussion and Conclusions

Our assessment of the implementation of Jeffco Life Science curriculum has provided a great deal of information about the particulars of what transpired in the Jeffco schools as well as what might be expected in a similar effort in other locations. It also provides insight into what is being requested by the various curriculum reform movements and some way of addressing the many challenges they present.

Reports on the status of middle grades education and what it needs to be in the future (Carnegie Corporation, 1989) indicate that we need nothing less than a paradigm shift on the part of teachers to transform the nature and quality of learning in schools. Many of the recommendations of these reports have been built into the Jeffco Life Science curriculum. Thus, one of the questions is whether or not there was a paradigm shift on the part of Jeffco teachers. Our answer is an equal "yes and no."

Our study provided evidence that teachers in Jeffco seventh grade classrooms were teaching differently than they had before. Where they had relied on lecture and discussion with occasional confirmatory labs, they were using a learning sequence that exposed students to new concepts through hands-on activities and interactive concept development. Where students had worked alone or with a partner (but only on lab activities) they did most of their science learning in pairs or small groups. Where the learning of factual information had predominated, concept development through encouraging higher-level thinking was more prevalent. Where breadth of coverage had been stressed, depth of understanding in a few major topics was emphasized. This is a description of major change for teachers and is particularly convincing when a large number of teachers report that they could not see returning to their old way of teaching ever again.

Yet there is also evidence that the shift has not fully occurred. In one way the curriculum itself is a barrier. The future of middle-level education, the reports tell us, is in a multidisciplinary approach, both across disciplines such as science, math, and language, and within disciplines, as with life science, physical science, and earth science. The Jeffco curriculum holds to the traditional discipline-based pattern.

Further, it is possible for teachers to use the curriculum without incorporating the learning cycle, cooperative learning, and higher-level thinking. We noticed a few teachers who did so. It is also possible for teachers to use the curriculum as simply a new resource or activity supplement to their text-orientated program. In these situations, clearly the curriculum does not represent a paradigm shift.

Finally, the assessment dimension of the curriculum is still fairly traditional. While a variety of sources of assessment information is needed, as is attention to concept development as well as understanding factual information, there are no innovative assessment procedures to help teachers think and act differently about assessing student progress. When accountability is still traditional, there is a tendency for teaching, especially its goals, to be so as well.

Has a paradigm shift occurred in Jeffco seventh grade classrooms? Probably not . . . yet. The most optimistic way to interpret the current condition is that it has the potential to shift the paradigm. Major changes have already occurred, and others are possible. What are some of these and how can they be encouraged?

Our interpretation of the implementation data is that the major change made to date by Jeffco Teachers has been that they now teach the curriculum: they are using a different format and set of materials to teach Life Science to their students. Because the learning cycle, cooperative learning, and higher-level thinking are built into the curriculum, these have become part of the teachers' routine, at least at a minimum level, depending on the teacher. What is needed in the future is a focus away from the materials (as the teachers have now mastered them) and on to these more difficult strategies needed to engage students in learning.

The Jeffco Science Department made a strategic choice in designing their materials and in-service workshops to focus on the activities rather than the teaching strategies required for the learning cycle, cooperative learning, and higher-order thinking. Several years previously, they had developed an eighth grade curriculum that embedded these teaching strategies in a much more robust way, with in-service workshops that focused on them as well. Teachers rebelled and implementation has been incomplete. This appeared to be because it was too much too fast, so the Life Science curriculum development took another tack.

With the Life Science materials in place in teachers' classrooms, there is a need for "phase two" of teacher development. This phase needs to focus on learning and teaching, with teachers fully engaged in constructing their own knowledge about what it means to learn scientific concepts and what teaching moves best promote this. It calls for attention to the teaching strategies noted above in a format that goes beyond traditional training. Staff development needs to include opportunities to read, reflect, discuss, see demonstrations, and practice. In-class coaching would be a helpful addition because of the focus on student-teacher interactions that can rarely be observed by teachers themselves as they are teaching.

Implementation of a new curriculum is a major undertaking, particularly when the curriculum includes the kind of transformation in teaching that is illustrated by Jeffco Life Science. With curricula typically remaining in place for several years—5, if not 10—it seems that a two-phase, intensive series of staff development opportunities for teachers is both legitimate and a good investment. The importance of teachers understanding new research on learning and how it should influence how they relate to students is clear. But it is only through extended experience with the ideas and working together to link the ideas to the realities of the classroom that the called-for paradigm shift will occur.

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SCIENCE EDUCATION: FROM THEORY TO PRACTICE

Science educators from 55 countries met in Jerusalem, Israel, January 3-7, 1993 at an International UNESCO-sponsored Conference on issues of theory and practice in science education organized by the Amos de-Shalit Israel Science Teaching Center. This book of readings is a collection of selected papers from the conference.

The goals of this conference were to review past experiences about theory and practice in science education across both developed and developing countries and to identify factors influencing successful practice around the world. One of the key elements explored at the conference was how best to bridge the gap between theory and practice in science education. The important differences between the context of research and practice, the fact that research can only offer partial solutions, the dangers of generalizing research results from one context to another, and the difficulty of implementing change - are all reflected in the papers.

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