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ABSTRACT

The proceedings of the final consultation meeting for the Pilot Project on the Teaching of Science and Technology in an interdisciplinary Context are presented. The goals of the project initiated by UNESCO were to develop and test ways in which the concepts, processes and skills of science and technology could be linked with or incorporated into the teaching of other areas in the school curriculum at both the primary and secondary school levels. Emphasis was placed on teaching methods and activities that promote understanding through active learning techniques, on efforts to link classroom learning with real-life experiences and on extending this teaching beyond the classroom. The countries of Bulgaria, Denmark, Indonesia, Norway, Scotland, Sweden, United Kingdom, United States, and West Germany are represented through the publication of 15 papers. Topics include interdisciplinary teaching at the primary and secondary levels, integrating science and math using bee hives, health education at the primary level, polarized light, environmental protection, scientific writing and chemistry, informatics, dimensions of integration, computer simulations, the history of science, computer-assisted learning, and the integration of language-mathematics-informatics. (KR)

The Teaching of Science and Technology in an Interdisciplinary Context

Vol. II

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The Teaching of Science and Technology in an Interdisciplinary Context

Vol. II

Summary of the Pilot Project
and
Proceedings of the Concluding Consultation
Plovdiv, Bulgaria
25-29 May 1987

Division of Science
Technical and Environmental
Education

UNESCO

ED-90/WS/20

Paris, 1990

PREFACE

In 1981, Unesco's Division of Science, Technical and Environmental Education initiated ten Pilot Projects in some 50 countries which were focused on the modernization and improvement of science, mathematics and technology teaching, and on the application of these subjects to daily life and to national development. The key concept was an interdisciplinary approach. A consultation meeting was held in 1988 to review the projects in terms of objectives and results achieved, and to make suggestions and proposals for future development of such projects. As a consequence, two Pilot Projects have been continued, and some new projects initiated. Another outcome is this present document.

The Pilot Project on the Teaching of Science and Technology in an Interdisciplinary Context, which continued for three years, terminated with a meeting of participants from the Project, as well as those from some associated institutions. This document is a record of that meeting.

Unesco wishes to express its appreciation to the editor, Harold Foecke, to the authors of the fifteen papers in this document, and to all those who took part in this Pilot Project.

The views expressed in this report are those of the authors and not necessarily those of Unesco.

Contents

I. Objectives and Achievements of the Pilot Project

Harold A. Foecke

1. *Framework.* The Pilot Project on the Teaching of Science and Technology in an Interdisciplinary Context was a part of a series of 10 pilot projects on various aspects of the teaching of science and technology at the primary and secondary school levels undertaken by Unesco's Division of Science, Technical and Environmental Education in a total of approximately 50 countries during the three successive biennia from 1981 through 1987.
2. *Objectives of the Project.* The objectives of the Pilot Project on the Teaching of Science and Technology in an Interdisciplinary Context (hereinafter referred to as 'the project') were to develop and test ways in which the concepts, processes and skills of science and technology could be linked with or incorporated into the teaching of other areas in the school curriculum at both the primary and secondary school levels. Emphasis was placed on teaching methods and activities that promote understanding through active learning techniques, on efforts to link classroom learning with real-life experiences and on extending this teaching beyond the classroom.
3. *Overall Characteristics of the Project.* The project was launched in 1984 and completed in 1987; the total regular programme resources devoted to the project, not counting staff time and travel, were $52,000. The project had two aspects - one concerned with education in the basic sciences and mathematics, the other with nutrition and health education. Five countries were officially involved in the project and received financial support - Bulgaria, Denmark and the United Kingdom for the first aspect, Thailand and Indonesia for the second; other countries which became interested and involved unofficially before the conclusion of the project were the Federal Republic of Germany, Norway, Sweden, the Union of Soviet Socialist Republics and the United States of America. The official conclusion of the project was the consultation held in Plovdiv, Bulgaria on 25-29 May 1987; the proceedings of that consultation constitute the remainder of this document.
4. *Constraints and Strategies.* In view of the relatively modest resources available for the project, the overall strategies of the project were to work with devoted individuals who already had both some experience of working with Unesco and some relevant activities underway, to strengthen these on-going activities with very small injections of funds (contracts averaging $4,000 each) during the first biennium (1984-85) and to facilitate an exchange of ideas and information among participating groups in various ways during the second biennium (1986-87).
5. *Criteria for Selecting Participating Institutions and Countries.* In accordance with the strategies described immediately above, the criteria for selecting participating institutions and countries were: (a) an explicit expression of interest, by a particular group or country, in participating in the project and (b) the existence of an organization or institution with interdisciplinary activities already underway.
6. *Results of the Selection Process.* The application of the aforementioned criteria led to the following choices for the reasons given: (a) in Bulgaria, the Educational Research Group of the Bulgarian Academy of Sciences (BARGEP) was particularly interested in participating

because it had launched an interdisciplinary project emphasizing science and mathematics in 27 schools throughout the country and was accordingly particularly interested in obtaining ideas and materials from other countries with comparable activities, (b) in the United Kingdom, the Primary Science Development Project in Scotland was attempting to get an interdisciplinary project implemented in Scottish schools and was willing to exchange experiences with other projects elsewhere and (c) in Denmark, there was great interest in launching interdisciplinary activities based on previous work at the Royal Danish School of Educational Studies.

7. *Recommendations of the Concluding Consultation.* The principal recommendations of the concluding consultation, the proceedings of which constitute the remainder of this document, were: (a) that the organizers of the project activities in the various countries should remain in touch, exchange materials, visit each others' projects and hold periodic consultations and (b) that Unesco should continue to assist these projects by providing them with resource materials and inputs gathered from similar projects in other countries.
8. *Materials and Publications Produced.* All of the participating projects have produced materials of various types for their own use; when these materials have been in languages other than English, summaries have sometimes been made (e.g., by Bulgaria) for purposes of sharing with other projects and with Unesco. In addition to this document, information about the various activities are most readily available in the following publications: (a) *The Teaching of Science and Technology in an Interdisciplinary Context: Proceedings of a Nordic Workshop* (Kollekolle, Denmark, 7-10 June 1985); (b) *The Teaching of Science and Technology in an Interdisciplinary Context: Approaches for the Primary School*, Number 19 of the Science and Technology Education Documentation Series (Unesco, 1986); and (c) 'Integrating the Natural Sciences and Other School Subjects', Volume II of *Innovations in Science and Technology Education* (Unesco, 1988).
9. *Principal Outcomes.* Interdisciplinary projects are continuing in all of the participating countries, including those which received no support for their activities, and exchanges of various kinds (by visits of personnel as well as by correspondence) are on-going. The Division of Science, Technical and Environmental Education continues to remain in contact with these groups, to share with them relevant information from around the world and, in general, to try to serve as a catalyst for innovations in the teaching of science and technology in an interdisciplinary context.
10. *Conclusions.* With very modest resources, Unesco has been able, as concerns the teaching of science and technology in an interdisciplinary context, to initiate and/or to give added impetus to pilot project activities which now not only continue on their own but serve as sources of ideas and materials for other groups desiring to make educational changes in this direction.

II. Proceedings of the Consultation

A. THE TEACHING OF SCIENCE AND TECHNOLOGY IN AN INTERDISCIPLINARY CONTEXT

Opening address by
Mrs. Sheila M. Haggis
Chief, Science Education Section,
Division of Science, Technical &
Environmental Education
Unesco, Paris

Ladies and Gentlemen,

It is a great pleasure for me to bring you the greetings of the Director-General of Unesco at the opening of this meeting. It is noteworthy that, nearly 20 years ago, in September 1968, the first International Congess on Integrated Science Teaching was held in Bulgaria. I was privileged to take part in that meeting, organized jointly by Unesco and the International Council of Scientific Unions (ICSU) in co-operation with the Bulgarian National Commission for Unesco. Much has happened in the field of science teaching in the last two decades and it is fitting that we should now be holding another international meeting in Bulgaria on an interdisciplinary theme.

In 1968, we were thinking about ways in which a more unified approach could be brought to bear on the teaching of the sciences. The scope of the present meeting is broader. While a unified approach to the sciences continues to be a major preoccupation, central to our thinking is a unified approach to the learning of the child. A young child does not perceive the world in terms of science, mathematics, language, music, art and so on but, in fact, in a much more holistic way. The child observes the world around him or her in all its aspects. The child talks about what he or she perceives and asks questions. The topic the child describes may be something that we, as adults, perceive as natural phenomena (science), something to do with the past (history), a tune (music), a picture (art) and so on. To the child, reaction to the world around him or her can relate to all aspects of what we call the curriculum. Our concern, in interdisciplinary work and, I would suggest, in this meeting, is to find ways of embodying this unification in our teaching, from the earliest years onwards.

We are fortunate that, in Bulgaria, a pilot project with this objective was launched several years ago under the auspices of the Research Group on Education of the Bulgarian Academy of Sciences. We shall have the opportunity of seeing it in operation in the schools we visit. Our Bulgarian colleagues can tell us something of the enormous effort that has been involved in defining the approach, developing and testing the materials, retraining the teachers and, perhaps above all, convincing the parents, the administrators and all others involved that the enterprise is worthwhile. As I understand it, the project has proved to be challenging, frustrating and demanding - but, ultimately, supremely rewarding.

We also have an example from Scotland. The Primary Science Development Project has aimed to make things happen in primary schools in Scotland. There is a saying, 'You can take a horse to water, but you can't make it drink.' In primary schools in many parts of the world, science is on the timetable, materials are available, but somehow the children don't really seem to learn science. In Scotland, it is different; children do science and learn science. The interdisciplinary approach is at the heart of this difference.

Many interdisciplinary experiments are taking place in the Nordic countries at different levels of the educational system. We have among us scientists and educators who have been working on these experiments and can tell us more about them.

I should like to mention four specific topics to which we may pay particular attention.

1. *The use of computers.* This meeting follows immediately an important conference on 'Children in the Information Age'. The computer can be a unifying and binding force in education. We need to think about ways in which its u e can be effectively exploited.
2. *Mathematics.* The concepts of mathematics and those of science are closely related, but this is not always the case in the way they are taught. So often mathematics is taught in an abstract way, divorced from the concrete realities of science. How can this be changed?
3. *Technology.* The processes of technology, which are essentially problem-solving, differ from the 'finding-out' processes of science. The two are closely inter-related but, until recently, technology teaching as such was neglected in many countries. It would seem important not only to draw children's attention to the ever-expanding range of technological inventions which enrich our lives but also to initiate them into the processes of design, invention and problem-solving. The more rapidly society changes as a result of the influence of technology, the more important it is that children should have an understanding of these changes and should develop the capacity to cope with them.
4. *Nutrition, health and environment.* Unesco's pilot project has encompassed the teaching of these subjects, which are interdisciplinary by their very nature. We have examples from Indonesia and Thailand of innovative ways of working in these fields.

We shall, of course, be discussing other aspects of interdisciplinarity, such as the use of language in the learning of science, links with art and music and with the social sciences and, last but not least, the historical and cultural aspects of science.

Unesco's pilot project on 'The Teaching of Science and Technology in an Interdisciplinary Context' was launched some four years ago with the aim of exploring different approaches to interdisciplinary work and bringing together the results so that they could be applied more widely. I hope that by the end of this consultation among those who have participated in this project, as well as those who are here because they are interested in working in this field, we shall be able to make suggestions for the further development of this work in various social, political and economic contexts, and at various levels of the educational system.

I should like to thank the Bulgarian organizers of this meeting for all the hard work they have put into making the arrangements for it. We have much to learn from each other and we have been provided with a wonderful opportunity to do so.

B: PAPERS BY ATTENDEES FROM COUNTRIES PARTICIPATING IN THE PILOT PROJECT

Teaching Science in an Interdisciplinary Context - The Scottish Experience

Sinclair MacLeod

Introduction

In 1965, HMSO published a policy statement on primary education in Scotland[1] which provided an up-to-date appraisal of the best practices in primary schools in Scotland and the principles on which primary education should be based. In this publication, science was included, along with history and geography within 'Environmental Studies'. Over the last twenty years, schools have been trying to cover the scientific experiences of children through environmental studies, which is now thought of as including history, geography, science and health education.

H. M. Inspectors of Schools Survey

However, in 1980 H. M. Inspectors of schools published a report[2] based on surveys, carried out by H. M. Inspectors of schools in 152 primary schools in 1978, of work being done in Primary 4 (8-9 year olds) and Primary 7 (11-12 year olds). This report indicated that, under the umbrella of environmental studies, science was being neglected and that there was little evidence of progression from one stage to another.

Tables from the surveys (see appendix) shed some light on the situation that existed in 1978 and indicated that there were many deficiences in the scientific experiences of children in these classes.

Two quotes from the report highlight the situation:

> Science fared badly, with 60 per cent of all teachers (P7) giving it little, if any, place in their curriculum.

> As a matter of priority, something has to be done for them (teachers) in science, but first it will be necessary to assess what schools can reasonably be expected to achieve.

The Primary Science Development Project

After the publication of the report, the Scottish Education Department set up at Moray House College of Education, Edinburgh, the Primary Science Development Project to run from October 1981 to March 1985.

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1 *Primary Education in Scotland*, HMSO.

2 *Learning and Teaching in Primary 4 and Primary 7*, HMSO.

The Project Team

Director	Mr. Sinclair MacLeod
Assistant Directors	Miss M. I. Weir - October 1981 till November 1982 Mr. G. Mills - from January 1983 Miss W. Philip - from April 1983

The Project Proposal

The aims of the project were to:
- develop educationally acceptable science experiences in the curriculum of all Scottish primary schools;
- make teachers more aware of the nature and aims of science in the primary school and how it relates to other aspects of the pupils' education;
- encourage and guide schools in the exploration and exploitation of existing curricular resources;
- establish the forms of support which school staffs require in order to produce school policies for science;
- examine ways in which science and health studies and science and mathematics can reinforce each other.

In order to achieve these aims, the project team liaised with education authorities and colleges, using existing groups of headteachers, teachers and advisers in association with college of education staffs and setting up new groups where none existed.

The Advisory Committee

An advisory committee, representing local authorities, schools, colleges of education and members of Her Majesty's Inspectorate was set up. These representatives were drawn from different parts of Scotland. The committee identified the following areas for investigation:
A - The scientific experiences of children in the early stages of primary education (5-8 years).
B - Inter-relationships between science and health education for children between the ages of 8-12 years.
C - Inter-relationships between science and mathematics for children between the ages of 8-12 years.
D - The development of science policy documents for primary schools.

Strategies for Development

PHASE 1 - November 1981 to June 1982

Links were established with all education authorities, through letters and, where feasible, meetings between the project director and respresentatives of the different regions. Liaison persons were nominated by every region.

The project team produced questionnaires and interviewed about 200 teachers and headteachers to try to identify the 'needs' of the schools, i.e., what they (the staffs of the schools) felt they required, in addition to pupil materials, in order to teach science in the primary school and to produce school policies for science.

The two major issues highlighted by the responses to the questionnaires were that teachers felt they needed help in the form of school guidelines covering a programme for science and classroom organization and also that they wanted adequate resources to be readily available.

PHASE 2 - June 1982 to July 1983

Science in the Early Stages

Members of the advisory committee, working with infant teachers in fourteen schools, carefully recorded all the work which related to science activities for the whole school year. This included photographs, slides, tapes and videos as well as written accounts. From this material the project team was able to identify a number of case histories which exemplified good practices in the early stages of the primary school. These were included in the published materials.

Links between Science and Health

Three groups of schools in different parts of Scotland were set up and, with members of the advisory committee working with them, each group looked for relationships between scientific experiences and health education. The teachers involved experienced little difficulty in relating the two aspects of the curriculum and indeed felt that the children's interest and performance improved in both areas. The teachers also commented on the range of opportunities for language work that arose from the combined study. Their detailed recording of the work covered included useful examples of cross-referencing between resources for science and health which the project team were able to use in their published materials.

Links between Science and Mathematics

Members of the advisory committee worked with two groups of schools in different parts of Scotland to try to introduce into the schools' programme for mathematics more practical work through scientific experiences.

One group working with 10-12 year olds found that it was better for a school to establish a science programme on its own and that it was not possible to produce a complete science programme linked closely with their mathematics programme.

The other group working with 8-10 year olds, found that links between science and mathematics, particularly in the topic 'Time', were easy to establish. Not only were good scientific experiences recorded but the teachers commented on how this more practical approach had benefited the teaching and understanding of mathematics.

Policy formulation groups

Groups of schools in six different areas of Scotland were set up and the following procedure adopted in each.

(i) A member of the project team met with the local adviser and the headteachers of the schools to explain the purpose of the exercise. The headteachers chose the pupil materials to be used.
(ii) Each headteacher reviewed (a) what was being done in his school and (b) what resources were currently in the school.
(iii) The headteacher (or member of the project team) spoke to the staff of the school to illustrate the importance of scientific experiences for primary children and to highlight the need for a school policy in science.
(iv) Some teachers in the school were given the pupil materials, previously chosen by the headteacher, and guidelines on how to start using these materials.
(v) These teachers used the materials with their classes for about a term (3 months).
(vi) The staff discussed the experiences of these teachers; other teachers tried the materials.
(vii) Promoted staff drew up draft policy statements.

PHASE 3 - June 1983 to March 1985

Based on the results of phase 2 the project team started writing small, easily-read booklets covering different aspects as follows:

Booklet 1. *Science in the Primary School - An Introduction*

This included (a) Why include science in the curriculum?
(b) What is science in the primary school?
(c) The need for a school policy in science.

Booklet 2. *A School Policy for Science - A Rationale*

(a) Why a policy for science is necessary.
(b) What a policy for science should cover.
(c) Some common features in approaches to formulating a policy.
(d) Time scale for formulating and implementing a policy.

Booklet 3. *Formulating a School Policy - A Strategy*

(a) Review what is already being done in science in the school.
(b) Decide on an approach - either core or thematic.
(c) Implementing a science programme using these approaches.

Booklet 4. *Activities in the Early Years*

Including (a) Environments for science experiences.
(b) Role of the teacher.
(c) Centres of interest/theme approach.
(d) Importance of play.
(e) Recording and assessment.

Booklet 5. *Links with Other Areas of the Curriculum*

(a) Links in general.
(b) Science/mathematics links.
(c) Science/health links.

Booklet 6. *Class Organization*

(a) Ways of organizing a class.
(b) Role of the teacher.

Booklet 7. *Assessment, Evaluating and Record Keeping*

What form of assessment is appropriate in science in primary schools?

Booklet 8. *Resources*

(a) Strategy for organizing resources for science.

(b) Pupil materials.
(c) Books for pupils and teachers.
(d) Documents for teachers.

Case Histories

Five case histories from schools were also produced. These included experiences of schools working on a core approach and a thematic approach, links between science and health, links between science and mathematics, and centres of interest at the infant stages.

The draft booklets were sent for comment to members of the advisory committee, the schools involved in the project work and the Scottish Education Department. These comments were collated and used to amend the booklets which were then redrafted and sent out to a further sixty schools for comment.

As a result of these last comments, the booklets were further modified and then printed.

Dissemination

Advance copies of the booklets were sent to every Director of Education in Scotland, every college of education and every adviser.

A national course was held in April 1985 to which regions and colleges sent representatives. At this course, members of the advisory committee and the project team introduced the booklets and suggested methods for dissemination and ways of using the booklets in schools. It was recommended that the booklets be given to schools in conjunction with a course, for promoted staffs, on the principles behind the project and how to use the booklets in schools.

Every course member was encouraged to discuss the outcomes of the course with his director or adviser.

After the national course, the booklets (sufficient for 2 to 3 per school) were sent to every region with a letter asking them to contact their national course representatives with a view to discussing the dissemination strategy best suited to their region.

Follow up

A further national course was held in September 1986 to assess the outcomes and evaluate progress in the dissemination of the project materials.

Conclusions

So many primary school teachers are insecure in science that, before they can be expected to teach science within an interdisciplinary context, they require:

- a workshop which includes 'hands-on' experiences of activities similar to those proposed for the children;
- detailed and structured guidelines on how to integrate the science experiences with the other areas of the curriculum;
- support and encouragement from their headteachers and local authorities;
- a statement from their national administrators that this is an important area which must be included in every school's curriculum.

Appendix

Table 1. Over-emphasis and neglect of aspects of the curriculum in the survey classes

	Over-emphasized in classes		Neglected in classes	
	Percentage at P4	Percentage at P7	Percentage at P4	Percentage at P7
Arithmetic/Mathematics	14	22	9	1
Number/Computation	26	16	-	-
Practical mathematics	5	-	17	19
Written English	1	3	16	18
Spelling	5	6	-	-
Spoken English (including Drama)	2	1	26	29
Language usage and reading comprehension	38	41	5	4
Environmental studies generally	1	1	21	17
History	1	2	10	12
Geography	1	1	13	13
Science	-	-	*30*	*36*
Art	2	6	24	28
Craft	-	-	61	54
Music	1	2	14	17
Physical Education	-	-	5	8

Note: In no class was science over-emphasized but in 30 per cent of P4 classes (8-9 year olds) and in 36 per cent of P7 classes (11-12 year olds) science was neglected.

'The evidence at both stages suggests that very little science was taught at all'

'The extent to which science is neglected, especially at P7 stage, is of very real concern and its contribution to the primary school curriculum will have to be examined'

Table 2. Programme of Work: Environmental Studies

	Percentage of P4 classes			Percentage of P7 classes		
	Hist.	Geog.	Sc.	Hist.	Geog.	Sc.
The programme is based on available textbooks	9	5	2	11	5	3
The programme of environmental studies is strictly contolled by a school syllabus	7	9	4	7	7	3
A school syllabus exists but teachers do not necessarily adhere to it	7	7	5	9	11	5
The school programme allows the teacher to choose some of her own work	11	11	5	10	10	5
The teacher is free to organize work within a very broad framework	18	19	10	17	18	11
There is no school programme but the teacher organizes his/her own in his/her own class	26	26	32	32	34	28
There is no school progamme and little attempt to organize a school programme	20	22	34	13	13	34

Note: The last two entries may be looked at separately or combined to show where there was no school programme at all. Comparisons between science and two other components of environmental studies can also be readily made.

Bees and their Mathematics

A project integrating math and science

Otto B. Bekken
Kristiansand, Norway

To be able to integrate mathematics and its history into science teaching in schools, it may be useful for prospective teachers to gain experience with such integration in their teacher training programme.

My talk will concentrate on one concrete example of how I think this can be done. I will give an overview of one of the more successful student projects from the course 'Mathematics and Society' in our programme.

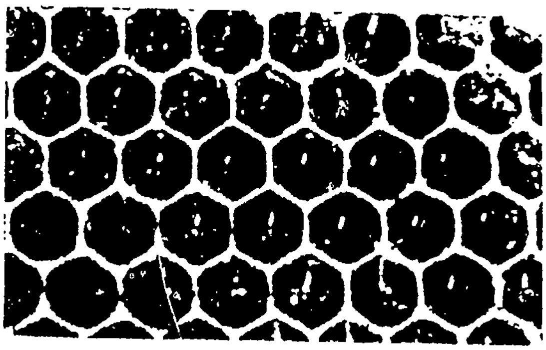
The project studied two aspects of the life of bees - the construction of their cells and the geometry of their dance. I can here only briefly discuss the first of these two, which turned out to be a rich starting point for studying aspects of:

- biology/chemistry (bees, their cells, honey, wax, . . .);
- mathematics (plane and space filling figures, their geometry, calculus of optimization, . . .);
- art (make models, Alhambra, Escher, . . .);
- history (the problem through Pappos, Kepler, Bartholin, Maraldi, Reaumur, . . .).

The oldest known commentary on mathematical aspects of the life of the bees goes back to Pappos of Alexandria (fl. 350 AD):

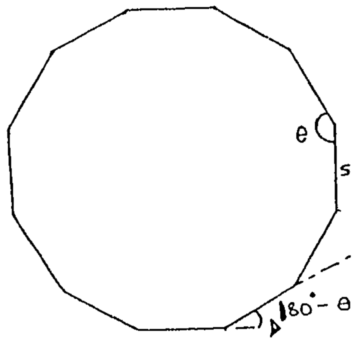
> There being, then, three figures which of themselves can fill up the space round a point, viz. the triangle, the square and the hexagon, the bees have wisely selected for their structure that which contains the most angles, suspecting indeed that it could hold more honey than either of the other two.

Two of the students actually had bee hives and could bring real bee cells to our class to look at



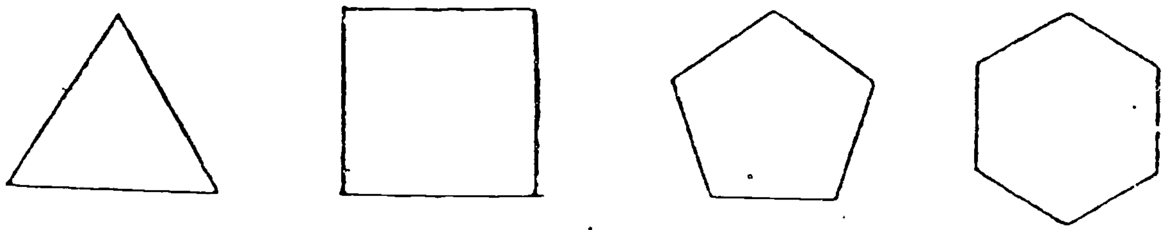
Back to Pappos - what is he talking about?

A polygon is called regular when all sides are equal and all angles are equal. In a regular n-gon, we get the angles



regular n-gon
side s
angle θ
$n(180° - \theta) = 360°$
i.e.
$$\theta = 180° - \left(\frac{360}{n}\right)°$$

The simplest regular n-gons are



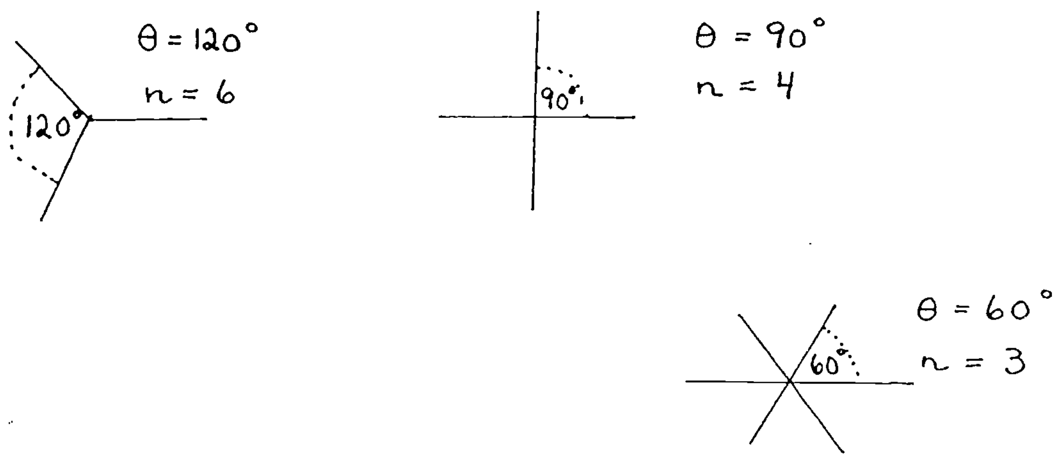
Triangle Square Pentagon Hexagon

The Pythagoreans (fl. 500 BC) could construct 3-, 4-, 5- and 6-gons, cf. Euclid's Elements (350 BC), and Theaitetos (fl. 375 BC) could solve the isoperimetric problem:

> To enclose a given area with shortest possible circumference, use regular n-gons. The higher n you use, the better. The circle is the best.

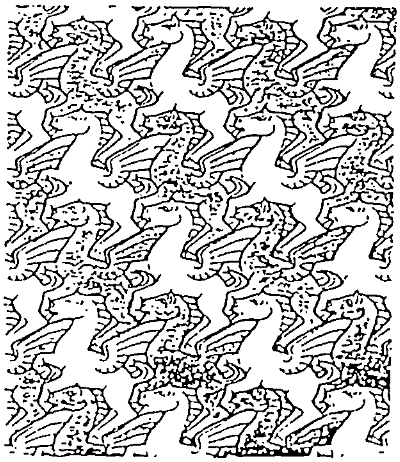
A sound proof by today's standards was first given in the 1800's by Schwarz and Steiner. This problem which can be explored by students, also has a rich history.

Which regular n-gons can cover the plane? Around one corner we have the following situations:



Thus, 3-, 4- or 6-gons will do the job, and the bees use 6-gons.

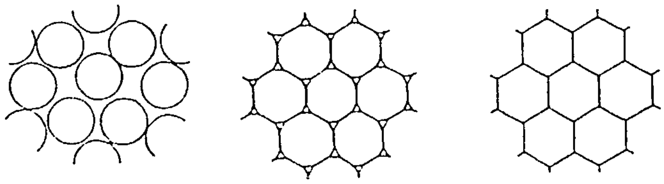
This touches upon the mathematical subject called tessellations, the master of which, in art, is Maurits Escher



who had the following to say about these works:

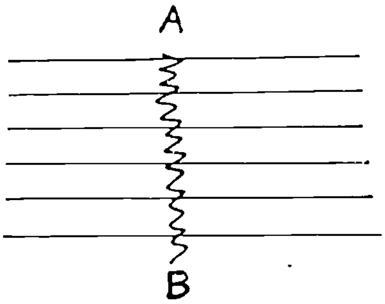
> In the course of the years, I designed about a hundred and fifty of these tessellations. In the beginning, I puzzled quite instinctively, driven by an irresistible pleasure in repeating the same forms, without gaps, on a piece of paper. These first drawings were tremendously time-devouring because I had never heard of crystallography; so I did not know that my game was based on rules which have been scientifically investigated. Nor had I visited the Alhambra at that time.

Pappos stated that 'economy of wax or honey' is the driving force behind the bees' choice of hexagons. There are other theories. Erasmus Bartholin (fl. 1660) expressed doubt and put forward 'pressure from other cells' as the natural reason behind the choice (cf. fig. below):



Space filling

Next we look at the space filling aspects of the bee cells.



Two stacks of cells meet along a rugged surface between A and B. What surface? Could regular polyhedra be involved?

There exist only 5 convex regular polyhedra. They were all known to the Greeks. They are often called Platonic, because they entered into his description of the world. If we put

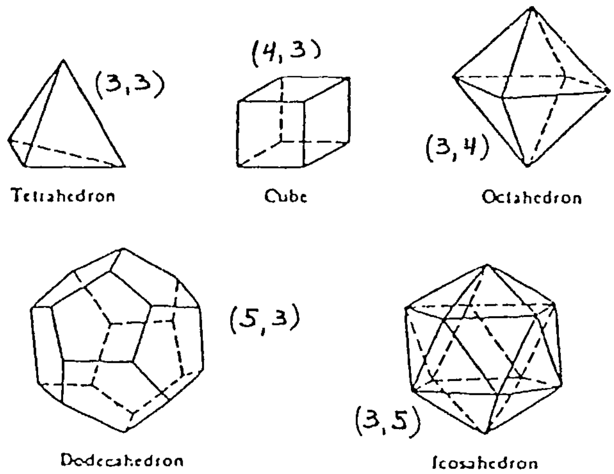
p = # of edges in a face
q = # of faces meeting at a vertex

convexity implies

$$\left(180^\circ - \frac{360^\circ}{p}\right) q < 360^\circ, \text{ i.e. } (p-2)(q-2) < 4$$

with the only possible values

$(p,q) = (3,3), (3,4), (3,5), (4,3)$ or $(5,3)$



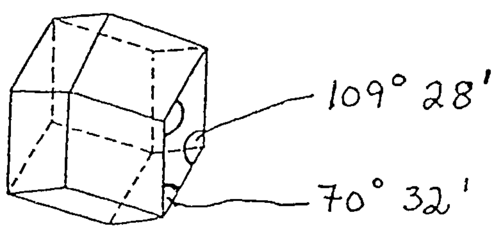
Except for our introduction of the Schläfli-symbols, this reasoning is essentially Euclid's. This may be used as a starting point for studying non-convex or semi-regular polyhedra, with contributions from Archimedes, Kepler, Poinsot, Cauchy a.o. There are many nice geometrical models for students to make; I brought three with me.

But, none of these regular or semiregular polyhedra are used by the bees.

Kepler (1619) suggested

the rhombic dodecahedron

as the pattern for their design.



Later Jacques-Philippe Maraldi (1711) gave the following careful description of the bees at work:

> . . . They begin by building the base, which is made up three rhombi or diamond shapes. They first build one of these rhombi, and trace two planes on two of the edges of the rhombus; they add a second rhombus to the first at a specific angle, . . . and trace two new planes on the two edges of this rhombus; finally they add a third rhombus to the earlier pair, and raise on the two exterior edges of this rhombus two more planes, . . . to perfect those which are newly outlined; they do this by means of their claws, with which they equisitely form the angles, ...

Maraldi measured the angles to be approximately 110° and 70°, coming close to Kepler's angles from the rhombic dodecahedron.

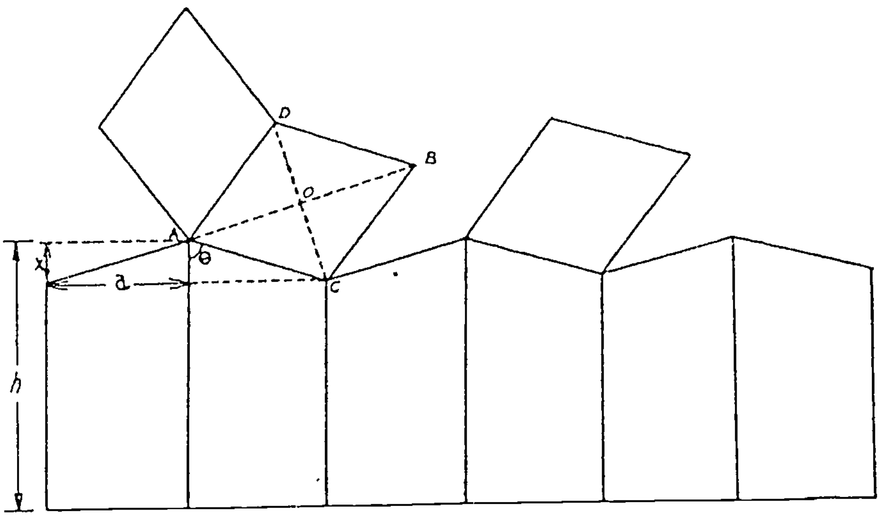
Reamur (1712) suggested that 'wax economy' could be behind this elaborate construction also, but Samuel König (1739) computed the most 'wax economical' angles, and got results slightly different from those of the rhombic dodecahedron.

Colin MacLaurin (1743), however, found an error in König's computation and could confirm Kepler's suggestion. This led to the following statements by

Lord Brougham: The bees were right and the mathematicians were wrong.

Darwin: The bees' architecture is the most wonderful of known instincts - absolutely perfect in economizing wax and labour.

Finally, let us look at these computations. If we 'cut open' the surface of a bee cell, we get the following:



$$CO = \sqrt{AC^2 - AO^2} = \sqrt{a^2 + x^2 - \frac{3a^2}{4}} = \sqrt{x^2 + a^2/4}$$

The area of one rhombus: $A_1 = \frac{AB \cdot OC}{2} \cdot 2 = \underline{a\sqrt{3} \cdot \sqrt{x^2 + a^2/4}}$

The area of one side: $A_2 = \underline{ah - \frac{ax}{2}}$

The total surface: $\underline{A(x)} = 6A_2 + 3A_1 = \underline{6ah - 3ax + 3a\sqrt{3} \cdot \sqrt{x^2 + a^2/4}}$

We find smallest area when $A'(x) = 0$. Then we have

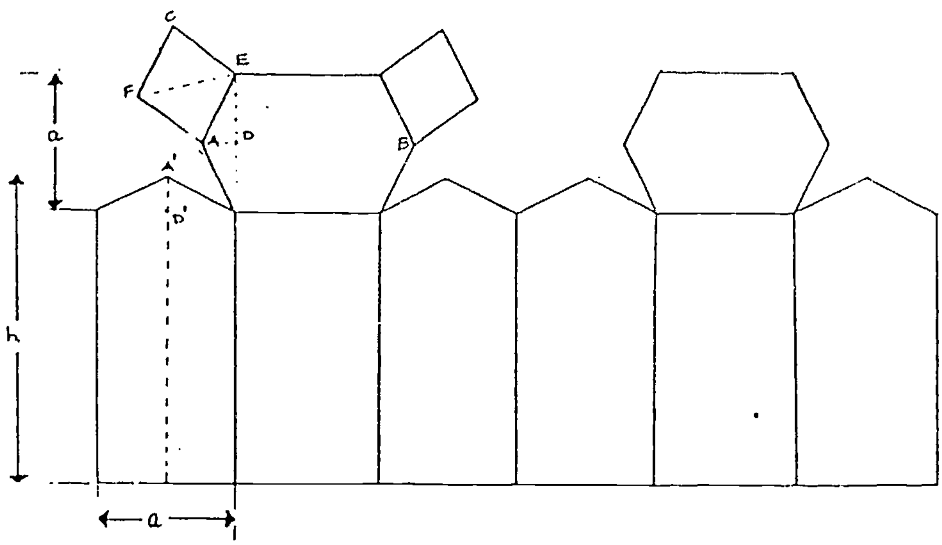
$$A'(x) = -3a + 3a\sqrt{3} \cdot \frac{x}{\sqrt{x^2+a^2/4}} = 0$$

i.e. $\frac{\sqrt{3}x}{\sqrt{x^2+a^2/4}} = 1$ i.e. $3x^2 = x^2+a^2/4$ i.e. $x^2 = a^2/8$ i.e. $x = \underline{\underline{\frac{a\sqrt{2}}{4}}}$

This gives $tg\theta = \frac{a}{x} = \frac{a}{\frac{a\sqrt{2}}{4}} = 2\sqrt{2}$ i.e. $\underline{\underline{\theta = 70.5288^{\circ} = 70^{\circ}32'16''}}$

Here too there have been other theories than 'wax economy' to explain the shape of the surface where the bee cells meet. Buffon (fl. 1750) did experiments to show that when cylindrical stacks (spherical tops) are deformed through pressure, they give exactly the rhombic dodecahedral shape.

Fejes Toth has even shown that by constructing bee cells differently, with a shape 'cut open' like below, the bees could save a 'wee bit' of wax ($\approx$ 0.009 a^2 by a computation):



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The Primary Science Project in Norway

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Introduction

The Primary Science Project began in Norway in the Fall of 1986 with the goals of improving the quality of science at the primary level through classroom research and curriculum development. The current problems associated with primary science in Norway are also problems associated with gender. We know that girls and boys enter the primary classroom with different experiences and attitudes towards science. We also know that the vast majority of primary teachers are women who themselves have come through a system that encourages boys more than girls to participate in the sciences.

The University of Oslo has a long tradition of studying the issues involving science education and gender issues related to science education. The Primary Science Project draws on this background beginning with the 'Girls in Science' project (Lie and Sjøberg, 1984), the GASAT conference held in Norway (1983), and most recently the National Version of the Second International Science Study (Sjøberg, 1986). A recent study of the current crisis in the recruitment of teachers to science teaching also serves as a basis for the project (Horsfjord, 1986).

This paper is about the Primary Science Project in Norway, beginning with a description of the Norwegian educational system and the placement of science in the curriculum. The development of science curriculum materials takes as its starting point the existing set of conditions found in schools. Classroom research serves as the basis for a clear understanding of what kinds of changes are possible in teaching science at the primary level.

The Norwegian Educational System

Norway is one of the Scandinavian countries in the northern part of Europe with a population of 4.1 million people. It is geographically a very long country with many different climates and environments. Because of the geographical variety found in Norway, one may find schools ranging from small, one-room schools housing 6 pupils from grades 1-6, to large city schools housing grades 1-9 with over one thousand pupils.

See figure 1 for a summary of the Norwegian educational system.

Primary and secondary schools

Compulsory education is 9 years from the age of 7 to 16. It is usually divided into a *primary* level, grades 1-6, and a *lower-secondary* level, grades 7-9.

A national curriculum describes, in detail, the subjects to be taught at the primary and lower-secondary school. Each subject in the curriculum is provided with goals and objectives, a timetable and content areas to be covered. The result of a national curriculum is that

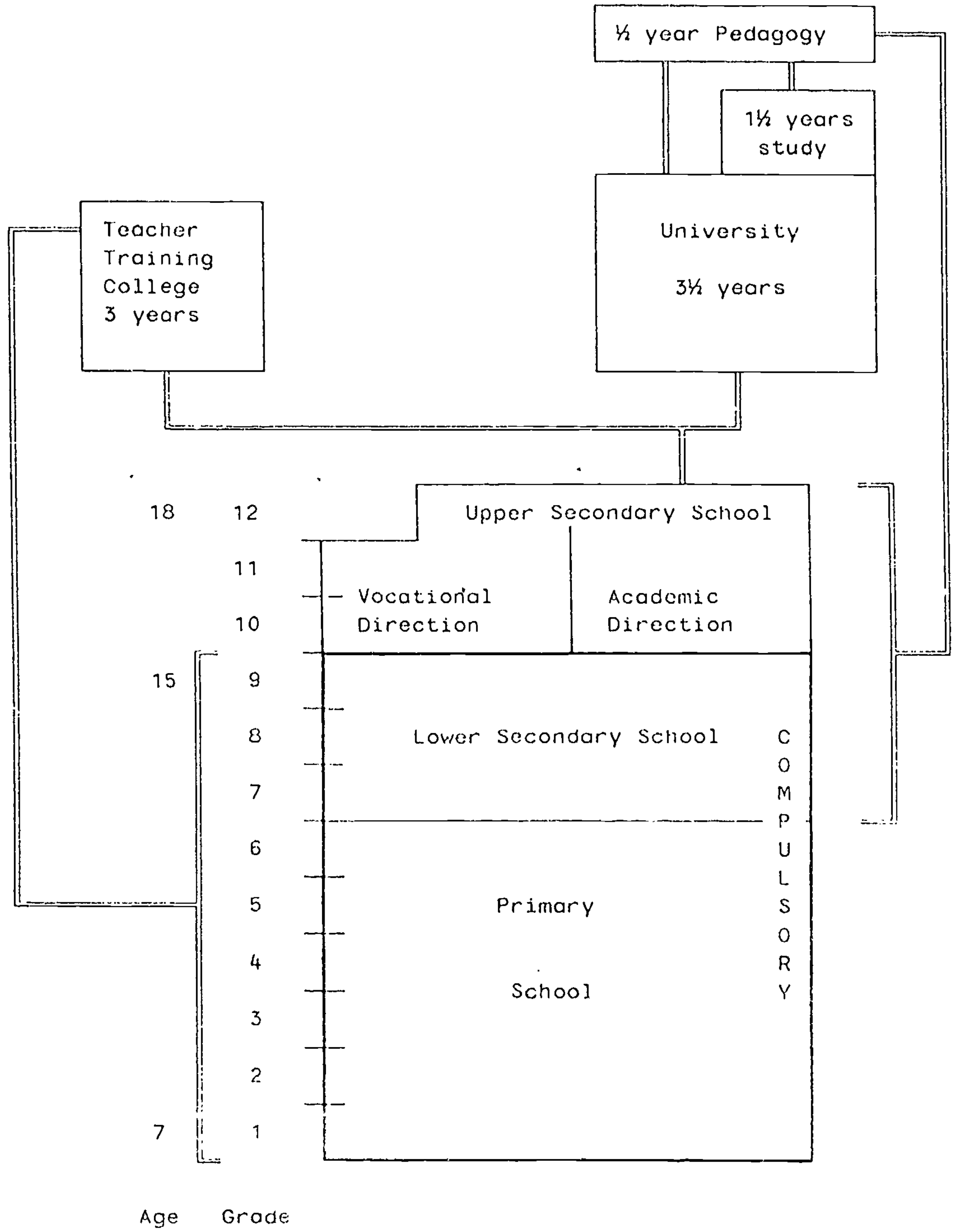


Fig. 1 The School and Teacher Education System in Norway

teachers throughout Norway are more or less teaching the same subjects and content for each class level.

Educational materials are written using the national curriculum as a resource and guide. They are approved by the Department of Education according to their adherence to the national curriculum and their adherence to gender equality regulations. Blatant sex discrimination in educational materials is not acceptable.

Teachers in Norwegian schools have a limited degree of choice within the curriculum with regards to interpretation of content matter and when subjects should be taught. At the primary and the lower-secondary level there is a strong dependency on the textbook as a guide to teaching.

Pupils remain together in the same class for the first six years of their education. One teacher will often follow the same class of pupils from grades 1-6 and then return to grade 1 to begin the cycle again. It is forbidden to group pupils from grades 1-9 based on ability level. The Norwegian school system places a strong emphasis on the social structure of the primary class. Pupils of all academic abilities, staying together over a number of years, is considered an important aspect in a child's social development.

The *upper-secondary* level is not compulsory. It is divided into a vocational direction and an academic direction of study under one administrative system. The academic direction gives entrance qualifications to the university and other institutions of higher education. Forty per cent of all pupils take the academic direction, and of these 56 per cent are girls and 44 per cent are boys. The other 60 per cent go on to vocational school with a small percentage directly entering the work force.

The first year of the academic direction has a comon curriculum which, among other things, includes science, mathematics, social science and language. Pupils choose an area of concentration during the last two years of study in either science, social studies or language.

Teacher education

The general rule is that teachers enter the profession from either a teacher training college or the university. Completion of the upper-secondary level is a requirement for entrance in most cases.

A. Teacher training colleges are a 3-year tertiary education. These colleges prepare teachers for grades *1-9*, giving them a general education in many different subject areas. There is a strong concentration on pedagogy and required courses in Norwegian and religion. Students themselves choose the subject areas within the curriculum on which they will concentrate.

B. University studies plus a half-year practical pedagogical training gives a student the qualification to teach in specific subject areas between grades *7-12*. University education may be a basic degree (3 1/2 years) or an advanced degree (additional 2 years). Most students receive qualifications to teach in 2-3 school subjects after completion of a university degree.

The situation at the secondary level (grades 7-9) is such that teachers from teacher training colleges and the university compete for the same jobs. The university-trained teacher is prepared with a strong subject background whereas the teacher from the teacher training college has a more general subject background with an emphasis on pedagogy.

Science in Norwegian schools

Science at the primary level

In the primary school (grades 1-6), science is not taught as a separate subject. Science is taught as a part of an integrated subject including social studies, geography and history. The reality is that integration means nothing more than a collection of the four subjects within the same book. According to the national curriculum, pupils in grades 1-3 should spend 2 out of a total of 17 hours per week on this integrated subject. Pupils in grades 4-6 should spend 6 out of a total of 27 hours per week on it.

Teachers at the primary level have little to absolutely no science education beyond their first year of upper secondary school (age 17). Primary teachers are educated only at teacher training colleges where there is a strong concentration on pedagogy. In the current system the only required subjects for all students are religion and Norwegian. Students have free choice when choosing other subject areas for concentration, making it possible, and often the rule, for primary teachers to complete their teacher training with no science education.

The majority of primary teachers in Norway are women in part-time positions. While they were students at the upper-secondary school, these future teachers usually specialized in the social sciences and language before entering teacher training colleges. They begin teaching at the primary level, where a national curriculum expects that they be capable of teaching science topics. Without an adequate preparation in the sciences they lack the confidence and knowledge necessary to teach simple science topics.

Science at the lower-secondary level

At the lower-secondary level (grades 7-9), science is taught as separate subjects, including physics, chemistry and biology, for 3 out of a total of 30 hours per week. Pupils take science for each of the three years of lower secondary school. In most schools, science is taught by one teacher with one textbook in physics/chemistry and one textbook in biology. The newly-adopted national curriculum in Norway states that science at this level should be taught as an integrated subject with a concentration on themes. It is unlikely that textbooks adopted in the future will be divided according to separate subjects.

Teachers at the lower-secondary level come from both teacher training colleges and universities. Science teachers from teacher training colleges have a strong concentration in pedagogy and some extra qualifications in science (usually between 1/4 and 1/2 year of science). Teachers from the university have a degree in the sciences with only 1/2 year practice and pedagogical training. There are very few teachers at this level who have an adequate background in all of the three sciences, physics, chemistry and biology, even though they teach a science course that includes the three subjects.

In the ideal situation, teachers from the two different educational backgrounds should have skills to offer to each other. The actual situation is that teachers from the two different educational backgrounds do not work closely together.

Science at the upper-secondary level

At the upper-secondary level (grades 10-12), pupils in grade 10 in the academic direction take a common science course for 5 hours per week. The course is most often taught as three separate subjects, divided between biology 2 hours, chemistry 2 hours and physics 1 hour. A newly-adopted curriculum for the upper secondary level states that the course should be taught as an integrated course. Those pupils who choose to concentrate in the sciences at grades 11-12 may choose between a variety of options including mathematics, physics, chemistry and biology.

Teachers at the upper-secondary level have a university degree which gives them qualifications to teach within their subject areas. Most teachers at this level are qualified to teach 2-3 different school subjects. As is the case at the lower-secondary level, few teachers have the qualifications to teach all three of the sciences which are currently presented in the first-year science course. In half of the upper-secondary schools in Norway, the course is taught by one teacher.

At both the lower- and upper-secondary levels, the number of male science teachers far exceeds the number of female science teachers. At the lower-secondary level, women in full-time positions are only 19 per cent of the total number of science teachers. At the upper secondary level, women teaching science in full-time positions are only 16 per cent of the total (Sjøberg, 1986).

Recruitment of science teachers

The situation today with regard to recruitment of science teachers is almost critical. There has been a drastic decline in the number of university-educated science students entering the teaching profession. A similar decline has occurred within teacher training colleges. Within the teaching profession itself, we have also seen a decline in the number of practicing science teachers as they seek new and better paying jobs in business and industry.

The result of these recent trends may be that science at every level is taught by unqualified teachers. A nation whose economy is strongly based on technology cannot afford such a crisis situation. As in the United States, part of the solution to this growing problem is to increase salaries and to improve the working environment. Another long range remedy is to increase pupil interest in the sciences and to encourage more pupils to pursue science teaching careers.

Why a Primary Science Project

After a close examination of existing conditions in science education, a decision was made to begin a research project which would concentrate on science at the primary level. A long tradition of research in science education at the University of Oslo provided a strong base for further work. The 'Girls in Physics' project (Lie and Sjøberg, 1984) and the National Version of the Second International Science Study (Horsfjord, 1987 and Sjøberg, 1986) give evidence to support the view that many of the problems teachers and pupils experience with science in Norwegian schools are problems that emerge very early in the educational system.

Initial observations of primary classrooms in Norway and interviews with teachers also provided reasons for working on science teaching at the primary level. A description of those observations follows, together with a description of research findings which point to the need to implement change at the primary level.

Student attitudes toward science

A national version of the Second International Science Study conducted in 1984 clearly indicated that children begin as early as 4th grade (10 years old) to form attitudes about science and scientists (Sjøberg, 1986). If we consider gender, girls have more of a tendency to form negative impressions of scientists and science than boys. The trend becomes even stronger as girls progress towards the upper secondary level.

Student experiences in the sciences

Girls and boys at the primary level come into the classroom with a different set of experiences (Sjøberg, 1986). The existing science curriculum often favours those experiences which boys share while failing to build on activities typical of girls. This clearly puts young girls at a disadvantage in existing science lessons and may be responsible for creating negative impressions toward science.

Early intervention is needed to create for girls a more positive environment for learning science. This can be accomplished by including more 'girl-friendly' examples in curriculum materials and by giving girls the opportunity to share in those activities that are typically boy-dominated.

Both girls and boys need to be given the opportunity to 'shine' in those activities and behaviours at which they are best. At the same time, they should be given opportunities to learn new behaviours and share in each others' experiences. A well-designed curriculum must pay attention to these differences and provide enough variety to encourage all types of pupils to participate and enjoy lessons.

Primary teachers

Teachers at the primary level have little or no formal science education and yet are expected to teach science topics. Teachers often lack confidence in their ability to teach science when they themselves are not able to answer questions and understand basic concepts. The result is that science is often a neglected part of the elementary curriculum.

An overwhelming majority of all primary teachers in Norway are women, making the problems associated with primary science also problems associated with gender. Women, more than men, tend to underrate their own abilities in science performance, with the result that fewer women study the sciences and fewer female primary teachers teach science topics.

Science, a neglected part of the curriculum

Because science is a part of an integrated subject at the primary level, it can easily be neglected in the curriculum. Science is found in the same book together with social studies, geography and history making it easy for teachers to hop over those chapters dealing with science topics.

The books written for this integrated subject are most often written by male authors who themselves have little formal training or understanding of the sciences. Science topics are often presented as difficult, abstract and old-fashioned.

If we are to teach science at the primary level, as the national curriculum states, we must provide pupils and teachers with materials that they are able and willing to use. Science at the primary level does not need to be difficult to teach. Activity-based materials using simple equipment can make science enjoyable for both teachers and pupils.

The need for science in our schools

It is clear that science and technology are playing an important role in today's society and that schools must take an active role in preparing pupils to participate in that development. Providing positive science experiences at the primary level is necessary if we are to encourage more children to continue their science studies, thus creating a science-literate society. Early and positive intervention is also necessary if we are to encourage girls as well as boys to seek careers in the sciences.

The Primary Science Project in Norway

The primary science project began in the fall of 1986 with the goals of producing and evaluating curriculum materials for grades 4-6 and conducting research on the primary science classroom. The project is funded through the Department of Education, with additional funding from the Committee on Gender Equality, and the University of Oslo.

It is the first time that such an extensive research and development project has been conducted at the primary level in Norway. It is also the first time that gender research is placed within the context of a subject area at the primary level.

The main research team is made up of personnel from the Centre for Science Education, University of Oslo. A full-time teacher is also employed through external funding to coordinate the project. Two primary schools with a total of 12 teachers work closely with the research team in the development of materials, classroom trials and classroom research.

See figure 2 for a model of the project development.

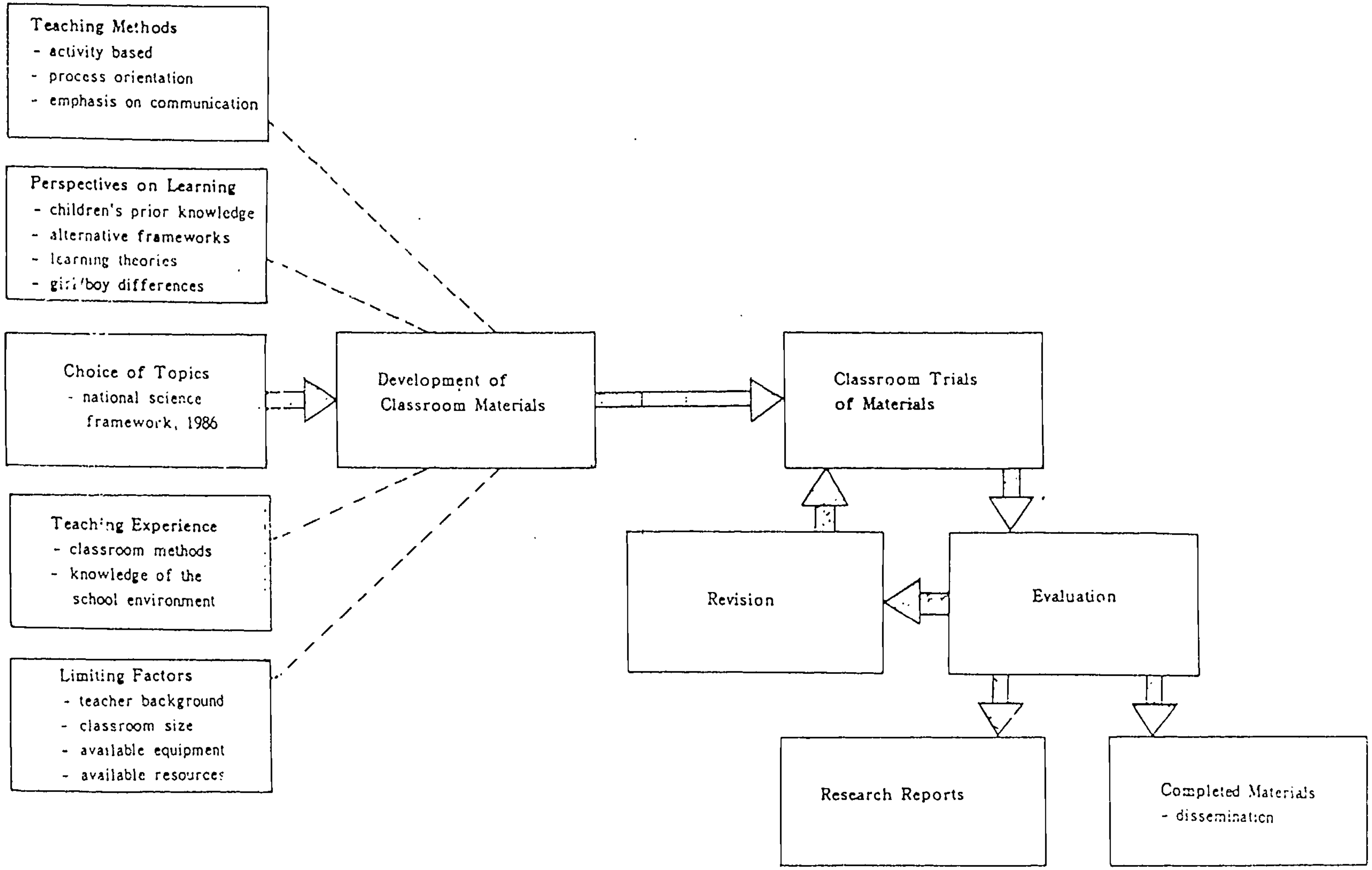


Fig. 2. The Primary Science Project

Curriculum materials

Curriculum materials are developed in the form of topic workbooks which include pupil activities, a teacher's guide for each activity and a pupil reader. The target group of pupils is grades 4-6 (10-13 years old). Each topic workbook is designed with activities for 6-10 lessons. We are guided in our choice of topics by a newly adopted national curriculum. Within this curriculum we choose topics that lend themselves to activity based lessons with the aim of encouraging pupil interest and participation.

See figure 3 for an example of curriculum materials.

Pupils activity worksheets. These are developed to instruct pupils in the activity and to provide stimulating questions and further activities. To aid in understanding, pictorial information is included as an important component of the worksheet. For most activities, it is recommended that pupils work together in groups of 4-5.

Teachers' guide. Each pupil activity worksheet has a corresponding guide for teachers to follow. The guide describes the activity and provides information that will aid the teacher in discussion. Actual questions from pupils are provided with some suggested answers. When applicable, ideas for integration with other subject areas are suggested. Particular emphasis is given to the development of writing skills.

Pupil reader. A short book, written for each topic, provides additional written information for pupils. Emphasis is placed on connecting the science activity to theory, history and everyday applications. When applicable, information is provided on careers within the scientific area. As with all materials, the pictorial materials pay particular attention to eliminating stereotypical gender role models.

Evaluation of materials

Evaluation of the materials is conducted in two phases:

Phase 1. 12 teachers from grades 4-6 from two local schools try the materials in the first version. Two observers are present for the lessons with one observer taking notes and the other taking video recordings. Short, informal interviews with teachers follow the lessons.

Phase 2. Teachers throughout Norway are given the second version of the materials to use independently in their classrooms. Written evaluation forms for each lesson are provided for teacher comments. When possible, a member from the research team visits the school during at least one of the lessons and informally talks with the participating teachers after the lesson.

After both phases of evaluation, the research team makes revisions of the materials based on classroom trials and teacher interviews. Our experience to date is that revisions are extremely important and necessary. Each phase of the evaluation process provides new information from teachers and pupils that is then incorporated into a new revision. We cannot overemphasize the importance of classroom trials in providing valuable information for the revision process.

Classroom research

An important component of the Primary Science Project is classroom research that will help to describe the primary environment. We are interested in describing the social interactions between pupils and teachers so that we can better understand what is necessry and what is possible for making a successful science lesson.

We are specifically looking at gender differences between pupils and teachers with reference to the science lesson. Our observations will hopefully guide us in the development of those methods most suitable for the primary science lesson. We need not only to involve young girls in scientific activities but also to involve teachers in the teaching of science.

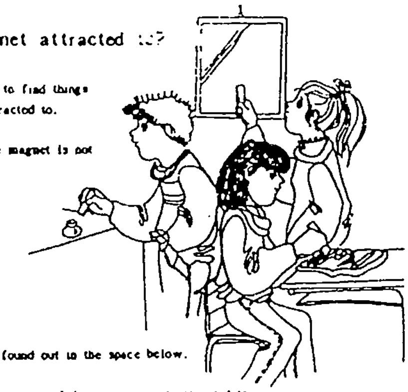
Magnetism Workbook, Activity 1

Pupil activity worksheet

What is a magnet attracted to?

Use your own magnet to find things that the magnet is attracted to.

Try to find things the magnet is not attracted to.



Write what you have found out in the space below.

A magnet is attracted to	A magnet is not attracted to

What is a common characteristic for everything a magnet is attracted to?

Teacher's guide

What is a magnet attracted to?

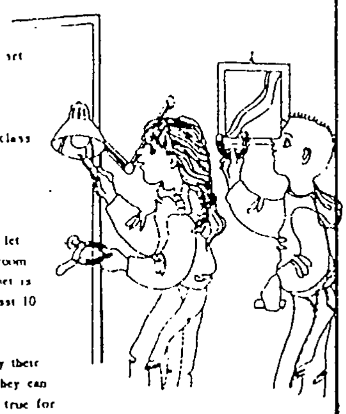
In this activity pupils will be introduced to a bar magnet. They will try to find out what a magnet is attracted to, and not attracted to. Pupils will also learn the names of some common materials, especially different metals.

EQUIPMENT

- bar magnets, preferably a class set

ACTIVITY

This activity will take about one class lesson.



• Experimenting

After the magnets are passed out, let your pupils go freely around the room trying to find out what their magnet is attracted to. They will need at least 10-15 minutes for experimenting.

Pupils should be advised not to try their magnets around watches because they can ruin the mechanism. The same is true for diskettes and cassettes which are magnetized and can be ruined by the magnetic field surrounding a magnet.

As your pupils experiment around the classroom, try to listen to the words they use to describe the way a magnet is attracted to objects. You will often hear them say, "The keys are magnetic". The keys are really not magnetic. Rather, it is best for them to say that the magnet is attracted to the keys.

The activity worksheet may be distributed to pupils after they have completed their experimenting.

• Discussion

It's a good idea to have a class discussion on the activity after children have completed their activity worksheets. A written summary on the blackboard has proven to be a good idea.

Children will soon find out that the common characteristic for the things a magnet is attracted to is that they are metals, most often containing iron.

Metals magnets are attracted to	Some metals a magnet is not attracted to
iron nickel steel (alloy of iron & carbon)	gold silver copper tin zinc aluminum brass (alloy of copper and zinc) bronze (alloy of copper and tin)

Most of the things children find that a magnet is attracted to contain iron. Magnets are also attracted to steel because it contains iron.

Nickel is very uncommon in the classroom. It may be interesting to mention that small amounts of nickel are often found in jewerly and cause serious skin allergies.

• Let's Go Further

Here are some questions you may use for further discussion or as homework.

- Do you have magnets at home?
- What do you use magnets for at home?
- Can you find several things at home that a magnet is attracted to?
- Have you seen magnets used other places?

Many pupils will first say that they do not have any magnets at home. After a closer investigation they find many different uses for magnets in their home (kitchen cabinet doors, refrigerator doors, toys etc.)

Fig. 3. Example of pupil activity worksheet and corresponding teacher's guide

The use of video recordings during the science lesson has proven to be a rich source of information on social interactions between pupils and teachers. Video tapes give a permanent record of observations and are used together with written comments to record the events that occur during the science lesson. They also provide a means of external evaluation and validation when viewed by researchers external to the project.

We are also interested in finding out why some teachers have success with science at the primary level when others do not. Are there certain characteristics these teachers share that can be documented and exploited? What contributes to a positive school environment for teaching science? The next two years of the project will place a strong emphasis on these research questions.

What have we learned

We have used the first year of the three-year project to develop a curriculum model for materials and to conduct extensive classroom observations. Our experiences and observations are constantly giving new insights into the primary classroom and helping us to determine what is possible for primary science. It is our hope that others working in the area of primary science will find the following comments both informative and perhaps generalizable to other situations.

Overcoming the fears

If you ask the average primary teacher if they would like to teach a unit on primary science, their first response is likely to be a negative one. There exists a genuine fear in teaching science topics, a fear that does not exist in other subject areas. A primary science curriculum will only be successful in Norway by recognizing those fears and then taking measures to overcome them.

The first requirement for implementing a successful primary science curriculum in Norway is to provide teachers with materials that give them the confidence and the willingness to 'jump in and get their feet wet!' Teachers are clearly asking for a teacher's guide that will provide them with detailed instructions on each activity and enough theory to grasp *simple* scientific concepts.

Our answer was to design a teachers' guide that places an emphasis on the teacher as both a guide in the lesson and a learner along with his/her pupils. Each pupil activity is provided with a detailed teacher's guide that:

1. Describes the activity;
2. Provides ideas for methodologies on how to carry out the activity;
3. Provides possible questions pupils may ask and answers to those questions;
4. Provides just enough theory to put teachers in a learning situation together with their pupils; and
5. Provides ideas and activities on how the lesson may be used in connection with other subject areas.

Our experience throughout the trial evaluations has been that teachers ask for even more information in the teachers' guide than we originally provided. Teachers are very dependent on the teachers' guide, which seems to give them that extra bit of self-confidence they need to 'jump in and get started'.

The second requirement for a successful science curriculum is to provide teachers with support in their school environment. Our experience has shown that a *group* of teachers in one school will have more interest in teaching a new curriculum than a single teacher in a school. The model we have found to be most successful is one where the principal or an interested teacher takes the initiative to involve a group of teachers in teaching our curriculum materials.

The advantages of this group model are that teachers can work together in a joint effort and give each other support. After trying out activities they can discuss them with each other, share experiences and give new ideas. It is also an efficient use of time for the assembling of equipment. One teacher can be given the responsibility of gathering a classroom set of equipment that may then be used by the other teachers involved in teaching the curriculum.

The third requirement for a successful science curriculum is early intervention into teacher education. As we have mentioned several times before, teachers at the primary level are not required to take science at teacher training colleges. The only required courses to date are Norwegian, religion and pedagogy, with teachers themselves deciding areas of further concentration. An educational system that requires teachers at the primary level to teach science topics and that does not, at the same time, adequately prepare teachers at teacher training colleges is doing an injustice to teachers.

The introduction of a non-threatening science curriculum at teacher training colleges may give teachers just enough confidence to take an interest in the sciences at the primary level. We do not ask teachers to be experts in the sciences; rather, we ask them to participate in the learning process together with the children. A primary teacher deserves to be given enough science knowledge to understand simple science topics and to know about available resources that can be used in a science programme. To give teachers the permission to redirect questions back to their pupils and to work with their pupils in the discovery process may be the most important lesson our future teachers can learn in teaching primary science.

Another component of teacher education is in-service training. Once again, we will be working on a model that involves groups of teachers from individual schools coming together to learn about our materials and methods. We believe that, whenever possible, teachers should be given the opportunity to try out the materials themselves before presenting them to their pupils. Any experience with science outside of the classroom provides teachers with an added amount of self-confidence.

With regard to overcoming the fears of teaching science, our most positive sign to date is that the teachers we have been working with throughout the evaluation trials keep asking us for more materials. Once through a topic workbook they suddenly realize that they have successfully taught science and that they and their pupils have enjoyed it as well.

Does gender make a difference?

Our initial classroom observations were made with eyes toward gender behaviour during the science lesson. We were interested in knowing whether teachers give girls and boys different kinds of attention, and whether children themselves have defined gender roles while participating in group work. We were also interested in observing whether gender differences among teachers made a difference with regard to pupil interaction.

We found obvious differences between the behaviour patterns of boys and girls that have been reported numerous places before. Boys in all of the class levels studied (grades 4-6) clearly received more attention than girls. Boys raised their hands more often and were more likely to be called on by their teachers. In addition, boys made more noise and were most often recognized for negative behaviour. Girls seemed to accept a limited amount of noise during the experimental phase of the activity but later needed the quiet and structure of a controlled classroom.

A closer look at just who answers questions reveals that only a limited number of pupils in a classroom participate in answering questions. With regards to girls, there are usually only a very few individuals who answer most of the time. The total number of boys answering questions is usually larger than the total number of girls.

A small change in methodology has shown some success in encouraging more girls in the question/answer sessions with teachers. When teachers begin a lesson by asking pupils what they know about a topic, the answers are dominated by male pupils. In many cases, boys have experiences outside the classroom that their female counterparts have never had. If, instead, we allow children to begin the activity at once, with little introduction from the teacher, all children have access to the experience. A discussion by the teacher after the activity, rather than before, encourages more participation by girls.

We have also observed that teachers who have worked with us in the two experimental schools have themselves begun to think about their relative interactions with boys and with girls. They are consciously trying to call on all pupils during a discussion and in some cases trying hard to increase the activity level of female pupils during lessons.

We have stressed the use of groups in our science activities. In many classrooms, pupils and teachers are not as used to this form of working as we originally thought. Learning to work with other pupils and accepting a somewhat higher noise level in the classroom during the experimental phase of the activity has been. a part of the learning process with our materials.

Our observations on group work show that when given free choice, girls and boys tend to group themselves in single sex groups. When teachers have placed pupils in mixed groups there have been some problems with boys and girls accepting that they must work together.

After one year, we cannot offer any clear conclusions as to which type of group structure (mixed or single-sex) is more advantageous. So much of the group structure is dependent on the individuals in the group. We do see a general pattern that girls work methodically through the activity worksheet, reading first before assembling equipment, whereas boys begin working and gathering equipment much faster, paying less attention to the worksheet. These differences should not be a major problem if we accept that they exist and work towards solutions that support both sets of behaviours.

To overcome possible problems between the passive and the assertive children working within a group, we must work on methods that will encourage both to participate in the activities. In some activities, it may be important to provide enough equipment so that every pupil in the group is allowed to have their own. In other activities, it may be important to provide tasks to each member of the group. In all cases, it will be necessary to alert teachers to the problems that can be associated with group work so that unwanted, aggressive behaviour can be discouraged.

We have observed similarities and differences between the three male and nine female teachers at the experimental schools. All teachers have the same tendencies to give increased attention and awareness to boys, even when they consciously recognize and talk about the need to increase their attention towards girls. It seems to be a pattern that is extremely difficult to change. Differences occurred when teachers interacted with groups of pupils. We observed a tendency for male teachers to give more practical help to girls and, in some cases, actually take equipment away from them to show them how to properly use it. Male teachers more often used verbal commands with boys, telling them answers when questions were asked. These trends were more apparent with older pupils.

In our interviews with teachers, male teachers gave the impression of having more self-confidence in teaching our science topics than their female counterparts. Female teachers asked many more questions about their own performance and showed a higher interest level in the project. The anxieties female teachers shared in teaching science often resulted in increased preparation and careful lesson planning. A primary science curriculum must take these fears into account when writing materials and developing in-service courses.

Creating an environment that gives equal opportunities to girls and boys is not an easy task. Teachers and children enter the science classroom with different experiences that are often gender-dependent and based on a long history of social behaviour. We will be studying girl/boy interactions more thoroughly in the next years of the project and hope to begin to find some solutions to existing problems that may have an impact on improving science education for both girls and boys. An improvement in gener-related issues in the sciences will hopefully be generalizable to other areas of the curriculum as well.

The Primary Science Project will continue to work over the next two years on the research and developmental issues relating to primary science in Norway. We would appreciate any comments on the project and are more than willing to share our further experiences.

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The School and Healthier Living

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Introduction

Primary schools are one of the most prevalent institutions in communities around the world. People want the best for their children and they hope against hope that the school will provide it. This includes wanting them to grow up healthy.

Health education in most schools is, however, at worst ignored and, at best, seldom reflects local needs and priorities. Nevertheless, despite numerous problems including staffing, equipment, and facilities, the primary school still remains the natural source through which the health of school children and the communities in which they live could be improved.

The Indonesian government appreciates this potential of primary schools and has established the School Health Service organized co-operatively by the Departments of Health and Education. Currently, the School Health Programme is being set up in all primary schools throughout Indonesia. The introduction of the programme to individual schools is preceded by a workshop in which teachers from schools in one area learn about the organization and contents of the programme. Subsequently, it is their responsibility to initiate and develop the health programme in their respective schools.

Despite this giant effort, many schools have not yet succeeded in developing creative programmes. Therefore, the Indonesia Sejahtera Foundation has attempted to record the experiences of several schools which have been able to develop imaginative school health programmes based on local needs. We trust that these experiences, as related in this paper, will provide inspiration for teachers and others who see the potential of primary schools for improving the health not only of the children entrusted to their care but also of their families and of the communities of which they are a part.

The School Health Programme in Primary School X as a Case

Primary School X is a government school set in a complex of schools in a hamlet on the edge of the city of Solo, Central Java. The office of the Sejahtera Indonesia Foundation is situated in the same hamlet.

In this hamlet there is a comprehensive community health programme which is actively supported by the local community. This programme was initiated by the Sejahtera Indonesia Foundation. Staff of the Foundation considered that a School Health Programme would add a new and valuable dimension to the community health programme. The steps and methods used to achieve this were as follows:

Step 1. An active member of the Parents' Association of the school was encouraged to discuss the idea of a School Health Programme with the teachers. The teachers, attracted to the idea, decided in a teachers' meeting to begin a School Health programme at their school.

Step 2. The decision of the teachers was then discussed at a meeting of the Parents' Association, which agreed to give their support. It was also suggested that the teachers make contact with the Sejahtera Indonesia Foundation.
On making contact with the Foundation, the decision was reached to hold a meeting between the teachers, representatives of the Parents Association and staff of the Foundation. At this meeting, several decisions were made on the implementation of the School Health Programme:

a. Before beginning the Programme, the teachers should be trained.
b. The Foundation would assist with the training.
c. Primary School X would be responsible for the arrangements for the training, including permission and costs.

Step 3. These decisions were conveyed to the District Office of the Department of Education, which agreed to give its support. They also made the suggestion that the training should not be limited to the teachers of Primary School X but that teachers from the other schools in the complex should also be included.
After receiving approval from the Education Department, the head of Primary School X wrote to the Municipal Health Service about the proposed training. A copy of this letter was sent to the Sejahtera Indonesia Foundation.

Step 4. Upon receiving the copy of this letter, staff members of the Foundation contacted the Municipal Health Service. They discussed with the Health Service how they could co-operate in meeting the request of the primary school for training in line with government policy on School Health Programmes. The Health Service provided the Foundation with information on the methods and content of the training and the required administration.

Step 5. Based on the result of the discussions with the Health Service, details on the training were drawn up in a meeting between the Foundation and the teachers who would be trained
It was decided that:

- the training would be held twice weekly after school;
- the training would be held in the school building;
- contents would include:
  - skills,
  - knowledge, and
  - development of attitudes required by teachers implementing the School Health Programme.
- all costs would be covered by the participating teachers;
- the Foundation would not charge for the training.

Note: The training team drew up the curriculum based on the needs of the participants and attempted to present the material as a unit. Training methods included discussion, experimentation, structured games, etc. The final exercise for the participants was to plan how they intended to implement the School Health Programme. The curriculum was as follows:

a. Discussion on what the training was to achieve and how	1 session
b. Community health	1 session
c. Minor illnesses and treatment	3 sessions
d. Practical nutrition	2 sessions
e. Child development	1 session
f. Environmental health	1 session
g. Environmental health	1 session
h. Sports and its relationship to health	1 session
i. Audio-visual aids and their uses	2 sessions

j. Practical agriculture and animal husbandry — 2 sessions
k. Population education and its relationship to family planning — 1 session

Step 6. The training was carried out as planned. It lasted 2 months, drawing to an end with all the participants planning the programmes they intended to carry out in their schools.

The training was concluded with a closing ceremony which was attended by officials from the Municipal Health Service and the District Office.

Step 7. The trainers, acting as consultants, made contact with the teachers to discuss with them the implementation of their plans. In this way, a School Health Programme was quickly set up in Primary School X, with the full support of the Parents' Association and the District Office.

Step 8. With the support of the Parents' Association, the School Health Programme had no problems in terms of organization of finance. However, follow-up was considered necessary and the division of tasks was as follows:

a. Education Department (District Office)
   - routine visits
   - progress reports on activities
   - expansion of the programme to other schools.
b. Municipal Health Service
   - provision of technical assistance
   - help with equipment and mecidines
   - occasional visits
   - progress reports.
c. Sejahtera In[illegible]esia Foundation
   - visits
   - encouragement of new activities
   - increasing skills of teachers if required
   - taking visitors to see the School Health Programme so that they could set up a similar programme.

Step 9. The success of the programme is being measured according to the following criteria:

a. Decrease in the incidence of illnesses, in terms both of the numbers of pupils and to the lengths of illnesses.
b. Decrease in the incidence of severe illnesses.
c. Improvement in the cleanliness of school rooms and the school yard.
d. Increase in students' understanding of nutrition.
e. Increased use of the school yard for agricultural and animal husbandry activities.
f. Increased funds from pupils' parents for use as health funds for the pupils and other activities.
g. Closer relationship between the school, teachers and Parents' Association.
h. Ability of the pupils from the 5th and 6th classes to responsibly examine the health of those from the 1st to 4th classes.
i. Improved health of the pupils as reflected in improved academic performances.

Step 10. Expansion of the Programme to other schools has been carried out by teachers using the following methods:

a. Motivating other teachers by giving information about their School Health Programme at regular district teachers' meetings.
b. Providing written reports to the District Office of the Education Department to encourage the Department to spread the ideas to other schools.

Expansion of the programme to the community has been carried out in the following ways:

a. Teachers have encouraged their students to carry out what they have learned about health and nutrition at home, particularly as related to improving the health and nutrition of children under 5 years of age.
b. Teachers are functioning as voluntary health workers in the community to spread ideas and encourage activities aimed at healthier living.
c. Teachers are encouraging the leaders and members of the community to carry out activities aimed at improving the health and nutrition status of the community.

School Health Programme Activities

1. *Personal hygiene - developing healthy habits*
   a. Regular examination of clothes, nails, hair, feet, etc. by class teacher or older child.
   b. Demonstrations on brushing teeth, cutting finger nails, bathing and washing hair, removing hair lice, etc.
   c. Brushing teeth together in grades 1 and 2.

2. *Physical examination and treatment*
   a. Routine weekly examination of general health by class teachers or children in higher classes.
   b. Measurement of weight and height every 3 months.
   c. Medicine box for medication of minor illnesses by trained teacher or senior pupils (under supervision).
   d. Referral to the local clinic if considered necessary (expenses are covered by school health funds).
   e. Pupils learn how to make and dispense oral rehydration for any member of their family suffering from diarrhea.

3. *Healthy schools environment*
   a. Sweeping classrooms and school grounds.
   b. Keeping toilets clean and supplied with water.
   c. Keeping the well and its surroundings clean.
   d. Provision of boiled drinking water by pupils.
   e. Pupils make a map of their village/or part of it. On it they mark health hazards, such as uncovered rubbish, stagnant water, etc. Encourage the pupils to discuss how they can overcome these problems.
   f. Pupils take note of the accidents which happen at home and around them. Encourage them to discuss how to prevent such accidents and implement preventive measures.

4. *Nutrition activities*
   a. Eating breakfast together once a week in grades 1 and 2.
   b. Cooking and eating together once a week in grades 3 through 6 in turn.
   Costs covered by: - rice brought from home
   - small subscription
   - vegetables from the school garden.
   c. Children visit the local market and note the foods sold there and their prices. Children draw up healthy, cheap menus, based on their observations in the market.
   d. Keep a school fruit and vegetable garden (in the school yard or on borrowed village land).
   e. Take care of small livestock, e.g., poultry, milking goats, sheep, etc.
   f. Open a school store which sells healthy snacks.
   g. Pupils can plant seeds of fruit trees, e.g., paw-paw, in cane containers or plastic bags at school. After observing their growth, they can be encourage to plant them and care for them in their garden at home.
   h. After learning about food and growth at school, pupils can be encouraged to make sure that their younger brothers and sisters at home get enough healthy food.

i. Pupils could detect children with vitamin A deficiency, e.g. those suffering from night-blindness. They could encourage these children to eat more dark green vegetables and yellow fruits.

5. *Health education*
   a. Mention as many aspects of healthy living as possible in all lessons.
   b. Give lessons on family welfare, e.g. on budgeting.
   c. Increase sporting activities.

6. *Economic activities*
   a. Establish a co-operative or credit union for students, to assist with purchase of school books, uniforms, etc.
   b. Establish a simple health insurance scheme with monthly contributions to cover costs of medicines and care at the clinic. Extra funds can be used as capital for a credit union or for other activities.
   c. Encourage students to open a saving account.

7. *Spread to community health programme*
   a. Teachers make visits to the homes of their pupils and discuss healthy living with parents.
   b. Teachers participate in village meetings and spread ideas on healthy living.
   c. Pupils participate in village improvement programmes, e.g. cleaning the roads, planting trees, etc.
   d. Teachers/pupils can distribute malaria tablets on a regular basis in malaria-infested areas.
   e. Pupils are encouraged to spread new information, etc. to their family, including younger siblings, e.g. on healthy snacks, on how to measure nutrition status with the Shakir strip.
   f. Teachers and others are trained as health cadre who promote activities aimed at healthier living in the community. Teachers can take the initiative for establishing this programme.

Many other activities could be developed through a school health programme. Let's be creative in working towards healthier pupils and a healthier community.

Conclusion

Through the School Health Programme, there are some significant results which are very fruitful and beneficial for students and the community:
- integration and inter-relationships among sciences;
- the sciences are translated into the practical and appropriate activities which fulfill the community's needs.
- the school takes on a role as an innovative agent for the community.

Why Teach Science in Primary Schools?

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In this paper I should like to explain my reasons for teaching science in the primary schools. But first I will tell a little about the Danish school system.

Compulsory education begins at the age of seven and lasts for 9 years; pupils can choose one extra year at the 10th level. They may start school at the age of six with a so-called 'kindergarten class'. We teach the subjects of physics and chemistry together - the same teacher for both subjects - with two lessons a week from the 7th level. Fewer girls than boys choose physics/chemistry at the 10th level, and fewer girls take the examinations after the 9th and the 10th level.

I have been teaching physics and chemistry in the Danish 'folkeskole' for the last 18 years, and during this time there has been only a little change in the girls' interests in and attitude to science, especially physics. When the girls start the subjects at the 7th level, many have already got the impression that 'physics isn't for them'.

I began seven years ago to study chemistry at the Royal Danish School of Educational Studies. I then had the opportunity to make some investigations in this area because here one has to study psychology and pedagogy in addition to chemistry. Then I made an investigation among all 7th grade students in the community where I am working. The design of the investigation was very close to 'Jenter og fysikk' and so were the results. Similar studies in other countries - England and the Netherlands - show the same results as well. In the following I shall mention some of the results.

Questions about pupils' interests

In the questionnaire used in the study, I included a number of topics which may be a part of the physics/chemistry teaching. The pupils were asked to indicate whether they found it important or exciting to learn about the matter in question. It appears that the pupils have distinguished between 'exciting' and 'important'. For example, well over half of the girls found it exciting to learn about the rainbow but few of them considered it important. A majority of the girls found a few (8 or 9) of the subjects, such as natural phenomena, additives to food, and pollution, exciting or important. See Tables 1 and 2.

Most of the students in the 7th class had learned about and/or worked with electricity in class during some time before the investigation was carried out and many of them indicated that electric current and electricity are important subjects at home but apparently not very exciting.

Experience within physical and chemical science

In a number of cases, the pupils were asked to indicate how often they had been doing this or that. Only a few activities, such as tape recording, usage of calculator, and photographing have been done by *both* girls and boys. Girls are experienced in domestic activities, boys in the activities that are often included in the traditional physics lessons. In general, girls are not as experienced as boys in the various activities. According to the boys' answers, there are only a few 'girls' activities' which have never been tried by boys. Boys generally 'try' more than girls.

Consequently, boys are much more experienced in technical fields, thus being better able to relate the theories of the physics teaching to their own experience. The pupils' opinions about what are 'girls' activities' and what are 'boys' activities' are surprisingly conservative (Table 3). However, the results are very much in line with what girls and boys actucally indicate regarding their everyday activities. However, I would like to point out that, although the computer is not indicated by the girls to be a pronounced 'boys' activity', far more boys than girls have been using it regularly.

Questions about attitudes

I also asked the pupils about their expectations concerning their future academic success in physics/chemistry. I found that girls had a low degree of self-esteem, expecting to find the subject of physics/chemistry difficult (Fig. 1).

The girls proved to be less interested in physics/chemistry than the boys (Fig. 2).

Conclusions and actions

My conclusion from the data is that the teaching of physics/chemistry ought to start earlier than in the 7th class. In connection with an investigation which I carried out last year with physics/chemistry teaching in a 4th and a 5th class, it turned out that even if both girls and boys were interested and absorbed in the material, a questionnaire showed that the pupils felt that to study to become engineers or technicians did not appeal to the girls. Consequently, with support from the Ministry of Education, I have started some experiments with a 3rd class. It is my intention that the class study subjects related to physics/chemistry until the normal start of these subjects in the 7th class. This may enable me to determine whether a change of the pupils' attitude to the subject will occur.

During this school year, as part of a biological subject, the pupils have, for example, worked with dissolution trials, with chromatography, and with tests with air. We have worked with the themes of 'wholesome food' and 'Greenland' because we got a new child in the class from Greenland. The girls of 3rd class do participate as eagerly in the trials and are as interested as the boys. Both boys and girls have, on their own, started to make experiments at home.

However, a difference has been found in the work of the boys and girls. The girls do pay very much attention to whether or not all group members are allowed to take part in the decisions and to touch the instruments. It will be interesting to see whether the difference in the socialization of girls and boys will become of importance as these pupils grow older.

The purpose of the present experiment is to try to influence pupils and parents over a long period of time in order to see whether we can change the generally traditional attitudes held by our pupils.

Fig. 1. How do you think you will do in physics/chemistry?

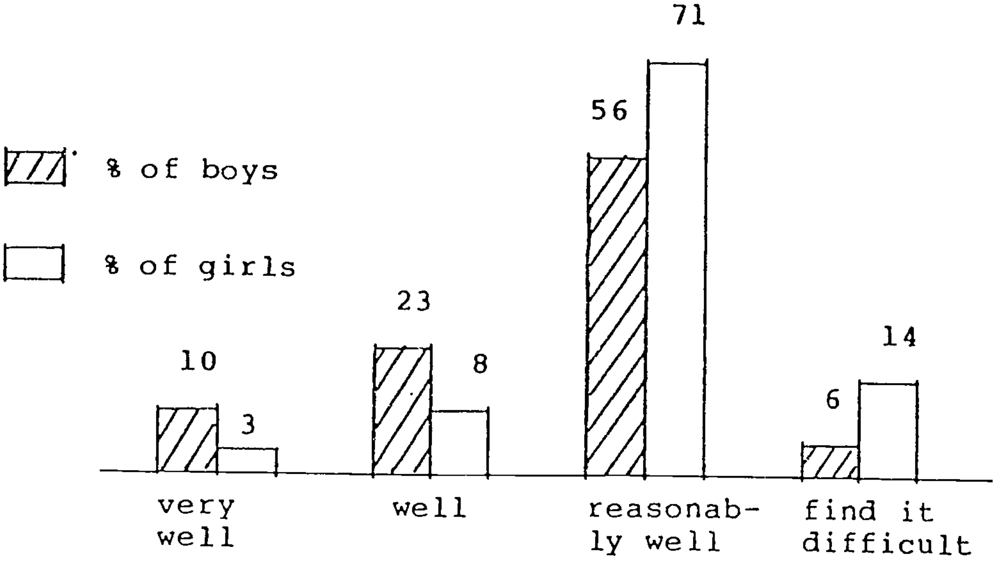

Fig. 2. Physics/chemistry is:

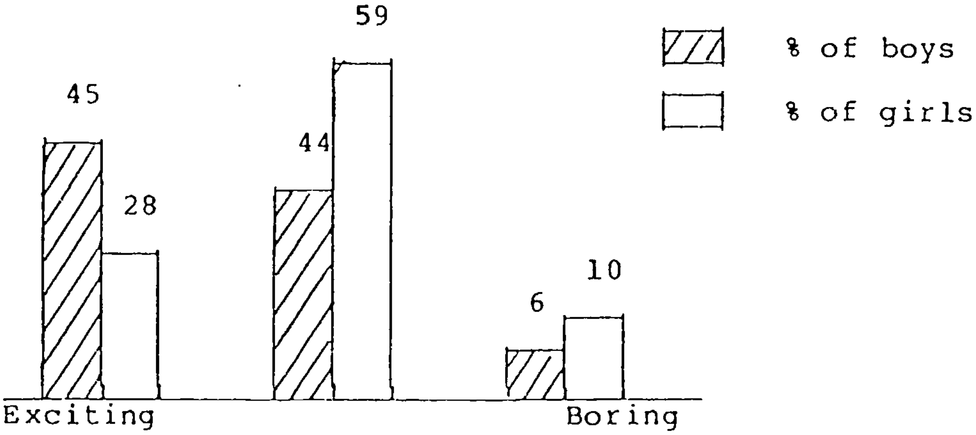

Table 1.

EXCITING 'GIRLS-BOYS'	100% GIRLS	BOYS 100%
RAINBOW	54	34
COLOURS	40	29
ADDITIVES	29	20
WHAT SALT IS	25	20
HOW TO MAKE BEER A. MINERAL WATER	42	38
FLASH AND THUNDER	50	47
WHAT AIR CONSIST OF	33	30
SNOW AND RAIN	28	25
POLLUTION	18	17
SOUND	37	40
THERMOMETER	16	19
THERMOS	7	11
WHAT AN ATOMIC BOMB CONSISTS OF	44	49
CAMERA	36	41
TELEPHONE	28	33
DOMESTIC ELECTRICITY	19	24
COFFEEMACHINE	12	17
STARS AND PLANETS	52	58
MUSIC AND INSTRUMENTS	25	31
REFRIGERATOR AND FREEZER	8	14
MICROSCOBE AND BINOCULARS	45	52
HOW NUCLEAR REACTORS WORK	39	47
NEW ENERGY SOURCES SOLAR ENERGY	28	36
LIGHT	24	32
DATAMACHINES	52	61
ELECTRIC CURRENT	26	35
RADIO AND TELEVISION	38	49
SYNTHEZISER	38	49
IMPORTANT INVENTIONS	32	43
FAMOUS SCIENTISTS	19	31
OIL WINNING	17	29
MAGNETS	24	37
HOW EL. POWER IS MADE IN H.R.	30	45
ATOMS AND MOLECULES	26	42
ROCKETS	43	60
MEASURING OF VELOCITY OF CARS	28	49
CAR ENGINES	18	45

Table 2.

IMPORTANT 'GIRLS-BOYS'	100% GIRLS	BOYS 100%
ADDITIVES	64	52
POLLUTION	50	46
HOW TO MAKE BEER A. MINERAL WATER	20	17
DOMESTIC ELECTRICITY	61	59
HOW NUCLEAR REACTORS WORK	51	49
FLASH AND THUNDER	29	27
WHAT AN ATOMIC BOMB CONSISTS OF	58	57
SNOW AND RAIN	16	15
RAINBOW	7	7
REFRIGERATOR AND FREEZER	32	33
COFFEEMACHINE	17	18
OIL WINNING	28	30
WHAT SALT IS	18	20
THERMOS	6	8
LIGHT	44	47
THERMOMETER	17	20
MUSIC AND INSTRUMENTS	11	14
SYNTHEZISER	8	11
WHAT AIR CONSIST OF	36	40
ROCKETS	27	31
ATOMS AND MOLECULES	41	46
STARS AND PLANETS	26	31
HOW EL. POWER IS MADE IN N.R.	34	40
SOUND	28	34
COLOURS	13	19
DATAMACHINES	60	68
CAMERA	16	24
MAGNETS	10	18
RADIO AND TELEVISION	40	49
TELEPHONE	27	36
FAMOUS SCIENTISTS	6	15
IMPORTANT INVENTIONS	27	37
MEASURING OF VELOCITY OF CARS	14	24
MICROSCOBE AND BINOCULARS	14	26
ELECTRIC CURRENT	51	64
NEW ENERGY SOURCES SOLAR ENERGY	27	42
CAR ENGINES	15	37

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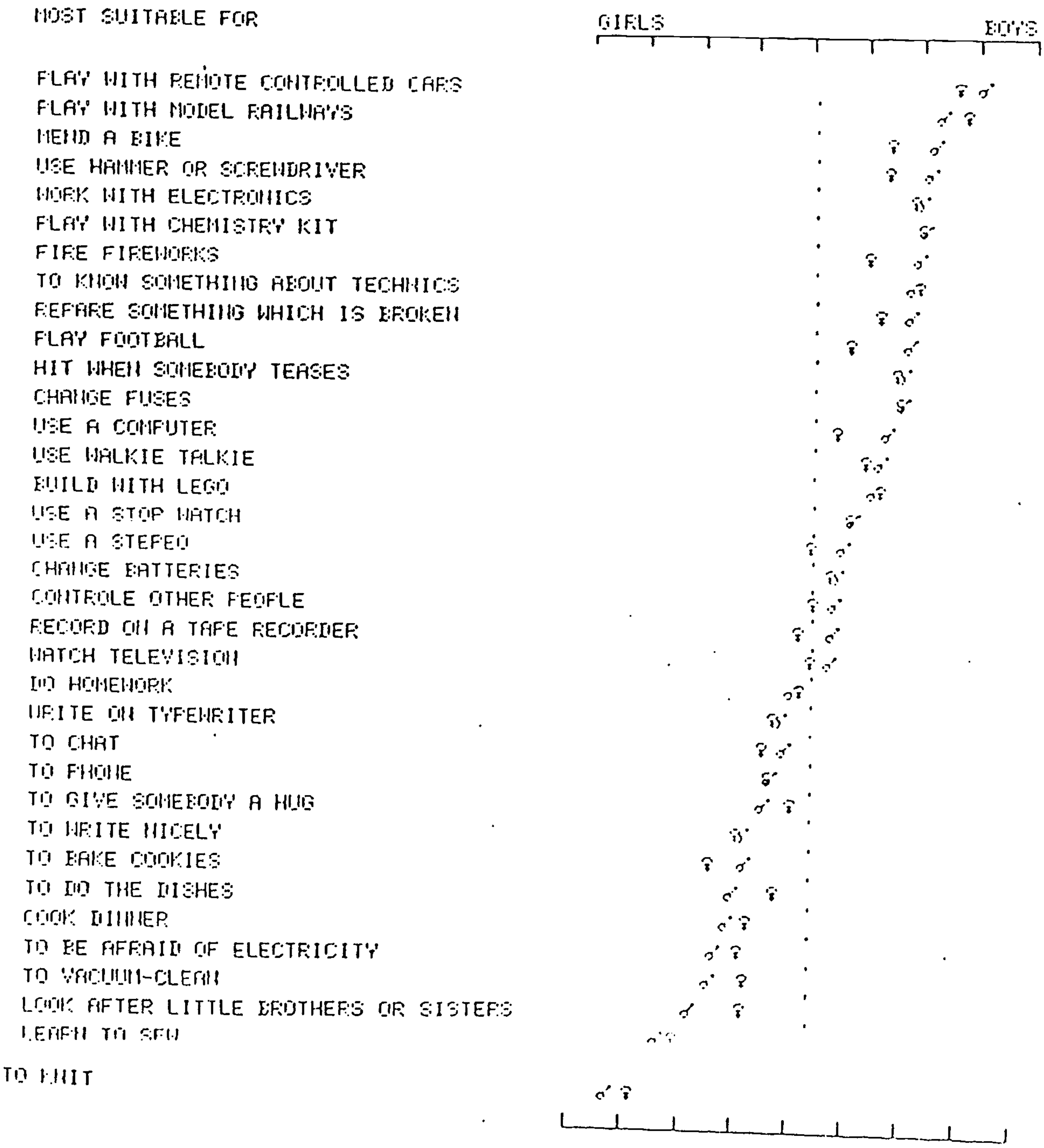
Table 3.



The figure shows the difference between those activities that girls and boys have indicated as "suitable for girls" and "suitable for boys"

Man, Nature, and Polarized Light

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What is 'natural' light? A beam of natural light is characterized by a direction of propagation. All directions perpendicular to this one are equivalent and contain the characteristic properties of light, its oscillating electric and magnetic fields. These fields are always perpendicular to the direction of propagation and are responsible for the name 'electromagnetic' radiation.

In linearly or plane-polarized light, the electric field oscillates in one direction (one plane) only. So does the magnetic field, which is perpendicular to the electric.

We are surrounded by polarized light. In fact, light in nature is usually not 'natural' but is rather partially polarized. One of several reasons is that when natural light from the sun is scattered, it becomes linearly polarized. One important example is the light from the blue sky. The knowledge that the colour of the sky is due to a wave-length-dependent scattering of sunlight has today replaced numerous century-old theories (many of which were considerably more exciting than our present knowledge). Light from the sun contains all visible colours from the short-wavelength blue and violet to the long-wavelength red and orange. If we attempt to look directly at the sun, we will see unpolarized white (i.e. containing all colours) light but, if we look elsewhere at the sky, we will find the short-wavelength components (blue) of the sun's rays which have been scattered in our direction by the atmosphere while longer wavelength components (red) have gone in other directions. At sunrise and sunset, the pattern is somewhat different, as we all know.

The light from the blue sky is polarized, at least partially, because of the scattering process in the atmosphere. The direction of the electric vector of the light is perpendicular to the plane which is defined by the observer, the sun, and the point in the sky being observed.

Also other kinds of scattered light are common in nature. Blank sufaces (e.g, snow, ice, water, even the pavement of a road) scatter light. This usually results in an unpleasant glare, which may even be dangerous in traffic. Fortunately, most scattering surfaces in nature are horizontal; this means that the electric vectors of the scattered light are horizontal too and therefore can be removed from our eyes in a practical way. The tool to be used is a dichroic polarizer, usually a polymer sheet which allows only components of electric vectors in one specific direction to pass. When such a sheet polarizer is hit by natural light, half of it is absorbed, the other half transmitted with perfect linear polarization.

If we use sunglasses in which the lenses are polarizers, which allow only vertically-polarized components to get through, we will avoid half of the natural light, including all glare due to scattering from horizontal surfaces. Such sunglasses have been known as 'polaroid sunglasses'. In the following we shall see why.

The Dog, the Doctor, and the Dough

In the middle of the last century, a doctor in Bristol, William Bird Herapath, was doing experiments on a dog which he fed with large doses of quinine. One day the doctor's assistant, Mr. Phelps, happened to drop some iodine in the urine of the dog. He noticed that a number of long, thin crystals were formed and brought some of them to his boss. Dr. Herapath looked at them under a microscope and found that the crystals removed all light where they were crossed. but allowed the light to pass where they were parallel. They were in fact dichroic polarizers. Being a research doctor, Herapath immediately wrote a short paper on the crystals, a chemical containing quinine and iodine, and it was name Herapathite after him.

At the time, the number of research doctors was smaller than today, and Herapath's paper was actually read by only a few people. One of them was Sir David Brewster, who mentioned the exciting crystals in his book on Kaleidoscopes in 1858. In 1926, this was noted by an undergraduate student in the United States, D. H. Land. Land had also studied the work by Ambronn of half a century earlier. Ambronn had stained natural tissues with iodine and had realized that polarizers could be produced in this way. Land immediately started investigating how a large number of Herapathite crystals could be aligned the same way, so that they could work as one large polarizer.

First, Land aligned the crystals in a strong magnetic field and fixed them with a nitrocellulose lacquer. Later he aligned the crystals on a stretched rubber sheet. Finally, fifty years ago, he fixed them by extruding, through a long narrow slit, a colloidal dispersion of the needle-shaped crystals. The latter method led to a commercial product, the J sheet polarizer, which was the basis of Land's new company, Polaroid Corporation.

The J sheet was a much larger and less expensive polarizer than any of its competitors at the time, but still not perfect. In 1938, Land introduced the H sheet, which was of better quality and even less expensive than the J sheet. It is still commonly used today and consists of chains of iodine atoms aligned in a stretched sheet of a modern polymer, polyvinylalcohol, PVA.

The H sheets have been used for numerous purposes and today the fast-growing liquid crystal display (LCD) technology is completely dependent on them. An LCD consists of liquid crystals, the alignments of which are determined by a set of tiny electrodes, each controlling a small area. The liquid crystal is placed between two crossed sheet polarizers, and the alignment is varied by means of the electrodes, usually in such a way that dark areas on a grey-white background form the wanted message.

Other types of sheet polarizers have been developed. Land produced a dehydrated PVA, polyvinylene sheet, the K sheet, which can withstand high temperaturs. His idea was to place such sheets in front of car headlights. Combining this with an H sheet placed in the windshields at a 90° angle to the headlight polarizers would prevent the long beam from disturbing drivers in approaching cars.

The project never became a success. The reasons were not only technical but also psychological; the first drivers using it would not benefit therefrom until other drivers also installed it.

The K sheets are today used in front of other hot lamps, e.g., those used in stereoscopic colour movie systems in which the viewers use glasses w' h two H sheet lenses aligned 90° to each other.

For use in hot and humid environments, e.g., for liquid crystal displays in automobile dashboards, new polarizer types are needed and very intensive industrial research is going on in the field, especially in Japan and Western Europe.

The Bees, their Dance and the Ants

Bees and other insects are expert navigators. Certain desert ants cover enormous distances, but usally return safely to their home in spite of the apparent lack of landmarks in the desert which they can use for their navigation. Several years ago this exceptional navigation ability was shown to depend on the detection of light polarization from the blue sky. Like other insects, the ants have eyes in which the rhodopsin photoreceptors are aligned and part of them are used for detection of the light polarization. If this part is covered, the navigation of the ants becomes confused, in spite of the fact that they can still see.

Bees are known to transfer information between each other through a 'dance', which describes for example the direction to flowers in the neighbourhood. If the sun is covered for the bees, their dance continues without considerable problem, but if a depolarizing transparent screen is put up, the dance immediately becomes confused. Thus, the bees are completely dependent on the light polarization from the sky.

The ability of insects' eyes to detect light polarization can be understood from the alignment of the molecules in the photoreceptor membrane. Other animals, such as mammals have a different eye construction and should not be able to detect polarization as well. As we shall see in the following there may be among humans exceptions to this rule.

The Vikings, the Sun, and the Stones

Around one thousand years ago, Olaf, King of Norway, visited a rich peasant named Rødulf. The visit was celebrated by a large feast. For some reasons (e.g., food and beverages), it became increasingly difficult for the participants to conceal their own excellence. Among the Vikings, who at the time were travelling to distant destinations such as Greenland or North America, navigational skills were extremely important. One of Rødulf's sons, Sigurd, claimed that he could distinguish the movements of the heavenly bodies, the sun and the moon, even when they could not be seen.

The next day the King called Sigurd before him and asked him to tell how high the sun was in the sky. Without hesitation Sigurd indicated an exact position, in spite of the fact that the sky was covered by clouds and it was snowing.

The story is told in the Icelandic saga from Flatey. The saga adds: 'The king held up his sunstone and saw how it shone and indicated the same position as Sigurd had said'.

What is a sunstone? From the Icelandic sagas describing the activities of the Vikings, it is clear that a sunstone is a valuable navigational tool, but how does it work?

This question was asked twenty years ago by a Danish archeologist in a popular Danish magazine on archeology. He got the same answer independently from two employees of Scandinavian Airlines System, both of whom wrote that a sunstone had to be similar to a 'twilight compass' which was earlier used for flights in polar regions, where a magnetic compass is useless. A 'twilight compass' is essentially a polarizer, which is used for the detection of light polarization from the blue sky. It seems clear that the Vikings were able to use the dependence of this polarization on the position of the sun in their navigation. In the North Atlantic, the sun is often below the horizon or covered by clouds but, in spite of that, its position can be determined as long as a sunstone or a 'twilight compass' is available.

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Project Work in Environmental Protection in the Natural Science Branch of the Upper-Secondary School in Sweden

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Since 1984, students in the three-year natural science branch of the upper-secondary school in Sweden have the possibility to specialize during the two final years. They can choose among computer technology, environmental protection technology, health science and, less often, energy technology and communication. Since 1984, Lindälvsskolan offers computer technology and environmental protection technology.

The students study environmental protection technology for four periods a week. In the ordinary curriculum for the natural science branch, these four periods are used for languages, history and psychology or philosophy. The curriculum for environmental protection technology recommends:

- a project-oriented work form
- co-operation between different teachers and subjects
- co-operation with society

In the first year of their studies, the students at Lindälvsskolan have two theorectical and experimental learning periods (with lectures, supervised laboratory work, written tests, etc.) on the main subjects soil and water. In the first term of the second year, they work on a project and, during the fourth and last term, they work on the subjects air, law, ergonometrics and environmental protection in a global perspective.

In this article, the project work will be described in terms of one of the projects carried out by a group of students in 1984. Their project work can serve as a model for what we aim at (but do not always achieve). It was carried out by three students with average grades in the main subjects. Their work was entitled, 'The Dying Forest'. It contains several important characteristics of interdisciplinarity and also of problem-oriented work. The intention of the work was to learn about different reasons and theories for damage to the forest and to sum up and comment on those theories. To achieve this, the students had to:

- plan experiments;
- collect tests samples in the field;
- carry out experiments in the field and in the laboratory;
- consider the accuracy of their methods;
- think of alternative experiments when planned ones turned out to be irrelevant;
- learn new experimental methods;
- collect facts from the literature;
- evaluate results from experiments and relate them to theory;
- teach the main results from project work to fellow students;
- write a report.

The students chose a test area and started to read about the subject. They contacted local authorities and talked with the forester in charge of the area. He ught them how to estimate the age of the trees. The students then made an inventory of the area and documented their findings photographically. They found examples of all of the typical signs of disease for fir and pine trees reported in the literature. An inventory of lichen showed that pollution of the area due to sulphur dioxide was relatively small.

Measurements of the acidity of water and soil samples gave alarming results, with pH values varying between 2 and 5. The students at first didn't believe their results. They checked their equipment, tried alternative methods, collected water and soil samples at different times and different locations in the area and made measurements in the field as well as in the laboratory. They also collected samples from another area, where trees showed few signs of damage. The higher pH values of these reference samples at least convinced them that they could rely on their findings.

They had planned to determine the buffering capacity of water and soil against acids. When they found out that the soil and water samples had no buffering capacity whatsoever against acids, they determined the buffering capacity against bases instead. Where alkalinity is low, aluminium concentration tends to be high. Consequently, the students decided to analyse water and soil samples for aluminium. This was done spectrophotometrically. They had to work out on their own a method for soil samples. Their results confirmed their earlier findings. The area was badly polluted.

Their next step was to consult local authorities to check measurements and also to consult experts on air pollution at a nearby university. They found out how complex the problem of the dying forest is and how many theories there are to explain it. In their report, they account for a variety of reasons, with their own comments on credibility. They also suggest measures to be taken to prevent pollution.

The three students became experts in their subject. They took their teachers and their fellow students to the test area and gave a brilliant lecture on the subject of their project.

Environmental protection is a subject where students become very preoccupied with the projects they work on. It is also a subject where they realise that biology, chemistry and physics are in fact parts of a whole and not just three different subjects.

Project Work in Chemistry and Scientific Writing in the Upper-Secondary School in Sweden

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In supervising project work, a common finding is that the theoretical and practical work of the students is of higher quality than their documentation of the work. A more general formulation of this is: How do natural scientists communicate their findings to the public and how could communication be improved?

In the curriculum of the natural science branch in the upper-secondary school in Sweden, nothing is said about the students having to learn to write scientific texts. Now and then they write short accounts of laboratory work, but this is done with no help from the Swedish teacher and only if initiated by the natural science teachers. Therefore, there is a great risk that errors in language and style are not commented on and corrected. Also, the students never really develop the skill of writing about science.

The purpose

During the spring term 1985, we decided to initiate a joint project in chemistry and Swedish at Lindälvsskolan. The aim of the project was:
- to enable. the students to practice scientific writing with instructions from both their chemistry and Swedish teachers;
- to develop an interdisciplinary teaching method for Swedish and subjects like chemistry, physics and biology.

Starting on a small scale

We started the project on a small scale with our first-year students. After having done laboratory work, the students were instructed to write a short account of the experiment. We wanted to find answers to the following questions before starting a full-scale project:
- Is it sufficient to practice writing during the Swedish lessons or do the students need more help from their Swedish teacher when writing about natural science?
- Do the students make an effort to write as clearly and as coherently when writing scientific texts?
- Do Swedish teachers know enough about natural science to be able to comment on scientific texts?

When we correct the reports together, we found both ambiguities and errors. The Swedish teacher found language errors, many more and more serious than normally, even in the laboratory reports written by the most talented students. Some reports lacked both style and structure. Working together was very constructive. Together we were able to give professional points of view on both content and language.

Starting up the main project

We started to work together on a larger scale a year later when the same students were to choose a field for project work in chemistry. We adopted the ideas of the national Writing Project, wherein 'process writing' consisting of five steps:
- pre-writing
- writing
- responding
- revising
- publishing

During the 'pre-writing' period, the students worked in groups on their chemistry projects for seven weeks. Each group was to:
- choose a topic for its work;
- clearly define the aim of the study and make a written work plan;
- write a diary;
- find and read suitable literature;
- plan and carry out laboratory work and study visits;
- make an oral report.

The students chose the following topics:
- Coca Cola
- Cosmetics
- Chemistry of Iodine
- Chromatography
- Olympic Games in Chemistry
- Synthetic Polymers
- Water
- Chemistry of Wine

After six weeks, the students accounted for their practical work and demonstrated experiments in front of the class.

Writing the reports

Now the second step of the writing process, i.e., 'writing', started. The groups wrote a first draft of the reports. The students in each group divided the material between themselves, each being responsible for one part of the report.

Then the 'responding' process started. Within each group, the students read and corrected each others' drafts, which were then put together to form a whole. The Swedish teacher was in charge of this part of the project; the chemistry teacher was only consulted when there were questions about chemistry. The students had great difficulty sorting out the material. The outline had to be rewritten many times before all the pieces fitted together. Then the reports were typed and copied. Every student got one or two reports from another group to read at home. A few days later they were supposed to act as opponents and give constructive criticism.

The class was divided into two parts, with one teacher in each group as an observer. The students first gave positive criticism and then constructive suggestions for improvements. Students in the group that had written the report being discussed, explained what they had intended when obscurities were pointed out. All suggested alterations were not accepted. Some groups defended their versions and insisted on sticking to them.

The students were then given half a day for 'revising', i.e., editing, drawing diagrams and retyping the reports. Then they were 'published'.

Evaluating the reports

At this stage, the whole material was finally available to us teachers. The overall impression of the reports was that they were quite coherently written and that the language was functional. But there were still imperfections:

- paragraphs were not always well connected and in some reports the connecting thread was almost lost;
- wrong tone and style;
- grammatical errors;
- laboratory work not well analysed and evaluated.

Some reports lacked theoretical reasoning and original thought. Instead, there was an abundance of facts. Students very seldom discussed failures, although there were some exceptions. They seemed to think that discussing mistakes should not be part of a written report. This might be due to the fact that students are not used to being responsible for laboratory work and experiments that prove to be unsuccessful. Most of the upper-secondary school laboratory work is arranged in such a fashion that as many students as possible get the 'right' results. Maybe students' project work is one of the few occasions for students to get to know what laboratory work is all about.

By working together, we have found that:

- Natural science students should practise scientific writing.
- Joint work makes language practice more satisfying.
- Laboratory work and project work form a good basis for writing practice.
- 'Process writing' is a method worth trying in this context.

The Integrated Course NATURE in the Curricular Structure of BARGEP

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Since the academic year 1979-80, the Research Group on Education of the Bulgarian Academy of Sciences (BARGEP) has been carrying out an experiment in 29 schools throughout Bulgaria. The experiment intends to be an innovative one, introducing a new educational or curricular structure. One of the main features of the BARGEP project is its integrated approach. This involves the creation of new integrated or agglomerated school subjects or disciplines, which are very unusual in the general practice of Bulgarian schools. It leads as well to the need to develop new forms of teaching such integrated courses.

In this paper, we deal with the fundamental ideas and features of the integrated science course called NATURE. Traditionally, such material was presented in different disciplines: physics, chemistry, biology and geography.

Which are the basic principles that have been guiding the designers of the course NATURE? Not mentioning well known and self-explanatory didactic principles, we would like to emphasize the following:

1. The course should create interest among the pupils.
2. The learning should be active and connected with a creative or research approach of the children.
3. The course should have a level adapted for all, but with possibilities for individual diversification.
4. The course should be integrated. Different topics should be presented comparatively and with a maximum number of interdisciplinary links.
5. Every possibility should be used to transfer the educational experiences out of the classroom, i.e., outdoors, in specialized labs, etc.
6. The course NATURE should create a *Weltanschauung* and a way of thinking; its goal is not just knowledge accumulation.
7. The textbooks should be redundant; not everything in the text belongs to the compulsory curriculum.

The curriculum within NATURE is structured according to the above-mentioned principles. In the primary school (grades 1-4, age 6-9), information on topics of science is given in parallel with the achievement of fundamental literacy and numeracy as well as with knowledge in the fields of history and the arts.

The integrated courses start with the junior high school (grades 5 to 7, ages 10-12). These courses are 'Language and Mathematics', 'Nature', 'Society', 'Technologies and Everyday Life' and 'Sports'. NATURE is carried out in three years with four hours weekly. An addition to this, the students also can choose between two optional activities, viz., 'Naturalist', which is a collection of entertaining and elementary experiments, and 'Ethnographer'

In the upper-secondary level (grades 8-10, ages 13-15), the students are divided into two streams or profiles: 1) science and technology; 2) social sciences and economics. Both streams have science as an integrated course and separate courses in physics, chemistry, biology and geography. We do not enter into details here because the design of the secondary level is not yet complete and many things are only in draft form.

Let us now go back to the structure of NATURE in the junior high school. It is centred around six integral knots. These knots develop as a helix through every one of the three academic years and respectively through the textbooks. They are named:

1. Particles of Living and Non-living Matter
2. Bodies and Organisms
3. Processes
4. Celestial Bodies
5. The Earth
6. Man and his Environment

The exposition in the textbook is based on the discreteness of matter and on the development of more and more complex organizations of particles.

The integrated approach is followed in the construction of every lesson or unit of the textbook. For instance, the relatively small knot, 'The Earth', includes information about water from the point of view of geography, chemistry, physics and biology. Important physical properties like specific weights or specific heats are connected with chemical bonding or with, e.g., the conditions ensuring life in water basins. The lesson on water solutions involves considerations of everyday life and health preservation.

In every unit, special emphasis is put on problems, exercises or assignments. They are very helpful for achieving integration. Here are some examples from the knot 'Water':

1. Propose an experiment involving a hot-pot, a cup and a testtube so that you can prove that, when boiled, water evaporates but, when cooled, the water vapours condense in water drops.
2. If you distil both sea water and river water, does the resulting distilled water have the same properties in both cases? If yes, why?
3. How much water do you personally drink in one year? How much water do you consume for other purposes?
4. Does distilled water conduct an electric current? If not, why? What about salt water?
5. What should a bottle of lemonade contain? What processes can you observe when opening the bottle?

As we see, the questions asked are complex and relate to everyday life. The answers require a knowledge of several sciences.

An important condition for successful teaching and learning is to use the didactics accepted in the BARGEP. It can be seen from the format of the textbook. Every unit is developed on two facing pages, even- and odd-numbered. The basic information is given on the first (even) page. On the margin, one can find new terminology, with etymological remarks and translations into Russian and English. On the second (odd) page, the student finds two short abstracts of the unit (one in Russin and one in English) and the list of problems and questions.

The students start by working by themselves on the basic text. This can take one-fourth to one-third of the available period. Later they ask questions about things they have not grasped. Answers are given by the students and, if needed, by the teacher. This can lead to a discussion of topics beyond the competence of the teacher; such topics are treated later, after the teacher prepares him/herself respectively.

Another period is designed for working on problems and assignments.

The practical guide, 'Naturalist', is used by those who are scientifically inclined. The experiments included are simple but interdisciplinary. The different experiments are numbered and every student is expected to give a 'name' to the experiment he/she has performed.

Integration is also sought with the remaining courses in the junior high school, such as, 'Language and Mathematics' and 'Society'. For instance, texts which are not sufficiently edited are given to be improved. The abstracts in Russian and English are a bridge to the direct teaching of these two foreign languages. Many activities included in 'Technologies and Everyday Life', make sense from the point of view of NATURE.

The experience during the period 1983-88 shows that NATURE is a stimulating course, students' interest being, on the average, high enough. Special evaluation of the results have been planned for the near future but, even without any measurements, one can see that the originality of the children is encouraged. And this has been achieved in considerably less time per week than in the framework of the traditional disciplinary systems.

Applying Informatics in Science Teaching: Some Examples

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I am told, I forget,
I am shown, I remember,
I do, I understand. . .

A Chinese proverb

Introduction

How to use the computer in science teaching in a reasonable way? We shall try to propose a possible answer on the basis of five years experience of teaching informatics in the schools of the Research Group on Education (RGE). This group was set up in 1979 and is supported by the Bulgarian Academy of Sciences and the Ministry of Education [1].

The RGE - Basic educational principles

One of the tenets which the RGE has been pursuing is the *integration of school subjects.* The training of active and creative skills has also been given special attention. The teachers working in the RGE schools (now 27) are required not only to teach but also to train the pupils in *learning by doing* [2].

In harmony with the principle of integration, several new courses have emerged-*Language and Mathematics, Nature, Society* and *Informatics*. They are taught in the junior-secondary cycle (11-13 year olds).

The principles of both integration and learning by doing can be put into practice in quite a natural way by the means and methods of informatics. By using the computer, children are enabled to work in a new kind of laboratory where they can carry out experiments with different objects (even imaginary ones), thus developing insight and intuition about some physical phenomena.

Newton's Laws and the turtle

RGE pupils get acquainted with Newtonian mechanics (in the textbook *Nature*) at a fairly early age. In usual school practice, the pupils begin their study of a physical phenomenon by getting acquainted with its formal side. For pupils who are not old enough, the contact with formalized knowledge becomes considerably difficult, which naturally brings up some questions about the methodology of teaching children such complicated matter [3].

Above all, a new scientific idea should be almost imperceptibly instilled into the children's minds and only afterwards be given a mathematical description. The computer language Logo is very helpful here. The turtle in Logo can take different mechanical characteristics which we can use, for instance, in the game *Orbit* [4]. The turtle spacecraft can move by inertia, i.e., uniformly along a straight line when no force acts on it. But the children go about controlling that object by intuition and practical experience. They know that a moving body will come to a halt if not acted on continuously. Starting the game *Orbit* they enter into a computer world where a true inertia object exists, the turtle spacecraft. They control it by the commands *kick*, *left* and *right*, but they have little success in the beginning. Each failure and each crash, however, make the pupil change his or her personal strategy for controlling the turtle and try new combinations between the magnitude of the applied force and its direction. The new strategies of the game which pupils continuously invent lead to better actions and a modified intuitive knowledge of the properties of the object they direct. They realize that if the turtle is to be acted upon in the right way, they must imitate the earth's gravitation, i.e., give consecutive commands for altering its course towards the centre and, after that, to give it a kick. Thus arises the idea of directing an object moving by inertia along a segment of a curve. The children also find out in what position of the turtle the command *kick* will actually reduce its speed (the action of a force opposite to the direction of motion). After repeated trials the pupils reach the conclusion that the applied force must have magnitude and direction. These exercises in controlling the turtle imperceptibly lead to their forming an idea of an object moving by inertia and the practical effects of applying forces to it. This preparation is a sufficient condition for proceeding to the formal side of Newton's laws of motion as presented in the textbook *Nature*.

The merits of such an approach lie in the fact that we can do without artificially feeding the pupils with ready knowledge. They already have an experience in directly communicating with objects possessing the necessary characteristics in the computer world of *the dynamic turtle*. The quantitative relation $F=ma$ is a synthetic, generalized expression of the intuitive knowledge they have acquired.

The turtle and the gravitation field

Another model that could be used is the model of a gravitational field where one can change the mass of the planet and the velocity of the rocket [5]. Thus, the influence of both the gravitational field and the initial velocity of the rocket over the rocket's motion could be investigated. To be more precise, the pupils examine how the turtle behaves if:
- they augment its initial velocity while keeping the planet's mass constant;
- it is in the cosmos, far from bodies with big mass;
- they change the planet's radius while keeping its mass constant;
- they make the turtle's acceleration depend on the distance to the earth's centre (assuming that the two poles are connected by a tunnel passing through the centre)

There are a great many processes and phenomena in nature that can be understood by studying the results of keeping certain characteristics constant while changing others. This method has been very often used in the classes of informatics.

Gas laws versus polyspirals

In the process of studying *Logo*, the pupils gradually acquire the skill of drawing a group of polygons and various polyspirals. We shall not consider the process of writing a procedure with parameters for drawing polyspirals [4]. We are interested in how such a procedure could be useful in forming heuristic thinking and a researcher's approach to the study of natural phenomena.

Let us take for instance the recursive procedure with parameters SIDE and ANGLE for drawing polyspirals. After having written the procedure, we can suggest to the pupils to study the spirals obtained when changing one of the parameters, e.g., SIDE, while keeping the other one constant. Thus experimenting, the pupils create a set of polyspirals, differing from one another, but still having certain common characteristics. What is useful here is not the exact types of spirals the pupils will obtain but the method they employ. The experiments could be made more complicated by introducing three parameters into the procedure and studying the results accordingly.

When studying the topics *Gas laws* and *The gas thermometer* (included in *Nature*), pupils can apply this method in deriving the laws of the ideal gas. By using the approach developed in their *Logo* classes, they can easily understand the method for studying the relationship between the three characteristics of the ideal gas - volume, pressure and temperature. These skills will also stand them in good stead in the future, when they study the isoprocesses with gases and their graphs.

Thus far we have considered micro-worlds where the children could build intuition about the relevant phenomena through experience with motion and by playing with parameters. There are some other interesting fields in science teaching where tools of informatics could be applied as well.

The game *Animals*

The well-known game *Animals* [6], where the computer asks yes-no questions in order to guess an animal you have thought of, is an example of an information system whose knowledge could be enriched. The information is represented in the form of a binary tree every node of which is a yes/no question and the leaves of the tree are names of animals [7]. (See fig. 1.)

By drawing what the computer knows in the form of a tree, we can get a more vivid picture of how the game works. We can think of the game as exploring the tree from the top, which is the 'Is it a vertebrate?' question.

The goal is to climb down the branches to an animal name. The animal being reached finally is the one it guesses. Let's play an imaginary game having in mind the secret animal *cat*. The answer to the first question (Is it a vertebrate?) is *yes*, so the programme follows the yes-branch to the 'Does it have wings?' question. Since the answer is *no*, the following question reached by the programme is 'Does it have legs'. The answer is *yes* and the yes-branch is followed to the question 'Is it furry?'. The next answer is *yes* and the programme follows the yes-branch to the animal name, panther, which of course is wrong. What makes the game interesting is that the computer can *learn* new animals. When it can't guess your animal, it asks you to teach it the animal and its distinguishing characteristics:

Tell me a question whose answer is 'yes' for 'cat' and 'no' for 'panther'.

A suitable question is:

Is it a domestic animal?

We must now replace panther with a new sub-tree, consisting of the question, 'Is it a domestic animal?', with a yes-branch leading to cat and a no-branch leading to panther. (See fig. 2.)

By learning new questions and new animals the computer becomes *smarter*.

The system could be transformed for any field of interest to the pupil by changing appropriately the tree of knowledge. For instance, he could start from a single country and develop an information system for countries, or plants, or minerals, etc. [7].

The important thing here is that the pupil is really motivated to classify objects (which he usually is not in the traditional science teaching). Furthermore, the teacher can study the history of the game (the developing of the tree) in order to derive conclusions about the pupil's knowledge and if necessary to improve it. From a psychological point of view, it is important that the child feels superior to the computer; *he* teaches *it*, not vice versa.

Conclusions

The teachers' experience, as reflected in the reports submitted to the May 1986 RGE conference [8], points to the following conclusions;

- Informatics can truly play a fundamental role towards an integrated approach to science teaching; a number of concepts can be illustrated and interpreted in a new way which makes their understanding easier;
- Such an integrated approach involves close co-operation between the teachers themselves; the computer programmes considered could be used during the classes of both informatics and science teaching;
- The play-like activities, in which the pupils are put in the role of investigators, helps them to gain intuition for things that are not derived from their life experience and to acquire deeper understanding of the relationships among natural phenomena;
- The role of the teacher is to supervise and guide the pupil's research, while leaving to the pupil the joy of discovery;

Such an attitude would strongly contribute to a natural transition from science teaching to science learning.

Acknowledgement

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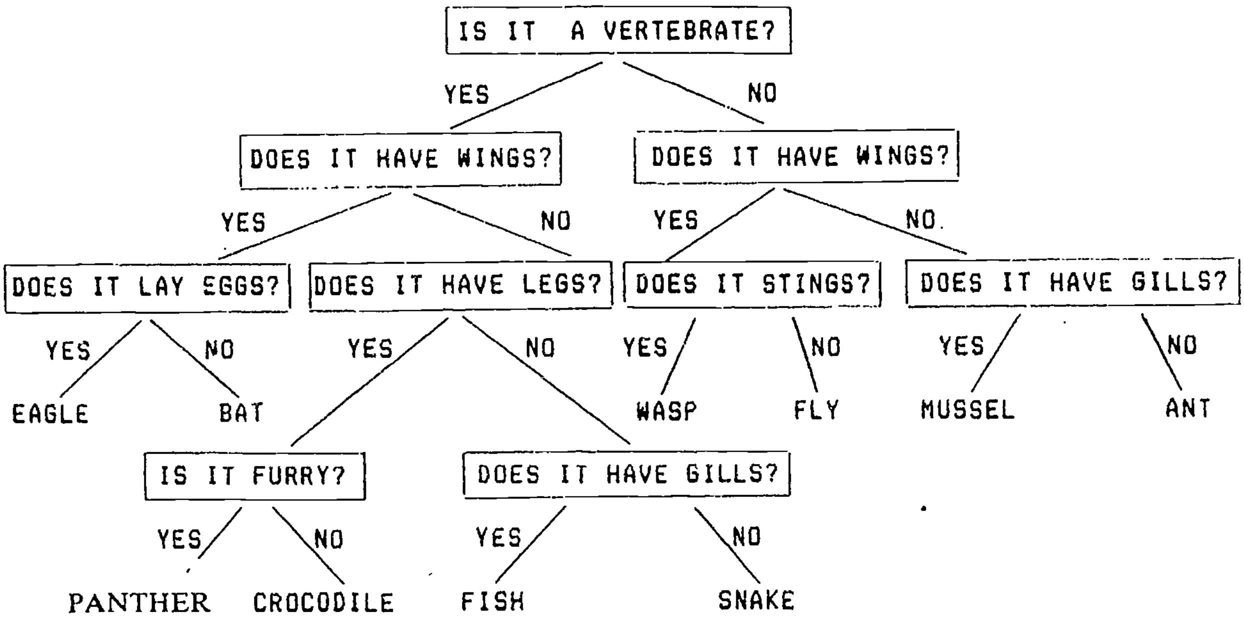
IS IT A VERTEBRATE?
YES
NO
DOES IT HAVE WINGS?
DOES IT HAVE WINGS?
YES
NO
YES
NO
DOES IT LAY EGGS?
DOES IT HAVE LEGS?
DOES IT STINGS?
DOES IT HAVE GILLS?
YES
NO
YES
NO
YES
NO
YES
NO
EAGLE
BAT
WASP
FLY
MUSSEL
ANT
IS IT FURRY?
DOES IT HAVE GILLS?
YES
NO
YES
NO
PANTHER
CROCODILE
FISH
SNAKE

Fig. 1

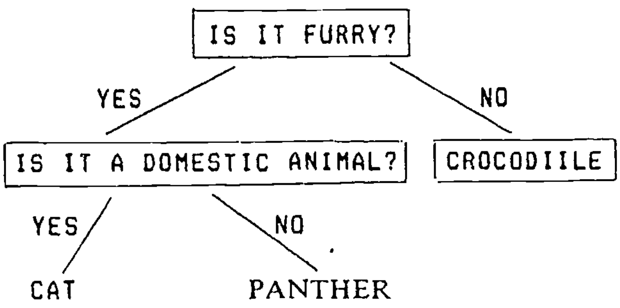
IS IT FURRY?
YES
NO
IS IT A DOMESTIC ANIMAL?
CROCODIILE
YES
NO
CAT
PANTHER

Fig. 2

Dimensions of Integration

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In the domain of learning and the study of learning, there are many points of view. The cognitive scientists (or cognitivists) define learning as a change in the learner's cognitive processing and/or structure. The processing of information refers to how information is received, what is done to it by the rational powers of the learner, and how it is retrieved and applied. The structure of knowledge refers to the way in which information is labeled, stored, organized, and associated in the learner's mind. The learner interacts with the environment (interactionalism), actively processes information, and constructs or generates knowledge by organizing or reorganizing knowledge internally (constructivism). The work of Bruner (1960), Piaget and Inhelder (1969), Vygotsky (1978), and Wittrock (1975) are representative of this perspective. This paper is based upon this cognitivist view of learning. The concept of integration is the unifying theme of this paper. Four dimensions of integration will be discussed: education as the integration of four learning/teaching factors, the integration of technology into the learning environment, the integration of science and mathematics education, and the ultimate integration of knowledge within the learner.

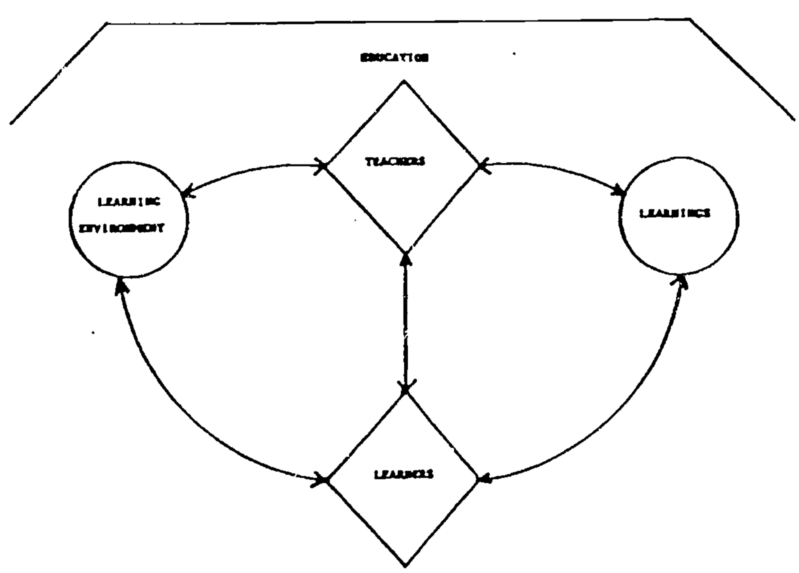

Fig. 1. Learning/Teaching Integration

Education is defined as the learning/teaching process. It consists of the following major factors: learners, teachers, learnings (content to be learned), and the learning environment. Figure 1 (which serendipitously evolved into the 'heart' of education) illustrates the interrelationships among these four factors.

The four principal factors are defined as follows:

a. Characteristics of learners include basic cognitive processes and structures common to all learners. Learning style is the unique behaviour pattern of cognitive processing and structuring which differentiates individuals.
b. The role of the teacher is viewed as that of a decision-maker, facilitator of learning, and co-traveller on the road of life-long learning. The teacher is neither omniscient nor omnipotent, but an active force integrating the other three factors in the educational process. The teacher is characterized by a teaching style.
c. Learnings have been traditionally defined as those specific concepts, skills, and processes fundamental to a subject matter area or content domain. Another view of the learnings is generic in nature; that of concepts, skills, and processes fundamental to problem-solving, decision-making, and critical thinking which transcend content domains and are the basis for higher-order thinking.
d. Learning environments involve the organization and management of human (teacher and learner), material, spatial, and temporal resources. Components include: teaching methods, teaching materials, teaching techniques, delivery systems, presentation modes, motivation techniques, environmental features, and environmental organization.

The first dimension of integration therefore is between these four complex factors involved in education or the learning/teaching process. The study of education and the development of effective and efficient instructional models need to attend to all four factors, their inter-relationships and integration.

The second dimension of integration is that of the integration of technology into the learning environment. The use of high-technology instruction is becoming increasingly available, flexible, and inexpensive. It is possible to present concepts in ways unavailable through the static printed page; use non-mechanistic strategies; provide individualized, interactive learning; provide a variety of curricular and teaching approaches; and retain data for monitoring and evaluation. Current and emerging technologies are affecting what is to be learned (the content) and the environment in which it is to be learned (e.g., teaching techniques, presentation modes). Modern technology provides educators with a myriad of tools which need to be rationally and systematically integrated with other instructional resources in the learning environment.

The incorporation of rational thought, theory, and empirical evidence is critical in the design of learning environments. A general instructional model or paradigm can be developed to guide the design of the learning environment, i.e., the classification, selection, and organization of instructional resources.

An example of a general instructional model developed by this author appears in Figure 2 (Berlin & White, 1987). The following guidelines were applied in its development:

a. learning theory based (e.g., provide for constructive, multi-sensory experiences);
b. supported by valued educational practices;
c. supported by empirical research;
d. attend to the four factors of learning/teaching (learners, teachers, learnings, learning environment);
e. rationally and systematically integrate technology into the classroom;
f. systematically classify, organize, and sequence instructional resources (past, present, and future);
g. facilitate and enhance the development of higher order thinking skills;
h. be suggestive, not prescriptive; and
i. generalize across the curriculum.

The model is based upon two dimensions: the continuum from concrete to semi-concrete to abstract, and the continuum from manipulated to animated to static. These dimensions are defined as representational level and movement. The interaction among the levels of Dimension I, Representation, and Dimension II, Movement, are illustrated by the nine individual cells in the model matrix.

Dimension I, Representational Level, describes a continuum from concrete to abstract representation. The concrete representational level is simply interpreted as a learning activity which involves physical objects which represent entities. The semi-concrete level involves representation of the objects in the form of pictures, cartoons, or images. The abstract representational level engages the learner with ideas, verbal descriptions, and symbolic representations of the concrete or semi-concrete experiences. Mathematical symbols, formulas, and texts are used to represent concepts at the abstract level.

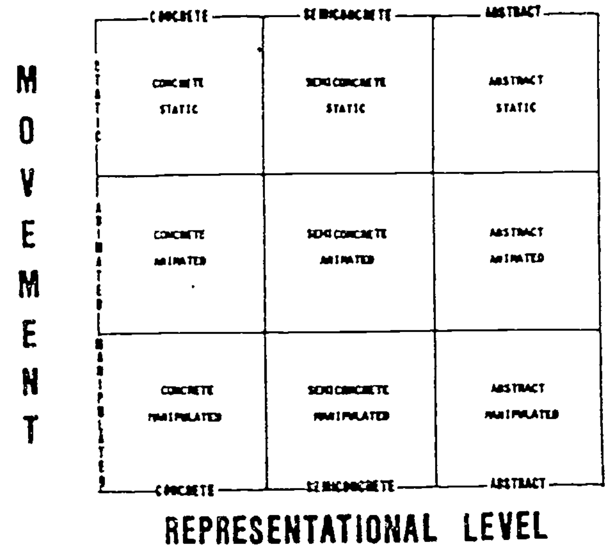

Fig. 2. General instructional model

Dimension II, Movement, is a continuum from manipulated to static form. It is fundamentally related to two factors: change and the control of that change. Manipulation is a condition involving observable change in which the learner actively interacts with the learning environment and therefore has a degree of control over the change. Learners can manipulate objects, images (e.g., computer simulations) or symbols (e.g., calculator displays). Animation involves an observable change but the control of that change and the factors influencing it are not controlled by the learner. The change can be controlled by the teacher or by some other means such as a film or computer program. The learner merely observes the movement of objects, images, or symbols. In the static condition there is either no change or evidence of change can only be inferred, not observed directly. The learner may observe stationary objects, illustrations, or printed words and symbols.

Current learning theory, empirical evidence, and educational practice would suggest an instructional delivery or sequence of the nine cells in the model in either a horizontal (left to right), vertical (lower to upper), or diagonal (lower-left to upper-right) direction. These sequences are only suggestive as any sequence selected should reflect the needs, preferences, and abilities of learners and teachers; the nature of the learnings; and the objectives of the curriculum.

These two dimensions were selected because they are consistent with and reflect current learning theory; instructional practices valued in the teaching of various curriculum areas (e.g., activity-based learning, hands-on activities, learner-centred, multi-sensory and multi-media environments); and technological developments. Of particular interest is the integration of technology in the model through the dimension of movement. The ability of technological resources to produce images, animation, and change over time is both instructional (comprehension, learning, and problem solving) and motivational (toward the subject and the technology) (Bangert-Downs, Kulik, & Kulik, 1984; Klein, 1985; Papert, 1980; Sherwood, Kinzer, Bransford & Franks, 1987).

Figure 3 provides examples of general instructional resources for each of the nine cells of the instructional model. This figure shows the infusion and integration of technology into the instructional process. The objects and manipulative materials provide for the concrete experiences; audio-visual media, computer graphics, and transparent materials provide for semi-concrete experiences; and textual materials and the calculator provide students with abstract, symbolic experiences. Attention has been given to the past or 'old' forms of technology (e.g., overhead projector), neglected forms (e.g., calculator) as well as present and recent advancement in technology (e.g., computer, interactive videodisc). The models allows for the integration of future, unknown technologies as well.

This model can be applied to various curriculum areas and topics. Figure 4 illustrates the application of the model to science and mathematics education and the concept of patterns.

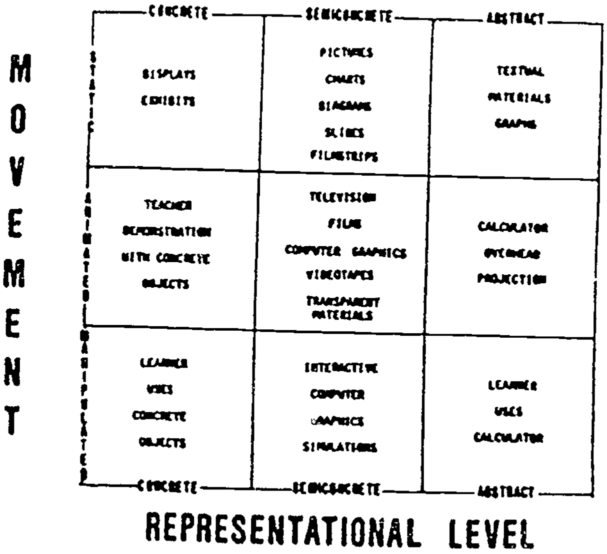

Fig. 3. Instructional model - general resources

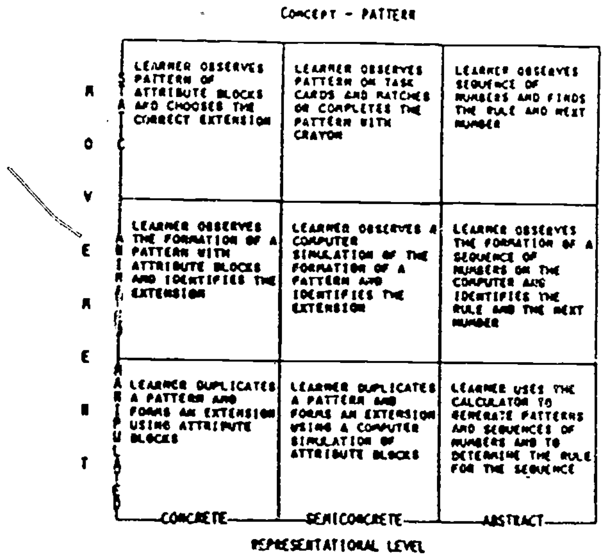

Fig. 4. Instructional model - science and mathematics

The specific sequence of activities and the duration of time allotted for each will be determined by the needs and requirements of the learner and the teacher. The selection and organization of instructional resources to teach other topics in science and mathematics as well as topics in other content domains can be developed in a similar manner using the general instructional model. This model can serve as a prototype of a learning environment which integrates the use of technological resources and can address different curriculum topics (learnings) and be responsive to the wide range of student and teacher needs.

The third dimension of integration is between science and mathematics education. Science can be viewed as the search for or study of patterns and relationships that exist in the real world or are the products of human creativity. Mathematics provides symbols to represent these phenomena and the means to quantitatively describe the relationships. The integration of science and mathematics education provides a rich source of concepts, skills and processes that overlap and provide a broad base for meaningful learning. Topics that integrate these two content domains include: patterns (e.g., attributes, rules); variables; spatial relationships; measurement; data collection, organization, and communication; modeling; ratio and proportion; prediction; statistics and probability; problem solving and decision making.

The need to identify and/or develop curricula and instructional materials that facilitate and promote the integration of science and mathematics is a challenge being met by the School Science and Mathematics Association (SSMA). This national educational organization has identified the early childhood (ages 3-7) and middle school years (ages 10-14) as areas for immediate priority in terms of the integration of science and mathematics (House, 1986).

The need for appropriate early-childhood science and mathematics experiences becomes evident as greater numbers of young children attend pre-school and kindergarten. Teachers of young children need to provide opportunities for children to actively explore their environment and develop concepts, skills, and processes through concrete experiences (Schickendanz, York, Stewart, & White, 1983; Seefeldt, 1980). The integration of science and mathematics can provide real world experiences and facilitate meaningful learning.

The growth of the middle-school movement has been stimulated by the recognition that this population is both unique and diverse in terms of cognitive, physical, and socio-emotional development. The National Association of Secondary School Principals has recommended the use of interdisciplinary instructional strategies to meet the varied needs of middle-school learners (NASSP, 1986). The integration of science and mathematics demands particular attention; research has shown that positive attitudes toward these disciplines begin to diminish during the middle school years (Fennema, 1984). The integration of science and mathematics can provide real-world applications to encourage student involvement and enhance the understanding of science and mathematics.

The Early Childhood and Middle School Task Forces of the School Science and Mathematics Association provide a substantive and effective response to the needs perceived at each of these levels. The charge given to the two task forces include the following:

1. To develop a series of teaching modules aimed at the integration of science and mathematics learning (SSMILES - *S*chool *S*cience and *M*athematics *I*ntegrated *Les*sons).
2. To develop resource lists of integrated science and mathematics curriculum materials, programmes, and projects.
3. To develop reference lists of theory, research, and development literature focused upon the integration of science and mathematics.
4. To disseminate these products and information to educators.

Development of the SSMILES will be based upon several important beliefs. Among them are:

1. Science and mathematics concepts should be taught, not merely applied, in an integrated format.
2. The sequence and selection of activities should be based upon theory, research, and effective instructional practice.
3. The SSMILES should be developed for integration into the curriculum.
4. There should be considerable teacher involvement in terms of generation, testing, and evaluation of the SSMILES.

The format of the SSMILES appears in Figure 5.

Title
Grade level
Mathematics and Science Concepts, Skills, Processes
Prerequisite Skills
Rationale
Lesson outline: Objective(s), Materials, Preparation, Procedures, Evaluation
Teacher notes: Special Populations, Extensions
References and Resources
Print Materials

Fig. 5. SSMILES

The SSMILES will be designed for use by individual teachers or science-mathematics teams. Both science and mathematics expertise will be utilized in the development and review of each of the SSMILES. It is hoped that a variety of individuals including pre-service teachers, in-service teachers, curriculum developers, and teacher educators will contribute to the development of SSMILES. Teachers are encouraged to submit SSMILES or ideas for SSMILES and will be provided editorial or subject matter assistance upon request.

Examples of some recent SSMILES that have appeared in the *School Science and Mathematics* journal include: 'Capture Recapture: Sampling with Replacement' (population, sampling, ratio, proportion, estimation), 'How Well Hidden: Modeling Natural Selection' (modeling, natural selection, variables, ratio, proportion), and 'Family Planning' (population, simulation, randomization, prediction).

In addition to the SSMILES, a data base of instructional resources and a reference list of literature that focuses upon the integration of science and mathematics education is being compiled. The work of these two national SSMA task forces will help meet the challenge of providing a variety of effective learning/teaching experiences aimed at the integration of science and mathematics.

The fourth and ultimate dimension of integration is that within the learner, the integration of knowledge within the learner's cognitive structure. The individual is a complex whole dealing with a holistic environment and as such must process and organize information in a Gestaltist fashion not in discrete partitions called subject areas or content domains. As the learner interacts with the environment and actively constructs meaning from these experiences, the individual strives toward the desired state of equilibrium (a consistency between the individual cognitive structure and the environmental information). This occurs by the simultaneous occurrence of assimilation (incorporation of new knowledge into existing schemes) and accommodation (modification of schemes) in the adaptation process. The aim of education should be to facilitate the adaptive process and the integration of knowledge within the mental structure of the learner (Piaget & Inhelder, 1969; Polya, 1963). While all of the integrations (the educational factors of learners, teachers, learnings, and learning environment; technology into the learning environment; and science and mathematics education) are important their value can only be judged by the impact they have on the ultimate integration of knowledge within the learner's cognitive structure.

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Computer-Simulations in Science Teaching

Aspects of Didactics and Software-Ergonomics*

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In *computer-enhanced learning environments*, we can distinguish between a number of computer applications (for details see ATEE86, Gorny86):

1. Open learning support:
   (a) problem solving tools ('Tools for thinking with'):
      - programming systems such as LOGO, PROLOG, BOXER, GARDEN, . . .
      - dynamic modelling systems such as STELLA, DYNAMIS, . . .,
   (b) tools for structuring knowledge by organizing data:
      - text processing and document preparation,
      - drafting and design,
      - data bases,
      - spreadsheets.
2. Guided-discovery learning:
   (a) simulation systems,
   (b) computer-assisted (educational) games,
   (c) process and robot control.
3. Resources for teaching and learning:
   (a) electronic blackboard, etc.,
   (b) communication systems,
   (c) information retrieval,
   (d) tutorials,
   (e) drill and practice.

Within these categories we find 'simulations' under the topics 1a, 2a and 3e.

Dynamic modelling systems (1a) allow the user to construct models of systems, while simulation systems (2a) contain complete unchangeable models, where the user is restricted to manipulating the model only by changing the data.

Examples of *dynamic modelling systems* are STELLA [HighPerform87], DYNAMIS [Häuslein86] and DYSIS [Bossel86]. STELLA and DYNAMIS are integrated systems, which allow the user to construct the model (with a visual language supplemented by some mathematical equations) and operate it with different sets of data. In DYSIS, the model construction process is done with paper and pencil in a visual language, but the user has to accomplish the

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*Remarks regarding my terminology:
- *simulation* (in our context) is the manipulation of a dynamic model or hypothetical components (of a physical, chemical or biological system) in order to reproduce its operation on a set of data as it moves through time. Within this paper I shall refrain from defining the terms 'model' and 'system' (see e.g., Lehman77).
- *didactics* is understood as a superclass to methodology (of science teaching) within the field of pedagogics.
- *software-ergonomics* is understood as a union of subclasses of informatics (computer science), cognitive psychology and the field of human factors in technology.

transformation to a computer model on his own by translating the visual description into a few (well-described) BASIC statements which thereafter are inserted into a frame programme.

There are many examples of *simulation systems*, which normally contain only one model. Sometimes the models can be 'loaded' into a frame programme, a method which is also practiced in DYSIS. The main characteristic of these systems is that the user has to be competent in a given programming language and the operating system at hand in order to change the model or to construct a new one. In the German literature, we find, as one example, the simulation programmes of [Koschwitz85]. A system with a thoroughly developed frame programme is SIMSEL [GMD86], allowing the teacher to programme new models in a special educational programming language (ELAN, under the operating system EUMEL). A Dutch example for a frame system is MacTHESIS [Zillesen87], which contains at least two very important achievements: the authors make full use of the possibilities of the results of software ergonomics research (see below) and they include the feature of interventions (in the running model).

The simulations included under the term '*drill and practice*' (3e) are dynamic models of technical systems, where the educational objective is to train the learner in operating the model and to reinforce certain skills while he operates it (e.g., a flight or a driving simulator). We will not discuss these systems here.

Nor we will consider industrial simulation systems often based on expert systems and implemented on high level workstation computers (e.g., LISP-machines), though these systems often have an exemplary user surface (e.g. SIMKIT [IntelliCorp85]).

From the point of view of didactics we have to point out that the *pedagogical objectives* are very different for modelling systems and simulation systems.

In a rather eclectic approach to learning theory and learning styles, we can divide *learning* into associative learning (learning of emotions), instrumental learning (learning of habitual behaviour) and cognitive learning (learning of knowledge structures) [Edelmann79]. Cognitive learning, resulting in the acquisition of structured knowledge, can be described as occuring within three layers (following Bruner and Klafki [Klafki85]), beginning with the lowest layer:

- in the direct exploration and proving of attributes and possibilities of the 'real world', in the direct verbal communication and in experiencing and discovering emotional-social relations (action layer - enactive representation of knowledge);
- in the medium of pictures, schemes and visual displays (schema layer - iconic representation of knowledge);
- in the medium of abstract notion ('symbols'), only mentally executed operations and theoretical argumentations (abstract-symbolic layer - symbolic representation of knowledge).

It is necessary to learn on the action layer first before learning can be successful on the schema layer, and before the abstract-symbolic layer can be reached. It has, however, to be stressed that this learning process is not linear but moves up and down between the layers of acquiring knowledge.

Therefore it is very important that a learner can gain practical experience (layer 1) with a physical, chemical or biological problem before he/she is presented with an iconic representation in a ready-made simulation system (layer 2). It is also necessary that he/she understands the abstraction that reality has undergone, the mathematical model beneath the simulation system surface (layer 3). A sound cognitive structure can only be acquired by learning to construct and/or change the model itself.

Donna Berlin [Berlin87] distinguishes between the categories of movement (static, animated or manipulatable representation of the model) and of representational level (concrete, semi-concrete or abstract). In her 'instructional model', the simulation systems are semi-concrete animated resources; the possibility of interventions (MacTHESIS) points also to semi-concrete manipulatable resources, while dynamic modelling systems can be categorized as abstract manipulatable resources (Fig. 1).

Transferring the categories and hypotheses briefly mentioned above from the theory of learning to learning objectives, a simulation system can only be used for the lower Bloom categories (knowledge, understanding, application), while modelling systems will also help to reach the higher categories of analysis, synthesis and evaluation.

Software-ergonomics with regard to computer simulations in the teaching of science is mainly concerned with the problem of transferring the inter-human communication to a human-computer interaction, in which the user communicates with the programmer(s) of the system via technical media, and all possible variations of the communication process have to be split up in advance into isolated dialogue steps by the system designer(s).

The state of the art of human factors research has not yet yielded receipts for the programmer, how to design a 'user-friendly' human-computer interface. There are, though, several catalogues of design requirements (for details see [Viereck87], [Balzert87] and [Schönpflug87]), most of them based on the IFIP model, which in Germany has lead to the draft standard DIN 66234 (dialog design) [DIN84].

The transfer of the three layers of learning from the learning theory described above to the design of the 'user-surface' of dynamic modelling and simulation systems leads directly to the requirement that the learner user should have the opportunity to manipulate data and to model in the most direct way possible [Daldrup87]. The design principles for user surfaces 'direct manipulation' and 'iconic representation' (on systems with the 'desk top metaphor' and 'windowing systems' on high resolution graphic roster displays, e.g., XEROX Star and Apple Macintosh) give the best foundation for application systems which do not distract a non-expert user from the topic to be learned - in our case science - even if a simulation system can only support the 'lower' Bloom categories or the two lower levels of learning (action layer and schema layer):

- The use of direct manipulation in simulation systems allows, for instance, the graphical input of data (in MacTHESIS and SIMKIT the 'scroll bar' is an analogy for potentiometers). (Figures 2 and 3)
- The direct output of the running model as a function graph is an animation of symbolic-abstract data. This is realized in STELLA, DYNAMIS, DYSIS and in the 'traditional' programs of [Koswitz85] but, for example, not in SIMSEL, where the results are stored on a disk before they can be displayed either as tables or graphs.
- The intervention, i.e., a change of variable values at any time while the model is running, gives the learner an immediate impression of the consequences of his decisions. (Figure 4)

The 'abstract symbolic' learning layer is directly supported in dynamic modelling systems, in which the learner can develop the model not only in the form of a textual representation in a programming language but in a visual representation ('visual programming') [Gorny87] and-without changing the medium - can run the model:

- The model is represented in a graphical (iconic) form in a net, which is a more efficient way than only in verbal (textual/numeric) representation as shown by [Vent85]. The user can construct this net as he/she would construct a circuit layout by adding and deleting elements to change the model. (Implementations of STELLA and DYNAMIS on Macintosh).
- The layout of the net can be changed by moving the icons and connections to modify the visual representation (STELLA and DYNAMIS). (Figure 5)

Thus the system produces a continuous direct feedback and allows an 'objective' observation of the manipulation of the model and the model data, and, in terms of learning theories and current artificial intelligence research, it offers the experimental testing of one's own cognitive structures in concrete models.

The possibility of direct manipulation of objects in the visual representation of models as semantic nets with the aid of an interactive net editor is also realized in the general-purpose visual programming systems BOXER and GARDEN (A.diSessa resp. S. P. Reiss in [Gorny87]).

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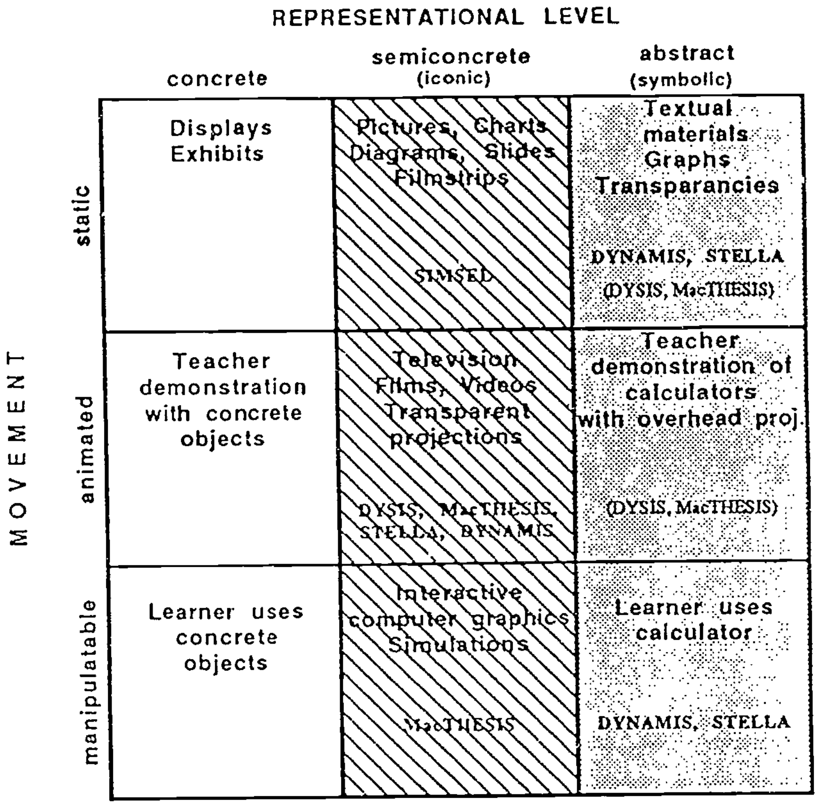

Fig. 1. The 'instructional model' [Berlin87] applied to simulations (striped area) and dynamic modelling (dotted area).
[Names of program systems and areas added by the author]

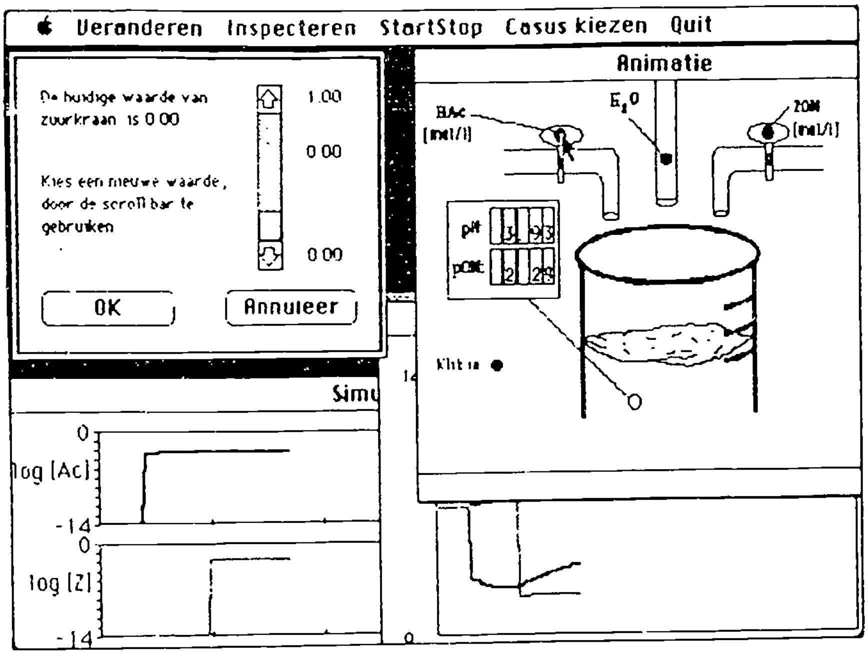

Fig. 2. Output from the MacTHESIS model 'CHEMISTRY' (a nitration experiment). By clicking the black dot (arrow) the valve can be opened to control the flow of a liquid. The value is input by moving up and down the 'scroll bar' in the input window at the upper left.

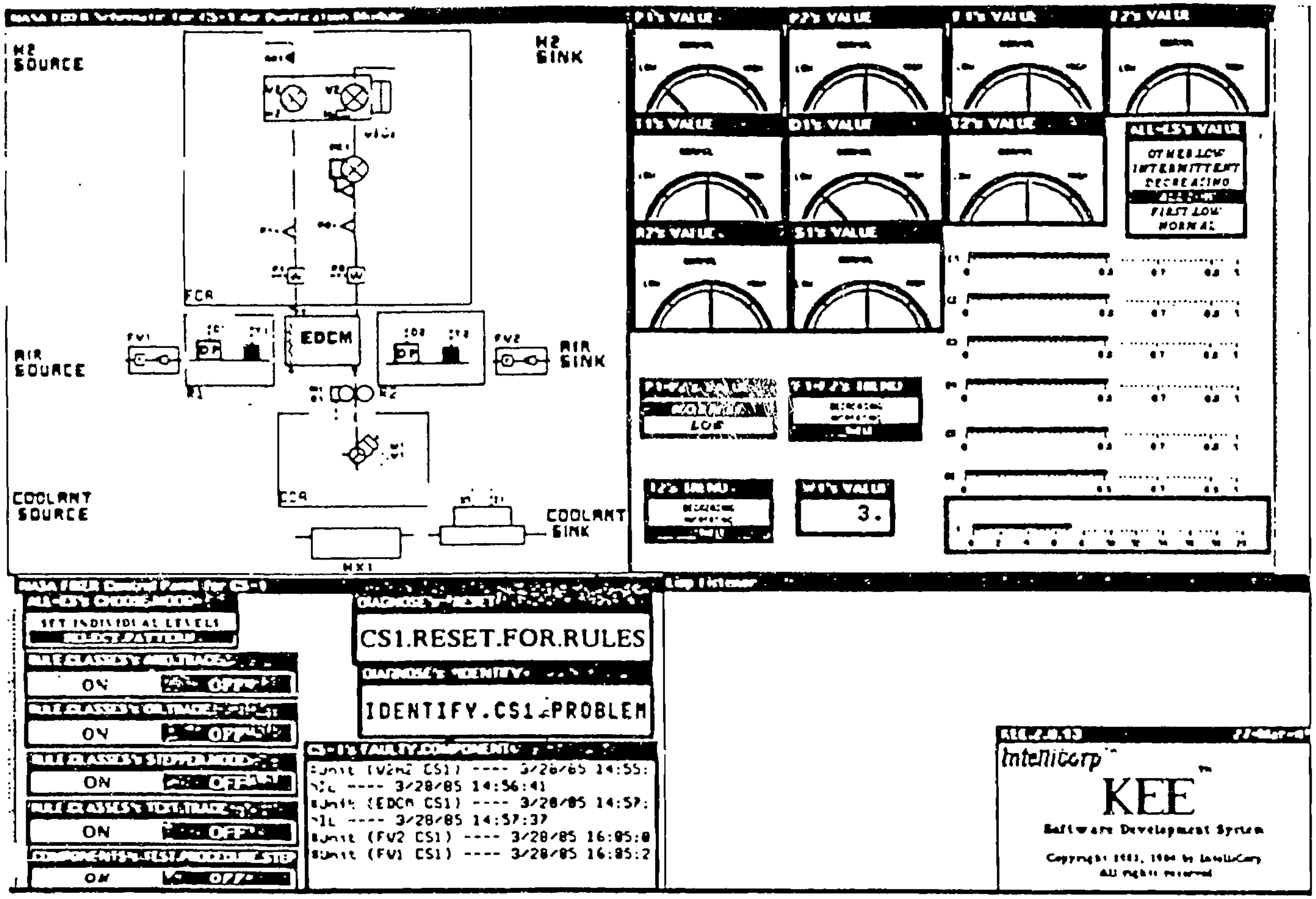

Fig. 3. This screen picture from the KEE system shows analog outputs (circular 'instruments' - upper right corner) and analog input devices (linear 'potentiometers' - right edge/center)

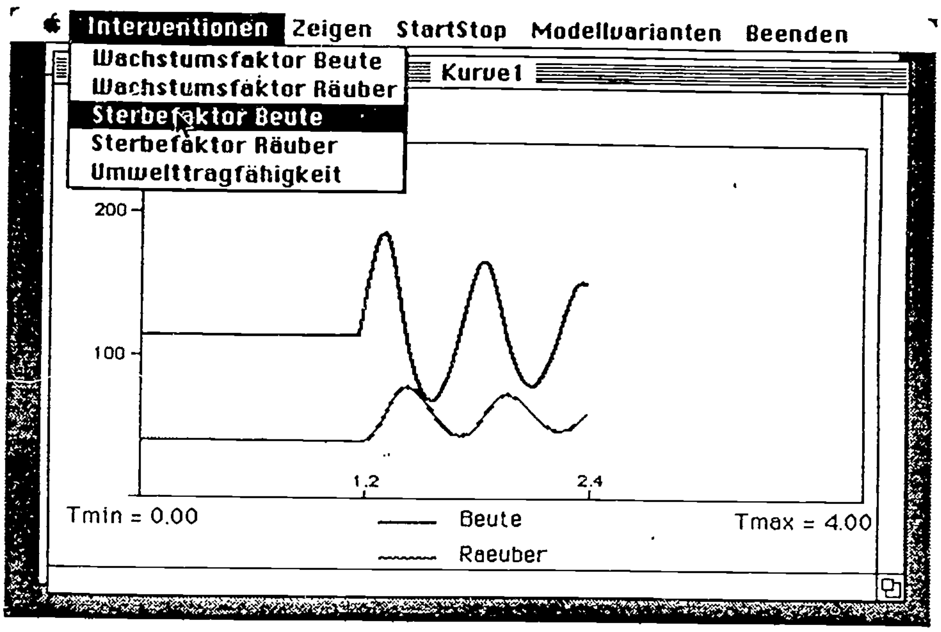

Fig. 4. MacTHESIS (German version by author) allows the user to intervene in the running simulation and change any of the model variables. Here the Lokta-Volterra model is stopped to increase the value of the prey birth rate ratio (1st intervention at t=1.2) and to change the death rate ratio (2nd intervention at t=2.4). The way to choose the new value is shown in Fig. 2 (scroll bar in the window at the upper left corner).

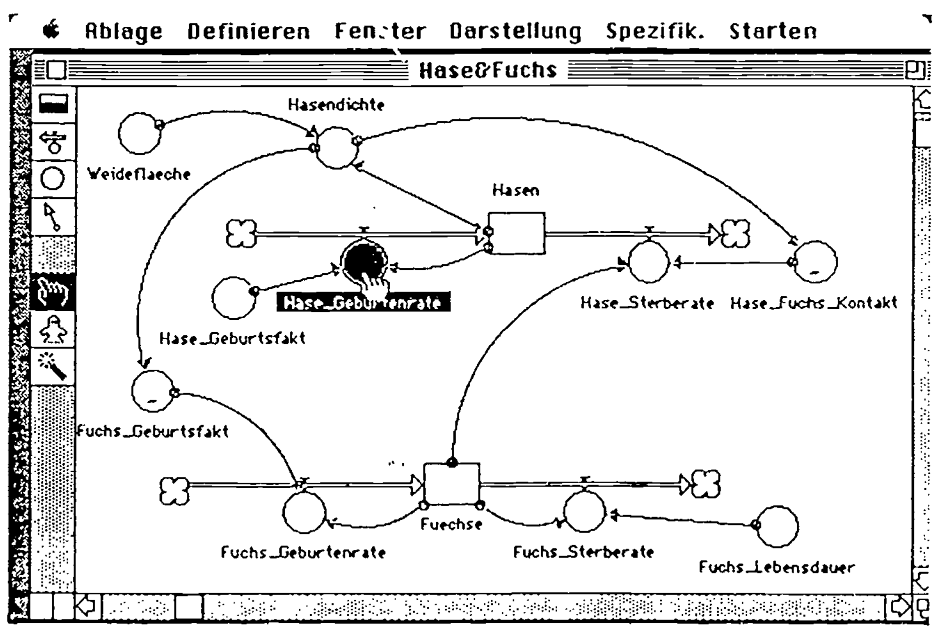

Fig. 5. The system diagram window of STELLA (German version by author) allows the editing of a network. The network is the graphical representation of the model. By pointing and clicking once at one network element this can be deleted or moved; by clicking twice it is 'opened' (then numerical or algebraic specifications of the model can be defined).

Consequences of the History of Science with Regard to the Learning Process in Science Education

von Altfrid Gramm

In 1983, Ludwig Knöpfel published an article entitled: 'Über die Verwendung des geschichtlichen Elements im chemischen Unterricht'. He starts from the point that, at the university, sciences are dealt with mainly dogmatically. This means that scientific contents are developed in the following way: Starting with the most general statements, with axioms, definitions, and superior principles, explanations of individual phenomena are deduced therefrom. Knöpfel rejects such an instruction method for general education at schools because the development of the mind will not take place using this method. He contrasts the dogmatic method with the historical-developing method. He considers the historical-developing method to be better because it responds to the students. Their present status of knowledge is the starting point for learning. The teacher guides the pupil by appropriate questions. Thus the student is forced to do his own thinking. He is encouraged to discover and produced new ideas. The educationalist Diesterweg characterizes such a method of instruction as natural and educational. Knöpfel concedes that this methodical procedure makes more heavy demands on the teacher than the 'geisttötendes Vortragen' (stupefying lecture). A great difficulty arises from the teachers' poor educational background because, at the university, they are taught by the dogmatic method. Knöpfel believes that the historical-developing method is not only accepted as the appropriate method but that the teachers try to master it in practice. Because of that, their interest in the history of science is understandable. Accordingly, a large number of articles are published concerning the history of science.

Knöpfel states that a new era begins with his method of education in science. Teachers of science have to be familiar with the historical evolution of science and have to take this into account during their teaching. The treatment of subjects is done by the logical-psychological method, which is deepened by consideration of historical development. Thus, Knöpfel asks for relating the historical-developing instruction that meets the demands of subject and learner to the evolution and establishment of science in the way it happened in history. However, this process does not take place. Knöpfel argues: The representatives of sciences - including the teachers of science - are extremely specialized. Because of their particular research interests, they have lost the general view of the whole. With such a specialization, they cannot represent science in education in a way which develops logically and historically the entity of natural phenomena. The historical aspect is realized by naming several discoverers and inventors when appropriate or by giving a few chronological notes or anecdotal trimmings. In Knöpfel's opinion, such a procedure neither makes the subjects more palatable nor more digestible. Altogether, Knöpfel emphasizes two aspects which demonstrate the effectiveness of the historical element in science education:

1. The subjects of science education are completed by details concerning history. Knöpfel rejects this method because, in this way, only supplemental facts are mediated which do not at all support an understanding of chemical processes.
2. Historical evolution may be a model for the developing method. Thus, reflections about history may support this method. It regards science as mental constructions being in the process of differentiation. While the dogmatic method required memorizing of the contents, the logical method represented the consistency of the scientific system and the

psychological method considered the learner in his cognitive faculty, the historical-developing method tries to be logical-psychological by including the historical development of science. This means, according to Knöpfel, that the contents to be presented is not only logically consistent but has to be developed psychologically meaningfully with regard to the learner. Thus, scientific contents can be mediated in a natural way that corresponds to the human mind. A model of this developing instruction method is the history of natural science.

Knöpfel's conceptions approach the idea of genetic instruction, which Friedrich Dannemann proposes in 1907 in his book 'Der naturwissenschaftlich Unterricht auf praktisch-heuristischer Grundlage'. The heuristic method of instruction is, according to Dannemann, a searching, as indicated by the socratic method. Dannemann characterizes the heuristic procedure as a dialogic one. First of all, the teacher sets, for himself and the students, a task concerning every lesson. This aim has to be well-defined and easy to understand and should arise from the preceding. It should be reached during an instructive dialogue. The direct observation or, if this is missing, appropriate means of illustration serve as teaching aids. Concerted reflection by teacher and students lead to the desired result of the instruction.

This heuristic method has to be completed by a second aspect, considering science education. Sciences are founded mainly on observations and experiments. Thus, the learner has to reach the results of learning by independently observing compounds and their reactions in experiments. Therefrom the 'praktisch-heuristische unterrichtsverfahren' (practical-heuristic method of instruction) for science emerges. Dannemann devotes a detailed chapter to the consequences of the history of science to the instruction outlined by this idea. The individual process of understanding and learning shall take a similar turn as the evolution of science.

These ideas are created following the biologist, Fritz Müller, who in 1884 defines that 'die Entwicklung des Einzelwesens eine kurze Wiederholung des Stammesgeschichte darstellt', thus the so-called fundamental biogenetic law. In this conception, the history of science has not only an important but a decisive function for the selection and succession of subjects. Dannemann calls this practical-heuristic method of instruction, which also considers the historical evolution, the genetic method. Dannemann substantiates this teaching technique by ideas of the educationalist Otto Willmann. Otto Willmann takes the view that the fundamental biogenetic law has to be used as a basis for teaching methods. From this point of view, the genetic method is the best one conceivable because the mediation of mental content has to keep to the important stages which were passed during the generation of this content. The genetic procedure is supported in its effectiveness if the learner is lead directly to the literature by authorities in science and acquainted with easy-to-understand sections of the epochal papers published by the great scientists. However, Dannemann warns of overstating the genetic principle: On the one side, not all wrong ways in the evolution of science have to be done but only those which are important for the development of conceptions. On the other side, in instruction one should disregard experiments, instruments, and theories which may be important primarily for a historian of science because they may take the learner away from the desired purpose.

Thus, we find an additional aspect in Dannemann's work which is already suggested by Knöpfel: The history of science offers criteria for constructing a sequence of subjects for instruction.

This survey of the history of instruction in science carried out by two examples explains three aspects:

1. Already at the turn of the century, educationalists of science wondered about the possibilities of making education in science more effective by means of the history of science. Simultaneously, it was demonstrated - and I have not yet mentioned it - that the value of education in science in the sense of the classical education of that time is raised considerably by regarding historical elements, i.e., by explicitly having as a theme the importance of the human mind for the development of science.
2. The problem of the interdisciplinarity of education in science did not confront the people at that time. The main reason may be that, at the turn of the century, the controversy about the introduction of the respective sciences as subjects was brought to a first close by the proof of their individual importance for education. The claim for interdisciplinarity was opposed to that.

3. Science education proceeded from the assumption that the learner possessed little or no information. Thus, science education was regarded as instruction to be done by the teacher, as a furnishing of the student's mind which was assumed to be empty of scientific thoughts.

Today we see the learning process totally differently: Learning is understood as the organizing of structures in the learner. The learner gains experience by acting and observing and tries to arrange these acquired experiences. In doing so, he develops a system of ideas which enables him to project actions and to predict the results of processes. By that, the individual is enabled to control processes by a variation of conditions and to plan his actions. The important difference from the elder methods of instruction is that the learner performs learning by actively examining and solving the recognized problems, which is subjectively satisfying. By that, learning is a process actively carried out by the learner, the course of which is always controlled by special contents. In doing so, the learner builds up a system of ideas which are interconnected. He can use it for solving other problems in the course of which new connections and also new ideas are formed or previous connections turn out not to be meaningful.

This conception of learning, outlined in the foregoing, is supported by Karl Popper's ideas. Popper devotes himself to the problems of learning in the book 'The Self and Its Brain - An Argument for Interactionism' by Popper and Eccles. He takes the view that we learn by experiences, through action and selection. Human acting always refers to an aim; we act with special expectations or theories. Above all, we anticipate that we will reach the desired aim or that we will get at least closer to it. Therefore, we construct programmes of action. Hence, learning is a process of modification and selection to which we are induced by disproving our expectations or by disappointments about the effectiveness of our programmes of action.

Here the term genetic learning gets a new different meaning: genetic learning no longer orients itself by the earlier-performed, historical process but is applied to the individual learning subject. In instruction, the learner no longer plays the role of an addressee for contents to be mediated but is regarded as an actor of his own learning processes. Martin Wagenschein was very successful in realizing these notions. According to his conceptions, instruction proceeds in a way that all learners express their subjective opinions even pre- or non-scientific ones - to a phenomenon with which they together become acquainted. The teacher does not determine the course of the learning process by informing the students with his own knowledge but the learners discuss their problem to bring about insight and comprehension. To realize this kind of learning process in instruction, one has, according to Wagenschein, to pay attention to several conditions:

- Every student has to be willing to mention everything he is thinking about a problem.
- The teacher has to be reserved and to keep back his perfect knowledge; he has to listen and, if necessary, to take care that the discussion sticks to the point.
- All participants have to feel responsible that everybody gets the opportunity to understand the other, so that all together can become absorbed in the matter.

The term 'genetic' gets its sense by constructing a new view in every single learner, a view that is based on conceptions developed earlier. The sciences are not put into the student by the teacher but they are built up by the student by problem-solving processes; they are constructed, so as to speak, as a new association of sense. Now we have to ask: what meaning has the history of science in this instruction method and where is what we call interdisciplinarity?

1. In Martin Wagenschein's genetic instruction - discussed immediately above - the role of the history of science has totally changed compared with the practical-heuristic-(genetic) method: the historical evolution of science is no longer a guideline of the instructional procedure. It is not mediated initially to the learner because the historical problems need not be the problems of today's learners. History is no longer the first mentor of the students. It is true that it can become the mentor of the teachers because, on the basis of its study, the teachers can become acquainted with the questions which have determined the development of the sciences.

   When the student has reached a first understanding of questions of biology, chemistry, or physics, it becomes meaningful to introduce the history of the sciences. The students can recognize how known problems were solved with the aid of notions and theories but also how accepted theories can blind one to other problem solutions: Aristotelian doctrine of principles, Phlogiston theory, Lavoisier's ideas of oxidation. The permanent interplay between theory and empiricism develops the sciences: theory driven empiricism and empirical control of theory.

2. The problem of interdisciplinarity too appears in a different light with Wagenschein's approach: the interdisciplinarity which we search again and again proceeds on the assumption that the world is divided into separate parts whose connection is lost. Science is determined by a specialization, by a limitation of questions, of methods for answering them and of targets.

   Using the genetic method discussed, the student realizes that gaining perceptions concerning natural phenomena means a grave renunciation of other possible aspects: it is the same moon which is observed by scientists, poets, and lovers - and each of them constructs a different picture of this moon. But, which is the correct one?

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Computer-Assisted Learning (CAL) in Science

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Introduction

This paper aims to demonstrate how the software for computer-assisted learning (CAL) in science produced by the Computers in the Curriculum (CIC) Project (King's College (Chelsea), London University) reflects the changes in the science curriculum from the traditionally content-based to a more interdisciplinary, process-based curriculum.

The computers in the curriculum project

The development of computer-assisted learning (CAL) materials began at Chelsea College, London University, in 1969 with a project to produce science materials for the 16-19 age range.

The Computers in the Curriculum (CIC) Project now produces CAL materials across the curriculum for the whole secondary school range (11-19 years) and has been supported by various bodies such as the Department of Education's Microelectronics Education Programme and Microelectronics Education Support Unit, the Schools Council, the British Broadcasting Corporation, the Nuffield Chelsea Curriculum Trust, the United Kingdom Atomic Energy Authority, and British Telecom.

Design and development of the packages

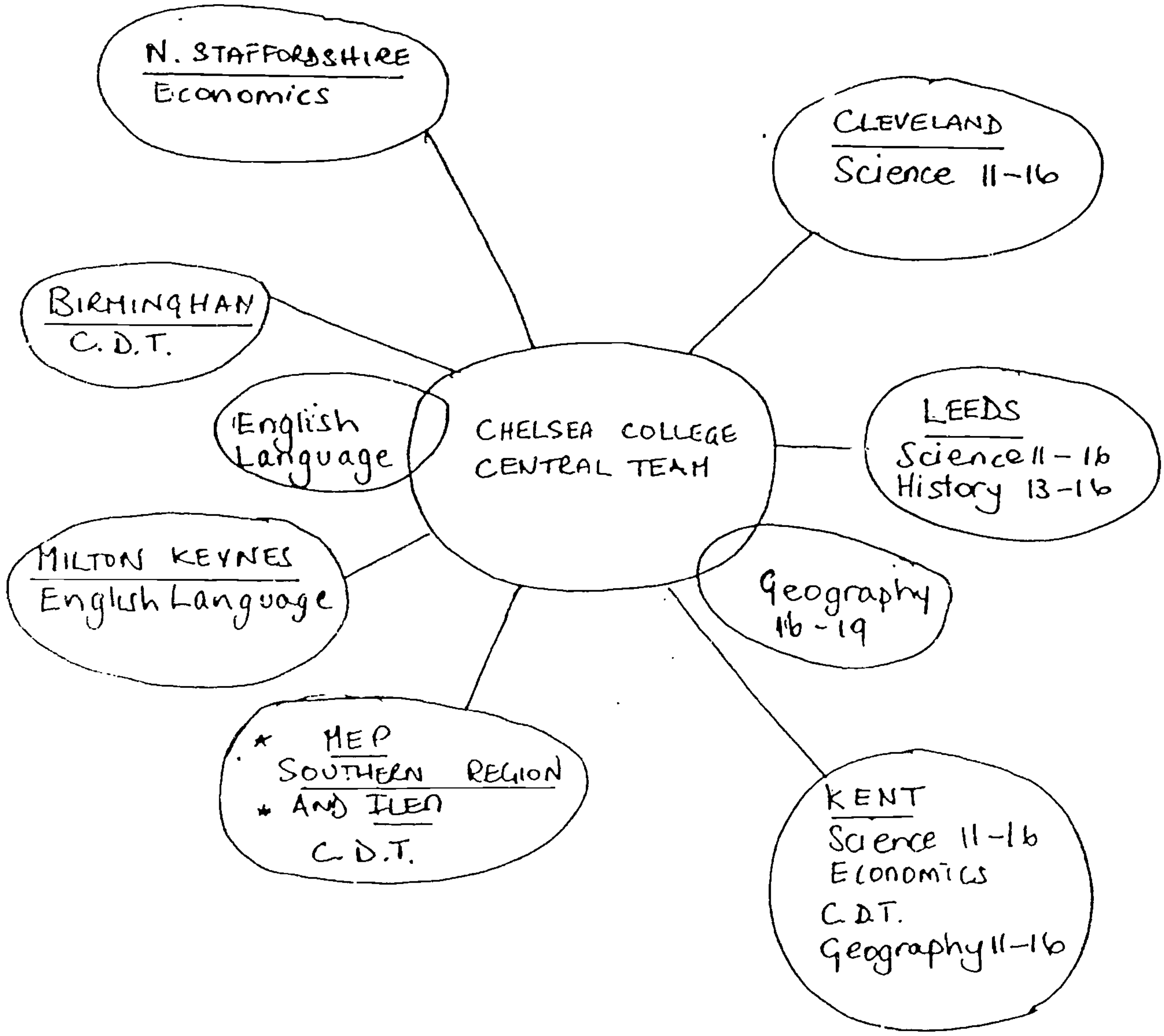
One of the most important considerations in the design of the materials has always been 'How will the teacher be able to use the package and incorporate it into the curriculum?'

The design of each package produced by the project is carried out by a group of innovative teachers who collaborate to provide the ideas to meet their teaching needs. See the flowchart showing the stages in the development of a science package.

The discussion of proposed units by the Science Panel, which met at regular intervals, ensured that resources were not wasted on educationally unsound developments and prevented 'reinventing the wheel'.

The use and evaluation of the materials during trials in the classrooms in many different schools led to many modifications but ensured that the materials were educationally sound, robust and could be integrated into different teaching strategies.

Most programmes are produced to run on RML 380Z/480Z Disc and Network, Apple Disc, BBC Disc and Network by using a Library of subroutines. These are the computers used in most schools.



* MEP - Microelectronics Education Programme
* ILEA -Inner London Education Authority

DIAGRAM OF PROJECT STRUCTURE DURING MAXIMUM PRODUCTION

IDEA

↓

Prepare outline of proposed unit

↓

Outline discussed by Project Science Panel

↓

Prepare detailed Specification for Programmer

↓

Programme written by programmer // Documentation written by author

↓

Programme prepared for trials (copied for different machines) // Documentation edited, typed and prepared for trials

↓

SCHOOL TRIALS

(i) Introductory meeting
(ii) School use
(iii) Feedback meeting

↓

Trials Feedback to Project Science Panel

↓

Programme and Documentation Revised according to trials

↓

Preparation for Publication (Central Team)

↓

<u>Published by Publisher</u>

DEVELOPMENT OF CAL MATERIALS IN SCIENCE

Computer-assisted learning (CAL)

In CAL packages, we make use of:

- Simulations
- Games
- Modelling
- Calculations
- Data storage and retrieval
- Collation and display of experimental results
- Direct collection of experimental results

Programmes using these techniques provide different learning environments.

In the classroom, CAL programmes can be used by:

- individual pupils to encourage the understanding of concepts by experiential learning;
- groups of pupils to encourage understanding of concepts and development of communication skills;
- the teacher as an 'electronic blackboard' to generate discussions and questions.

Changes in software

The last 15 years have seen many changes in the educational software packages produced by the CIC project. These have been brought about by many factors both external and internal to the project.

(i) Hardware

In the 1970's, some schools had teleprinter terminals served by regionally based mainframe computers. With the advent of the microcomputer, the Department of Trade and Industry together with the Local Education Authorities and secondary schools, provided funding to place a microcomputer in every secondary school in the country, to be used in an interdisciplinary context.

Further funding has provided a second computer, peripherals and software. In the mid-80's, BBC microcomputers were introduced into the primary schools, supported by in-service teacher training courses. Since then, most schools, primary and secondary, have increased their number of computers, with many secondary schools having at least one in each department.

(ii) Supporting material

In the earlier software packages, extensive Teacher and Student Notes were included because, to many teachers and students, the computer was a very unfamiliar medium for learning. As well as providing a useful extra resource to enhance the learning for students, the software had a part to play in educating the teachers. The Student Notes were structured to provide Worksheets with questions to lead students through the programmes, thus easing the workload for the teacher.

It was expected that, once teachers were familiar with the software, they would want to construct their own worksheets according to the abilities of their students and the place in the curriculum. From my experience, many teachers did not have the confidence in the 'new medium' to exploit the flexibility of the CIC educationally sound programmes. They were unable to recognize that programmes could be used at different levels with differing abilities.

With increasing computer literacy among teachers and pupils, there has been a reduction in the quantity of the supporting material, although teachers still feel the need for suggestions for use and background material for the topics.

(iii) Programme control

Initially programmes had a dialogue style of programme control dictated by the teleprinter terminal of the mainframe computers. The programmes were linear and unwieldy, especially if only one or two parameters needed changing, e.g., the programme ANALYSIS 5:

How many compounds to be specified? 4
How many compounds to be chosen at random? 0
Which column do you want ? 1
Give number of compound and proportion in mixture separated by a comma, e.g. 2,10
1 ? 17,1
2 ? 18,1
3 ? 19,1
4 ? 1,1
Do you want to change maximum number of lines (it is now 120)? No
Do you want to select the chart speed? No

With the introduction of microcomputers, considerable use was made of the static screeen with pictures, diagrams or graphs. An option style of programme control was adopted, in which each option module has an associated keyword. A *primary keyword* initiated one option, e.g., Temperature (TEMP or T) may prompt the user to supply a temperature. GRAPH will supply a graph of results.

A *secondary keyword* initiated a sequence of options, e.g., DEMO could invoke a suitable sequence of options producing a demonstration of the programme. For example:

Option ? TEMPERATURE
What is the temperature(°C) ? 60
Option ? GRAPH
The results will then be displayed as a graph

As the programmes made more use of the excellent graphics facilities, so the programme control changed to single key entry, with a menu usually on the screen at all times. For example:

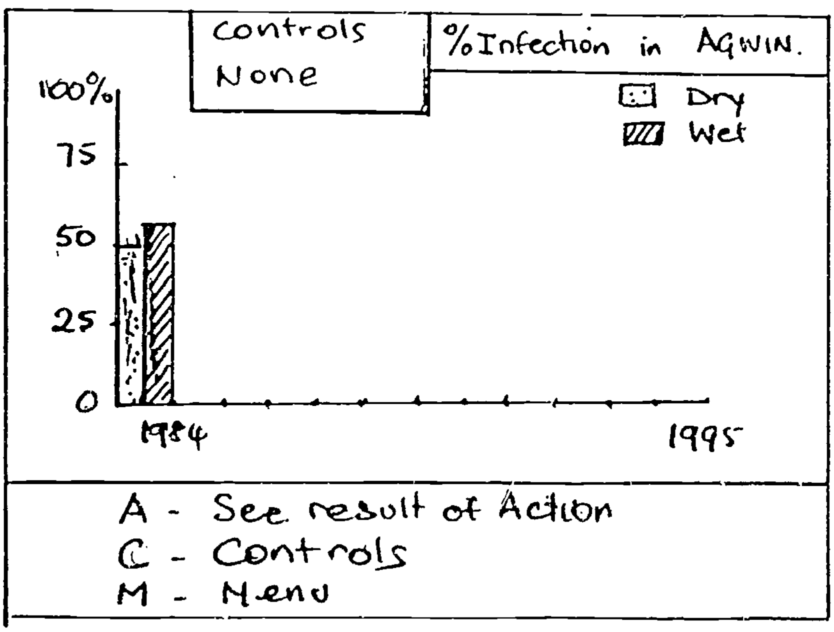


Diagram of one screen display from RELATIONSHIPS

(iv) The science curriculum

School science is changing rapidly. This is in response to the changing nature and needs of society and the national movement towards a broader, more practical and vocational curriculum and system of examinations.

The changes in the science curriculum are reflected in the CAL software packages. Earlier packages were very closely related to the subject content of the science syllabuses and were mainly produced for biology, chemistry or physics courses for 16-19 year olds. For example:

Biology	- Pond Ecology
	- Limiting Factors in Photosynthesis
Chemistry	- Organic Synthesis
	- Gas Chromatography
Physics	- Mass Spectrometer
	- Momentum

The Secondary Science Curriculum Review (SSCR) was set up in 1981 to consider the implications of providing suitable science courses for all students aged 11-16 years and to stimulate and support the development work that is required to enable schools to make appropriate curricular provision. It was undertaken by the Department of Education and Science, the Association of Science Education and the Schools Council, which recognized that there were three central problems in the provision of science at the secondary school level:

1. Early specialization in biology, physics and chemistry.
2. As a result of the foregoing, difficulties in accommodating other specialist sub-sets (e.g., geology, astronomy, microbiology) and alternative integrated approaches to science teaching (e.g., environmental science, social biology).
3. Specialized courses tending to emphasize the structure of the subject at the expense of such issues as how the subject matter is applied and used, its social relevance and the nature of its historical development.

The development phase of the SSCR began in 1983 with the establishment of many regional groups of teachers working to produce curricular materials In parallel with this, and preceding it by about 18 months, the CIC science groups began looking at areas in which CAL could enhance the changed curriculum following the review. There was a change in emphasis from subject-based software to the newer ideas on science teaching:

- Interdisciplinary topics
- Science and society
- Science and industry
- Investigative skills
- Problem-solving
- Information technology topics

The result of this development work has been the production of many packages aimed at covering boys and girls of all abilities in the 11-16 age range.

Some programmes provide experiential learning in an open-ended and unstructured way. Thus:

WORLD OF NEWTON

* provides a 'dynamics laboratory' having an object which moves according to Newton's laws of motion in an ideal environment.

DOMESTIC ELECTRICAL FAULT TRACING

* provides opportunities to solve problems in a heuristic way;
* enables the development of good strategies to find a solution;

* emphasizes the relationship between science and everyday life.

THE DYNAMIC MODELLING SYSTEM

* enables pupils to develop an awareness of the strategies involved in problem-solving;
* allows them to propose and investigate models of physical and biological phenomena.

SITING A BLAST FURNACE

* develops an awareness of the many factors associated with industrial location;
* relates science, industry and society;

Another innovative development related to hardware, syllabus and changing trends resulted in the production of 10 CAL programmes which enhance, extend and complement a television series 'Science Topics'.
One example of this is the programme 'RELATIONSHIPS' which:

* provides an opportunity to control the level of malaria in an African Village. (The TV programme deals with the relationships between different living things and gives pictorial information of malaria control in Africa.)
* Gives the pupil experience in:
  (i) Data interpretation
  (ii) Looking for patterns
  (iii) Predicting
  (iv) Decision-making
  (v) Interrogation of a data base
  (vi) Relating science and society
  (vii) Understanding social and economic problems.

The later development work has also reflected the influence of information technology on science education.

The 3-D DATA ANALYSIS PACKAGE currently undergoing school trials can deal with the full range of collected and stored data commonly used in secondary schools. It makes full use of window techniques and the larger capacity of the more powerful microcomputers such as the IBM and RML Nimbus.

This short paper can only serve to give a flavour of the work carried out by the Computers in the Curriculum Project during the last two decades in Britain. However, it is hoped that it will provide a reference point for other countries to continue to develop computer-assisted learning materials which help to further the teaching of science and technology in an interdisciplinary context.

Software demonstrated

ENZYME KINETICS
Chelsea Science Simulations
M. T. Heydeman and Sophie McCormick
Edward Arnold (Publishers) LtD. 1982

LIMITED FACTORS IN PHOTOSYNTHESIS
Fry, Hunter and Rose
Longman Microsoftware 1984

WORLD OF NEWTON
Jon Ogborn
Longman Microsoftware 1986

DOMESTIC ELECTRICAL FAULT TRACING
Alison Rose and Gordon Varley
Longman Microsoftware 1986

SITING A BLAST FURNACE
John Oversby
Longman Microsoftware 1985

RELATIONSHIPS
Alison Rose and Anita Pride
BBC Publications 1985

A Basis for a Triple Integration:
Language-Mathematics-Informatics

A. L. Semenov

This paper reports on a system of education based on new information technologies started in the Soviet Union. The work is conducted by the Soviet Academy of Sciences within the framework of the project 'SCHOOL-1' directed by Prof. E. P. Velihov.

The direct sources of the project are the activities of the Department of Structural and Applied Linguistics at Moscow University and the Research Group on Education under Prof. Bl. Sendov at the Bulgarian Academy of Sciences (RGE). In the sixties and seventies, the Department of Structural and Applied Linguistics worked on an integration of language and mathematics within the framework of the Olympiads in mathematics and linguistics taking place in Moscow in those years. The REG developed the ideology of such an integration and introduced it at its experimental schools within the subject of 'Language and Mathematics'.

Before discussing the main point, it would be useful to list the general principles underlying the pedagogical concepts of the project SCHOOL-1, i.e., an active approach to the process of training and more generally to man's way of life:

1. Formation of a system of clearly understood goals, beginning with most general ones, and ending with the most minute of those which pertain to the separate steps in problem-solving.
2. Self-control in contriving these goals, a possibility of taking a side-look at one's activity and to evaluate it.

Remarks: 1. The goals should, of course, be reasonable. Considering the usual marks or grades as a general objective does not make sense.

2. As happens in other cases, a misuse of reflection/evaluation is, of course, possible, but this is still a situation too far ahead for the school system of our days. Objectives, only gradually realized in the process of achievement, or after it, will exist always.

3. Honesty in evaluating the extent to which goals have been attained. Knowing rules by heart does not mean that they have been understood.

Creativity in learning. The idea of a creative attitude to the learning process is clear and simple. But, how to achieve such an attitude is not so clear. However, separate steps in a given direction are evidently possible, their value being largely dependent on other principles. More specifically, the principle of creativity does not contradict the principle of consciousness. The goals in themselves can and must lead to creative acts.

Equal possibilities within individual training. The equal right to education presupposes equal possibilities for everyone to obtain the education he or she needs, he or she can or must receive. All children must be given an opportunity to be trained as fast as they can and in such an amount that would suit their needs and abilities.

Continuity and steady improvement. The contradiction between inertia, the conservatism of educational systems, and the constantly changing world is especially sharp at present. All of the principles here proposed furnish one or another solution to this problem. But here we would like only to stress that the new education should contain all of the main elements of the old one. Moreover, the need of a steady improvement must be built into the new system; reform must be continuous and not consist merely of radical alterations from time to time. Education should not lag behind life; it ought to be ahead of life.

Curricula in various areas should be designed by those who create and change these areas. Linguists, mathematicians, biologists, specialists in the other areas of knowledge, engineers, managers. . ., all who represent the structure and methods of contemporary and future science and its application, and not experts in the theory of education in linguistics, production, etc. should play the main role in developing curricula. It is often worthwhile to ask a biologist to write a textbook on chemistry and a mathematician a textbook in (their) native language.

Integration of knowledge. A comprehensive integration of the study of the phenomena and laws of the real world is also relevant to the common tasks of education. It is not in contradiction with the variety of viewpoints on a subject, it harmonizes with that variety. To show the differences in the methods of the different languages of art, science, philosophy, mathematics, biology, etc. is of major importance.

New information technologies in education. Their use, more particularly the use of computers at school, is of course not a principle or aim for its own sake. We only hope that it will be instrumental in the materialization of all of the other principles. The best children's books were not written for children. At the present stage of using computers at school, it seems that the best educational software does not train directly for anything. The cases with the best effect of computers in education usually look as follows: an applied system or class of systems, with a sufficiently wide range, is taken, and possibly adapted, and is then put into the hands of a child. What are the existing computer applications in school? They are:

- text processing;
- information systems (data bases);
- machine graphics;
- modelling;
- mathematical calculations (calculator);
- management;
- telecommunications;
- symbolic transformations;
- analysis and synthesis of sound and video signals;
- programming.

In the words of Sendov, a child who easily handles one of the calculation devices is a new subject of training - 'a child with a computer'. If he (she) has a calculator, he (she) can check his (her) solutions of arithmetic problems or entirely read them on the computer; if the student has a data base, he (she) can fill it with weather observations, for example; machine graphics will enable him to carry out his drafting assignments much faster and much better; the system of programming can place in his hands a universal medium of modelling the world around; a musical synthesizer enables a child who originally has no musical ear and performance abilities to compose and also perform his own musical compositions; an access to large data bases and expert systems makes it possible for a child to learn more than anybody around about the question he is interested in. This list could be made much longer.

Maybe it is worthwhile to tell the story of the emergence of ideas which underlay the course proposed here so as to clarify them. In starting our work on the essence of primary school education in Russian language, we proceeded from only one objective of education; to teach a child how to write correctly. Apart from that, we permitted the use of the computer. As work went on, it became evident that, along with the natural achievement of the aim of orthography, other aims were also attained, although only in part, which traditionally were formulated not within the course on native language but in the framework of courses in linguistics, informatics and mathematics. Furthermore, it seems to us that the course presented here may also prove to be useful in producing a number of sufficiently common habits of thinking. On the other hand, the explication of the general linguistic and mathematical aspect of things makes it possible, by furnishing many examples at a very early stage of training, to enable children to feel the difference between the mathematical and the linguistic views of the phenomena under study.

An analysis of the current courses in the Russian language shows how unsatisfactory these courses are, not only from the point of view of present-day linguistics but also from the point of view of elementary logic. We shall confine ourselves here to just one of the many possible examples. All children learn, and almost all adults remember, the rule 'Write "жи", "ши" with "и"'*. A keener comprehension, which can hardly be heard clearly explained by one out of a hundred teachers, may consist in that the rule advises that it could be done when possible, i.e., when you hear "жи", you write "жи". Understood in this manner however, the rule simply is wrong: it advises people to write 'жилатин' instead of 'желатин'. The fact that this rule is present in all textbooks and the fact that its absurdity is not noticed both show that substantial progress remains to be made.

The following are the ideas lying at the basis of the course offered here.

Language undoubtedly is one of the integrating factors in school training. This is already obvious from the fact that, being a means of communication, language is needed in each subject as well as in practically all human activities.

It is highly important not to divorce the study of language as such from its usage. The task of teaching communication using language should not be discrepant with the task of the correct use of language. Such a discrepancy appears, for instance, when we forbid a learner to write the wrong way, when we reproach incorrect writing as wrong and thereby suppress the endeavour to use written speech for communication. On the contrary, the child should realize that incorrect writing is not bad in itself but most of all because it renders communication difficult. This implication becomes directly tangible for a child when handling a computer. A computer does not 'understand' wrong words, be they incorrectly spelled terms of language of programming or an incorrectly spelled name of the stock of information.

It should be noted here that the use of a computer as a means motivating semantic correctness is even more functional. Let us dwell on the question in some more detail. When we begin to ponder the development of communicative habits in a child, the task of giving explanations about a road in a town often comes to our minds: 'you come to the crossroad, then turn right, and then to the left'. If a child supplies such an explanation to a computer, he will promptly watch visually the result of his explanation. If he makes a syntactical mistake, the computer will simply not understand the order. If the mistake is semantical, it is immediately expressed in the computer operations. In a case similar to the road explanation, the fault may be expressed in that the computer-manipulated cart will not go there. Instead of the physical move of the cart, the drag of a turtle may be seen on the screen. When a computer is used during the process of explanations about a road, we face a pedagogical as well as purely practical game.

But let us go back to the task of correct literate writing. I would like to recall that communication is the main motive for that task. However, this task is closely connected with the study of language structure itself. And the appearance of the native and foreign languages as subjects of study should be motivated mainly by the needs of their usage.

On the other hand, considering language as an object of study is, quite naturally, included in a mathematics-informatics context. Let us begin with the fact that sequences are objects of language. A sequence of letters makes words, a sequence of words makes sentences and so on. Naturally, grammatical concepts and rules are formulated in the terms of sequences. But a sequence is also the chief object of informatics. Other sequences should appear in language context even before the grammatical treatment of sequence, e.g.:

- sequence of physical objects,
- sequences of events,
- sequences of digits,
- sequences of people (queues) etc.

Problems about such sequences may also include operations with the sequences (concatenation, etc.) as well as other set-theoretical and combinatorial concepts. Thereby, the study of sequences becomes a common basis for native and foreign language, mathematics, informatics and linguistics.

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*A native Russian will be tempted to write 'ы' instead of 'и'.

The syntactical relationships between objects (sequences in this case) are characteristics for mathematics. In informatics, the processes are discussed along with statistical data. An understanding of the system of concepts in informatics related to the algorithmic processes is helpful in making of a computer an editor of texts. The computer milieu similar to the one in use in the LOGOWRITER system is of great value here. The situation is similar to the aforementioned case of road explanation. There is a text, a milieu where an activity is taking place. The activity may be carried out directly, by pressing the keys which place in subsequent order the performance of different actions. But the programme of action may be set in advance, then switched in, and the results of its work on the text may be seen.

The text editor may be 'intellectualized'. But, for this purpose, the student himself should put into the system the grammatical knowledge needed. And here we see again that the pupil finds himself in a situation in which, by the help of a computer, he separates knowledge into a strongly-algorithmatized one, understandable for the computer, and other knowledge. The elements of an algorithmic, mathematical and informatical culture continue to develop. Grammatical terms and rules are used, of course, along with algorithms and statistical relations. Grammar rules and their analogues relevant to sequences, but not to the natural, real substance of language, constitute the genuine material for the study of a number of theoretical multiplication concepts.

It is important not only to seek what linguistics and mathematics have in common but also to demonstrate the difference in the methods of these sciences. For example, it is important for linguistics to grasp the typical situation, but not all cases.

After learners have begun to freely operate mathematically with non-language sequences and with sequences of their native language, they can start solving problems with them referring to other languages. Each of these tasks requires the input of a limited material referring to concrete languages. All of them form together an exuberant material which familiarizes a learner with the methods of present-day linguistics; they develop a mathematical and general humanitarian context that covers the whole history of the human race.