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ABSTRACT

This volume marks the completion of Phase II of the Centre for Educational Research and Innovation (CERI) project of inquiry into the issues inherent in the introduction of new information technologies in education. It summarizes the issues discussed and the recommendations made by four working groups at an international conference, each of which focused on the effects of new information technologies on instruction in one of the four basic skills, i.e., reading, writing, science, and mathematics. Members of these groups included representatives of Australia, Canada, Japan, and the United States as well as various western European nations. Noting the increased pressure on governments to provide better basic skills education, it is suggested that two emerging forces can help to provide a sound basis for the introduction of new technologies into education--inexpensive information processing power, especially computers; and the growing field of cognitive science that can rigorously study, understand, and improve the educational process. Each of the four basic skills is examined in the context of: (1) current instruction; (2) existing information technologies; (3) promising areas of research and prototype development; and (4) the implications of the new technologies. It is recommended that OECD (Organization for Economic Cooperation and Development) member nations encourage course demonstration and development; reexamine the basic skills curriculum in light of changes brought about by new information technologies; cooperate with other countries to develop software that is both effective and affordable; and encourage research in the cognitive and instructional sciences. The text is supplemented with various figures, a bibliography is provided at the end of each of the four major sections, and a glossary is included. (EW)

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INFORMATION TECHNOLOGIES AND BASIC LEARNING

READING, WRITING, SCIENCE AND MATHEMATICS

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INFORMATION TECHNOLOGIES AND BASIC LEARNING

READING, WRITING, SCIENCE AND MATHEMATICS

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TECHNOLOGIES DE L'INFORMATION
ET APPRENTISSAGES DE BASE

Lecture, écriture, sciences et mathématiques

This volume marks the completion of Phase II of the CERI project of enquiry into the issues inherent in the introduction of new information technologies in education.

Phase I produced a first evaluation of current trends and examined the possible impact of developing technologies on learning and education systems. (Its final report *New Information Technologies: A Challenge for Education* was published in 1986.)

Phase II concentrates on the present and potential role of new technologies in enhancing teaching and learning with a specific focus on basic skills at the compulsory education level. It is appropriate here to take a rapid look at the international scene within which this task was conceived.

Quality in education is a central preoccupation in all OECD Member countries. But improving the quality of compulsory education is above all a matter of ensuring that *everyone* acquires basic skills and knowledge. Countering new forms of illiteracy, which are increasing to an alarming extent in certain countries, reducing inequalities, preventing underachievement at school, preparing for the occupational needs of society, enabling everyone to pursue studies or take them up again, and encouraging personal fulfilment all depend on a sound grounding in the basic skills. This is not new. But the rather spectacular "return" towards emphasizing the basic skills – which remain to be defined in the context of present-day evolution – represents a striking resurgence of the definition of the school as, first and foremost, an institution for transmitting and acquiring knowledge. In this perspective, improving the quality of basic education obviously comprises a number of measures concerning curricula, teaching methods and the organisation of schooling, with particular emphasis on the role of teaching staff.

The school is also increasingly concerned with the dynamics of information technologies as tools for teaching and learning, especially for the basic skills. It was particularly relevant to this second phase of the CERI enquiry to try to confirm the conclusions of the Phase I concluding conference (July 1984): "use of information technologies offers an unprecedented opportunity to improve the effectiveness of the basic learning processes which pose a problem in all countries"; and those of the Ministers of Education meeting at the OECD in November 1984 that: "the new information technologies could make an increasingly significant contribution to learning, especially for the low achievers".

To handle properly this very wide commitment, two preliminary requirements were necessary: first, to focus our attention on the main basic skills at the compulsory level of education, and in fields where sufficient experimentation was taking place, namely: reading, written expression, scientific and technological concepts, arithmetic and mathematical concepts; second, to ensure that researchers among the best in our Member countries participated in the work. Working groups were set up at the end of 1985, with the objective of producing reports for each of these four fields. It was also considered necessary that the main issues regarding the basic learning required in today's world and the role of information technologies should be put forward in a general report. These completed reports were submitted for discussion to an International Conference at the OECD Headquarters in October 1986 which was attended by over a hundred decision-makers and experts from the Member countries.

These reports, revised following the Conference debates, provide the substance of the present volume. It will be seen that information technologies already play a positive role in basic education and that, beyond this, they will have considerable potential in the near future, not only to improve the teaching and learning of basic skills, but also for a better understanding of their related cognitive processes. This convergence of a better comprehension of the psychological mechanisms of learning with a rapid evolution of computer tools offers a real hope for the school.

To realise this potential, countries must show a political willingness to increase research and experimentation on a large scale, backed by appropriate financial provision. Furthermore, international co-operation, which has already proved essential in this fast-moving field, must be strengthened still further.

The Centre is most grateful to all the researchers who contributed to the reports, and in particular to those who accepted the heavy burden of preparing them: Gilbert De Landsheere from Belgium, Bertram Bruce from the United States, Yves Le Corre from France and Jim Howe from the United Kingdom. Alan Lesgold from the United States undertook not only the authorship of the general report – a delicate assignment – but also that of general rapporteur of the October 1986 Conference. I would like to thank him warmly, and, too, Pierre Duguet of the CERI Secretariat who animated the whole project from its start.

J.R. Gass
Director
Centre for Educational
Research and Innovation

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Part One

INFORMATION TECHNOLOGIES AND BASIC LEARNING: MAIN ISSUES AND FUTURE PROSPECTS

by Professor Alan M. Lesgold,

Co-Director, Learning Research and Development Center, University of Pittsburgh, United States

General Rapporteur of the Conference

Introduction[1]

Some educators would advise caution and warn against the possibility of creating too great expectations.. Such views are praiseworthy but we should not be daunted by the magnitude of the task. The application of information technology to education requires new and imaginative approaches. The potential return is very high indeed.

Denis Healy of Ireland, Conference Chairman

OVERVIEW OF THE CONFERENCE

We live in an age of rapidly changing technology. New tools to enable productive labor appear each day. Each tool affords new ways for people to perform services that others will value and pay for, while it simultaneously replaces a previously valued human skill. Combined with the increased lifespan in OECD countries, the pattern of continual technological change forces most workers to acquire new skilled job roles throughout their productive lives and not only at the beginning. In addition, the demands of participatory democracy are beginning to impose a similar need for continual learning. Citizens in OECD countries regularly face decisions of historically unprecedented complexity when they evaluate and vote for their parliamentary representatives. In court procedures requiring juries, such as the IBM antitrust case that spent so many years in US courts, the ability of average citizens to understand issues of technological and intellectual property has been challenged, a challenge that goes to the core of constitutional democratic government.

Modern economic and political demands require a basic education of higher quality. Many of our grandparents acquired a lifetime's occupational skills in a single apprenticeship of three to fourteen years. While they relied on formal schooling only to prepare them for citizenship, on-the-job apprenticeship and transactions in a simple marketplace, our children will need to be more continually educable. Because the unskilled productive roles in our society are the first to be replaced by machines and because a spirit of egalitarianism requires more universal education, we now, for the first time, ask our schools to provide a strong education for all of our children. Thus, we need a higher quality of basic schooling and we need to provide it much more universally than ever before.

Faced by these needs, there has been a partly positive and partly negative pressure on governments to provide better basic skills education in the school systems. Not understanding that everyone needs these skills, not just those whom schools easily teach, and not understanding that a higher level of basic skills is needed than ever before, the public has demanded a "return" to basic skills education as the focus of the educational system. More likely, there was no period of ideal, universal basic skills education, so the "return" must be a step forward. Nonetheless, we must now provide a high quality education to all children in those basic skills that can support continual learning and relearning, training and retraining, throughout citizens' lives.

The same basic skills are needed as before. Our children must learn to acquire information, to communicate, to reason qualitatively and quantitatively and to solve everyday problems. They especially need the self-awareness skills that will permit them to continue learning on their own. Traditionally, and today, these skills can be summarised by the terms *reading*, *writing*, *mathematics* and *science*. However, it is important to note that those traditional subjects are often taught in ways that defeat the goal of building reasoning, problem solving, learning, and communicating skills. Memorising a definition does not teach one to use the methods of science to solve problems. Memorising a number fact does not lead *ipso facto* to improved quantitative skill or understanding. Transforming sentences from one tense to another does not teach one to communicate. Each of these acts might enable additional learning but is not itself sufficient.

Going beyond the rote and the trivial is labor-intensive. Students' essays need to be critiqued; their mathematical problem-solving skills need to be analyzed and sometimes remediated; the information they gain from reading a text needs to be challenged and evaluated. All of this requires teacher time and skill. However, our school systems are under great economic pressure and have been for many years. This is the dilemma. Providing high quality basic skills education sufficient to meet the needs of a long life in a rapidly changing world is expensive and may require skills that are not always present in those willing to be teachers.

Two forces have emerged that might enable us to solve this dilemma: inexpensive information processing power and a blossoming cognitive science that can rigorously study, understand, and improve the educational process. The ever-increasing availability of cheap computational power makes it possible to imagine computers being used to supplement the limited supply of human teachers. However, as in every area of computer usage, educational computer applications cannot be developed without an understanding of what it is we want the computer to do. Computers have been employed most easily and successfully in areas where there is clear understanding and widespread agreement on what information processing activities are desired, e.g. accounting, routine assembly-line operations, and the performance of mathematical computations.

Until recently, there has not been much potential for clear theory and practical technology in education. It is no accident that computers have been used to mimic a variety of teaching practices, some good and some bad. Since the most valuable teaching practices – encouraging, coaching, explaining, criticising – are the hardest to describe with precision, they have been the least likely to appear in educational computing products. While a number of products that are quite useful have been designed by excellent teachers, they often depend upon having an excellent teacher at hand when they are used and are thus of more limited value.

Fortunately, great progress has been made in understanding the processes of learning and thinking. Psychologists, computer scientists, linguists, anthropologists, and philosophers have contributed to a cognitive science that is beginning to have sufficient power to drive the development of intelligent computer systems that can engage in rich interactions with a student and promote learning. Similarly, techniques are being developed that afford a better opportunity to understand how such artifacts as educational computers are received in real classroom settings and what effects they really have. Together, the tools and rigorous methods of cognitive science offer the possibility that computer systems can be vested with sufficient intelligence to function as major teaching tools, supplementing and enhancing a teacher corps whose numbers are insufficient and whose members vary in capability. Indeed, if the best teachers' methods can be understood and reproduced (even partially) by computers, then those computers can not only teach but also serve as examples of effective teaching from which other teachers can learn.

Sensing that all of this promising scenario exists in prototype fragments but that most current computer usage in schools is still primitive and of uncertain value, the OECD Secretariat worked with Member countries to create four Working Groups to examine the state of educational uses of new information technologies in the basic skills areas of reading, writing, mathematics, and science. The members of these groups are listed in Part Two. Each group met at OECD in Paris in October and November 1985. Thereafter, group members interacted with the group chairs by electronic mail and the post, and the group chairs developed reports of conclusions the groups had reached[2].

The groups agreed that there is great potential for uses of new information technologies in education. They further agreed that education stands at a crossroads. The reification of ineffective teaching practices into computer artifacts will not improve education, nor will handing potentially useful information tools to teachers who have not been trained to use them. While the computer revolution and the emergence of cognitive science offer the hope of improving the effectiveness and productivity of education, a major effort is needed to refine and demonstrate new educational science and technology and to train teachers to use the new tools. Without such an effort, the computer will simply be one more potential tool that is ignored or misused by our schools.

The Working Groups' conclusions are summarised at the end of this book, and the specific details of those conclusions are most important in assuring that effort focused on educational technology is not wasted. A brief summary of the issues and concerns common to the four groups includes the following:

- The new information technologies afford the opportunity for new classroom teaching methods. They also change the relative value of various skills in the labor market. Both of these changes require a careful examination of current curriculum content and instructional methodology for all grades and forms of schooling;
- While much of the software currently available to schools is not adequate, each group was able to identify a number of items which had demonstrable positive effects in the classroom;
- Cognitive instructional science and technology offer great potential for improving the productivity and effectiveness of education, but only if high quality research, development, dissemination, training, and evaluation efforts are made;
- Because computers are specialised to cheaply execute routine algorithmic performances, higher-order thinking skills become more important in assuring that our children can be productively employed. Because human activities, when aided by technologies, become more complex, these same skills are needed by all who wish to participate fully in democratic government. Fortunately, it appears that the very same technologies that make analytic skills more important also can be used to help teach those skills.

These group reports were the basis for the International Conference. During that Conference, four new working groups met to consider the reports, and several plenary sessions focused on issues that cut across the subject matters. A summary of the thinking that was evident during this Conference appears in the General Conclusions.

The Conference began with a charge from its chairman, Denis Healy from Ireland. Mr. Healy posed the following questions to the Conference:

- Taking account of demographic trends, societal needs and technological developments, what facilities, methodologies and organisational patterns can be provided to enhance the quality of education?

- How can we make the maximum use of information technologies and the developments in cognitive science to improve the efficiency of the teaching/learning process and reduce costs?
- What are the priority areas for research funding in activities related to information technology?
- What strategies must be developed to promote the production of high quality courseware?
- What new patterns of in-service training and resource allocation will be required for teachers?

While the discussions were sometimes detailed, and many specific matters were addressed, the following conclusions appeared to have broad consensus during the discussions and provide a partial summary of the more detailed deliberations summarised at the end of this Part and in Part Two.

- *National demonstration efforts* will probably be needed if the information technologies are to achieve their potential contribution for education. Such efforts can show the populace what is possible. More important, they can help us discover the logistic underpinnings needed for the possible to be achieved. The gap between the feasible and that which currently exists is quite large. With free world economies organised largely for short-term profit, some bridging of that gap must be demonstrated before the public and private participants in educational product development can make prudent decisions to begin broader and more substantial efforts. At the international level, it may be useful for these national projects to interact and to discuss the complex issues involved in translating educational software for international use.

  The information revolution provides new potential for education just as it does for other sectors of society. It is, in fact, so pervasive that a broad *re-examination of the basic skills curriculum* is appropriate. Because the new information technologies provide new opportunities for teaching and learning, this re-examination should address the organisation of school systems and classrooms as well as the content and goals of schooling.

- The rapid development of *cognitive* science, the science of thinking and learning in people and machines, is behind many of the new potentials we see for education. However, there is a large distance to be covered between a new science, with potential applicability, and an adequate technology with its needed infrastructure. To realise the potential of the new information technologies for education, it will be necessary to support short-term research aimed at extracting a workable technology from the emerging science and longer-term research aimed at strengthening and elaborating the scientific theories themselves.
- Lacking adequate logistic support as well as clear and widely-understood principles, the current efforts to use technology in education are very much at the mercy of *accidental marketplace phenomena*. The world of education will probably not be able to determine which hardware and software standards gain market acceptance and consequent economies of scale. However, it would be very useful for national educational planners to receive early reports of relevant standardizing efforts, both formal and market-driven. For example, current efforts to standardize compact disk technologies may be as important as earlier, more market-driven standardization of personal computer architectures.

CONTEXTS FOR PLANNING AND DECISIONS: THE POLICY CONTEXT

Overall, the conclusions of the Conference and the Working Groups must be viewed from the perspectives of several contexts. First, there is the policy context. Decision-makers in national governments and local schools have problems they must address, and the conclusions in this report are relevant to those problems. Second, there is the pedagogical cont xt: what must be taught and how shall we teach it? Finally, there is the technological context, in which new things continually become possible and in which some exciting possibilities become affordable.

The policy context within which uses of technology for education must be considered is complex and includes forces which compete with each other and with efforts to achieve long-term improvements in education. There are a variety of economic and commercial considerations that must be taken into account, and there are also a variety of social and political concerns. The fundamental social contracts on which our society and its political systems are based have been placed in jeopardy by the recent and continuing explosion of ' chnology, and this has produced many strains.

Economic and Commercial Considerations

Economic forces work on many time scales, from generations to years to hours. Our social structure is based upon expectations for lifetimes and for multiple generations. If I work hard, then I can earn enough money to live in a place with good schools and good teachers, and I can send my child to a university. If I am less wealthy or more idealistic, I can support a government that will select my child for elite education that opens the doors to a more pleasant life. However, these cause-effect relations take place over years, even decades. Rapid technological change helps to produce an economy that optimises with respect to periods of three months to one year, since no one can predict what will happen ten years from now.

Thus, we see industry demanding particular training for our children. Of greates interest to a business is that the children graduating from school soon should have the skills needed to fill jobs that exist today without requiring expensive on-the-job training. Education that can support continual learning as jobs change in character is a longer-term proposition. Furthermore, if many businesses are now using specific pieces of software or specific computers, there will be pressure to use these in schools, so that new workers come already familiar with the equipment of the job.

A second economic pressure comes from the computer industry. Every computer company hopes that schools will buy its products, both for the direct sales this will generate and because those who use a particular computer in school may be more inclined to buy one later on for their business. All computer businesses within a country can agree that only computers made in that country should be used in its schools. There is also great pressure on schools to buy computers in quantity, since the education market, because of the number of schools and students, is attractively large. Small countries are impressed with the prospects of such industries as educational software, because of the minimal investment needed to begin such businesses. Another, more subtle, pressure favors simplistic software, since the costs of training teachers to use the software, consulting on how to use it, and even maintaining staff to determine the validity of warranty complaints (e.g. did the computer fail because it was defective or because the teacher used it inappropriately) are all very high.

Prices change very rapidly in the personal computer market, but the mechanisms for making purchase decisions are often slow and cumbersome in schools. As a result, schools often have underpowered and nonstandard computers that happened to be the cheapest available the day information was gathered and that may not run any of the most useful software. Low budgets and the inability to purchase opportunistically and quickly have tended to force standardization of computer hardware for education that is not otherwise prominent in the business world. As a result, many routine (but educationally useful) tools of the commercial sector are not available to schools.

Only a clear sense of what possibilities can be realised, and when, and at what cost, can drive the strategic planning needed to overcome the economic forces that tend to force low-efficiency computer uses onto schools.

Social and Political Considerations

In many countries, parents and young people are pressuring schools to buy computers. Parent associations sometimes buy the first computers for a school and thus help shape the choice of hardware for the future. School leaders are under pressures of varying types in matters of educational technology. Parents believe that familiarity with the specific computers of today will make their children more employable tomorrow They see advanced uses of computers in mass media fiction and embellished documentary presentations and want their children to be part of a world of tomorrow that is only partly real. Since most people have difficulty understanding how much of a computer application comes from the operator and how much from the computer or whether the application can generalise beyond the specific demonstration situation, they associate more power with small personal computers than is currently present.

Misunderstanding about computers is widespread and easily manipulated. A few years ago, a minority group in an American city opposed the use of computers in schools because they suspected that schools in their area would lose their teachers and be taught only by machines. Some administrators oppose all computer usage in schools because the particular hardware and software they experienced was worthless. Others are driven by experiences in fantasy environments, such as the Disney Epcot Center.

What is needed to improve on this situation, in which self-perpetuating poorly-informed decisions dominate? The recommendations of the Working Groups and the Conference participants go beyond the usual calls for research, better planning, and the abandonment of self-interest by the powerful forces within our society, though aspects of each of these idealistic requirements are identified as critical. A strategy of prototype development, demonstration, and evaluation is needed. The first substantial uses of the information technologies for education will be expensive, but a sense of what is possible must be developed before cost is optimised. Few parents, businessmen, politicians, or teachers have seen schools in which the computer is as pervasive as the textbook. Only by seeing demonstrations of what is possible can they begin to develop a critical understanding of what is desirable and how the desirable can be achieved.

As noted in a later chapter, the computer is also ideally suited for testing educational ideas, since it can keep detailed records of what actually happens in an educational interaction with a student. More generally, evaluation is critical to the future of computers in education. The bulk of the educational software currently available is clearly of minimal use, and some is probably detrimental. The good products must be identified, and the characteristics of good products must be documented. This process must be intensive, since superficial standards are worse than none at all.

Finally, demonstration and evaluation must take place in real school settings, since it is characteristic that most innovations work when tested in ideal settings and fail when placed unsupported in impoverished school sites. There are two sides to this. First, the purpose of demonstration must be to determine what is practical, so one outcome should be a clear understanding of what level of teacher training and institutional support is needed for a system to be effective. Second, initial demonstrations may need to be supplemented with resources schools do not generally have; we do not want to rule out an approach as useless in principle if it merely needs tuning to make it practical.

Chapter 1

THE PEDAGOGICAL CONTEXT

In approaching the task of describing the potential of new information technologies for education, it is important to take account of the specific needs and economic limitations of each OECD country's education system. It is also important to attend to recent results in cognitive science that help clarify the appropriate uses for new information technologies. To date, the reaction of the less wealthy countries has been to favor the more mundane uses of computers that can work on very minimal hardware, on the argument that: *a)* improvements in education are needed immediately; and *b*) bigger computers are expensive. However, bigger computers keep getting cheaper, and the real benefits of the new technologies lie not in what is already possible but rather in what is just starting to be possible. This is because the less wealthy countries are least able to provide an adequate cadre of master human teachers and least able to afford the inefficient current forms of education, in which many students fail to achieve more than the temporary ability to pass school tests.

In recent years, much has been learned about expertise in many different areas, and one way to view education is as the conveying of expertise to children. We continue to expect our children to be facile at the basic skills of reading, writing, and arithmetic computation, but increasingly, we also expect them to respond flexibly, like experts, to continuing technological change. This is in striking contrast to earlier views of basic skills, which treated them as routines to be automated. It still seems appropriate to think of *facility* as a core requirement for basic skill, but it is no longer appropriate to think of these skills as being completely routine. Facility seems to involve not only minimal load on conscious thinking capacity but also knowledge of how to apply routines adaptively to a wide range of situations. That is, we want our children to be experts in applying the thinking and communicating skills that our increasingly technological world requires.

- We expect children to be able to use their arithmetic skills in everyday life, not just to be able to solve numerical problems their teachers set for them;
- We expect children to understand what they read and relate it to what they already know, not simply to store a copy of a symbol stream in their heads;
- We expect children to learn to communicate effectively in writing, not just to transform the ideas of others into sequences of grammatical sentences;
- We expect that the science training our children receive will prepare them to understand the complex decisions about new technologies that citizens must make in the future, not just to be able to carry out routines that are already automated and done by robots in our factories.

With these goals in mind, a few comments on the recent course of basic skills education and of instructional science seem in order.

GOALS AND PROBLEMS OF EDUCATION IN BASIC SKILLS SUBJECTS

While the basic skills are highly regarded throughout the OECD countries, there are widespread difficulties that seem to affect basic skills education in many OECD countries[4]. Not every country has every problem, or notices it, but each is sufficiently widespread to be worthy of mention.

Student Problems

- Time exerts great pressures on education. There is a rush to cover course material, and the slower student often falls progressively behind. In cumulative subjects like mathematics, the eventual result is that students end their mathematics learning altogether. Paradoxically, a number of studies suggest that only minutes of each school day are spent in learning-inducing activities, that much time is lost to classroom management activity and to the inability of the teacher to deal directly with every student at the same time. As new subjects accumulate faster than old topics are deleted from the curriculum, this problem increases;
- The pressures produced by the time problem just mentioned, combined with other weaknesses of education systems, have led to a widespread belief that educational standards have been lowered. In response to this, a variety of achievement monitoring programs have begun in various school systems. One effect of these programs is to focus student and teacher attention on aspects of subject matter performance that are perhaps too shallow to sustain later learning. For example, it is easier to focus on memorising number facts than to try to understand the underlying relations that generate those facts,
- There are sex differences in learning. Girls initially do better at learning to read, and boys tend to prevail in the later years of math and science;
- The rapid pace of our society, and particularly the media, reinforce the belief of many children that skills can be acquired very quickly, when the results of recent psychological investigations suggest that thousands of hours of practice underlie any form of expertise;
- A variety of forces and beliefs result in too much stratification between the pursuit of advanced levels of basic skills vs. technical training. As a result, the more able students leave school with no exposure to technical skills or practical technology and those following vocational tracks leave with inadequate basic skills and an impaired ability to learn on their own or to be trained for different jobs. Again, there are sex differences, with bright girls being particularly deprived of practical technology experience.

Teacher Problems

- Teachers do not receive adequate training once they are on the job. As a result, they are often trying to teach what they were taught rather than potentially more generative basic skills;

- A variety of examinations shape the goals teachers have. In addition to direct monitoring of student achievement, the entrance and placement examinations of universities also shape teachers' goals more than in-service workshops, teacher journals, and other information sources do;
- Teachers with long histories of service may not have received adequate training in dealing with the wide range of ability levels now represented in our classrooms;
- Many teachers of mathematics and science have not received adequate post-secondary training in those subjects. Thus, they are unnecessarily narrow in the content and teaching strategies they can employ and have an incomplete sense of the goals of basic education in those fields;
- Areas of sparse population cannot attract or support the most skilled teachers, especially in science and mathematics.

Curriculum Problems

- The basic skills areas are dynamic, shaped by progress in science, mathematics, and the humanities. However, the curriculum is seldom changed in these subjects, so children receive an education couched in terms of ideas that are sometimes foreign and sometimes obsolete. Superficial reactions to the call for a "return" to basics have increased this problem, in some cases;
- The necessary updating represents knowledge that is also missing in the adult population, so there is need for refresher courses in basic skills for adults. There is also need to carry the new goal of universal basic skills education back to the generations of older citizens for whom that goal was not existent or not achieved;
- All of the basic skills involve both procedural and factual knowledge. Factual knowledge, acquired through memorisation, is only a fragment of the total competence needed, yet schools are generally organised to teach that fragment primarily;
- There is a lack of adequate emphasis on the procedures of maths, science, writing, and reading, as well as a lack of adequate resources and classroom structures for providing individual attention to each student, even though detailed critical feedback seems to be essential to the learning of these skills. Increases in class size, combined with increases in the diversity of aptitudes in a class, further compound this problem;
- There are a number of demonstrations, especially in mathematics and science, that key concepts are not acquired by most students, even though they pass tests involving those concepts. The knowledge apparently does not generalise beyond the world of textbook examples;
- Especially in science, the amount of important knowledge continues to grow. It is always easier to add to the curriculum than to redesign it, and thus we see a continuing pattern of teaching less about more. Combined with the enduring bias toward memorising of facts, this trend insures a continual force toward superficiality of learning.

Facilities Issues

- Schools have inadequate laboratories, often consisting mostly of outmoded equipment. Funds are usually not available for expensive laboratory refurbishment;
- Even when equipment is appropriate, it is often poorly maintained. In many cases, no one in a school knows how to maintain the equipment or even how to arrange for it to be maintained.

WHAT DOES COGNITIVE SCIENCE HAVE TO OFFER?

Against this long list of educational problems, there are two new forces to be employed: *i)* the ability of the computer to cheaply and speedily replicate information processing of great complexity; and *ii)* a new science of thinking and learning, cognitive science. In this section, we briefly discuss the contribution that cognitive science can play. In particular, we address recent research done on the nature of human expertise and on how an expert's knowledge can be taught to a novice. This work is of relevance, since it is quite reasonable to think of the basic skills as a set of expertises that we expect all our children to acquire. Indeed, perhaps this viewpoint is part of the antidote to the excessive focus on memorisation of facts that has been mentioned above.

Goals of Education: The Psychology of Expertise

Considerable work has been done comparing experts with people of lesser skill in a variety of domains. While this approach has a smaller literature in the school subject matters, there are several findings that recur in all the domains of skill thus far investigated. These findings seem appropriate sources of suggestions for concerns that are likely to carry over into school subject skills as well.

Understanding vs. executing procedures. A repeated finding is that compared to novices, experts spend more of their time understanding a problem situation and less of their time actually carrying out the solution process. For example, given a textbook problem, physics experts work at understanding it and then use that understanding to suggest a solution. Novices, including students who have taken a physics course, immediately try to fit an equation to what is given, without first understanding the problem. Many textbooks and teachers make it difficult for students to learn the circumstances for which various techniques appply. Mathematics textbooks almost always cluster problems of a given type into one place. Thus, students may learn very superficially to apply one algorithm to those problems without ever learning when that algorithm is appropriate. Put another way, we often teach the THEN side of IF-THEN rules without spending enough time on the IF side. When teachers offer rules of thumb that are themselves superficial, this makes things worse[5]. We should ask whether the approaches currently being used will move students toward expertise or merely reinforce superficial and generally useless knowledge.

The threefold way. Another emerging principle is that expert performance can come from multiple sources. Specifically, expert performance comes from a mixture of three capabilities: efficient but flexible basic routines, substantial general knowledge in the relevant domain, and powerful strategic skills that enable one to reason beyond one's current knowledge. To some considerable extent, these three sources of successful performance are interchangeable. That is, if a person is short of one of the three, this can be made up by greater strength in the other two. For example, very bright students can often solve geometry problems, especially multiple choice test items, without ever having studied geometry, using just their everyday knowledge of vocabulary and of lines and shapes combined with powerful reasoning strategies. At the other extreme, a student might do well on a test item dealing with "analytic" aptitudes if he knows specific routines for dealing with the type of problem posed, even if his general analytic capabilities were limited.

In evaluating new technologies, it is important to consider whether the devices and programs we examine aim at what is most important to teach. Some software teaches algorithms without ever expanding higher-order thinking skills, thus overlapping rather than improving upon existing educational practice. Other programs may allow the clever student to succeed too often on generalised or "weak" methods[6], never seriously engaging the specific domain the program purports to address. Much research remains to be done on this problem, particularly on the relationship between understanding and performance. However the concerns expressed above are already worth addressing.

Learning

The strongest contribution of the cognitive sciences to education is to provide a clearer understanding of the active nature of thinking and learning. In contrast to earlier views of learning, which characterised the process as one in which responses were tied reflexively to categories of stimulation or symbols were passively accepted and stored, an emerging view is that knowledge is constructed. This viewpoint is not novel. Philosophers, and psychologists like the early *Gestalt* psychologists and such contemporaries as Hochberg, have long held this position. What is more recent is the emergence of sufficient methodology, in the form of formal theorising approaches and methods for verifying formally stated theory, to allow serious testing and elaboration of *how* knowledge is constructed.

Much of current education, and especially of educational technology, aims either at drill or at the storage of knowledge in students' minds, rather than at what knowledge students might construct in response to interactions with a computer system. If we really believe that students learn by constructing their own knowledge, then the specific words we spray on them in lectures or show them on book pages have only a temporary importance. They are, in Robert Glaser's terms, *pedagogical* knowledge, temporary knowledge important only as a means to induce the desired learning in the student.

The implication of this is that technological artifacts for the classroom must be examined in sufficient depth to determine what *learning activities* they induce, not what words they display. From a more conservative point of view, it will also be critical to determine empirically that their *potential* for learning activity is actually realised. For example, discovery environments, such as the LOGO, offer the potential for considerable learning but no specific guidance to the student or the teacher. In contrast, the approach taken with LOGO by Howe in Edinburgh attempts to assure realisation of that potential by providing rather specific directions concerning the activities which might lead to important learning.

The specific question raised by this difference is the extent to which empirical evidence favors one approach over the other. The more general issue is the relationship between technological artifacts and the specific teacher expertise that may be required to use those artifacts to advantage. Using computer tools to make up for a lack of trained teachers requires understanding which of those tools can stand alone and which depend upon skilled teaching by a person.

As is described in the chapter below on the technological context, a technology sufficient to be useful does exist, though it needs refinement. Computer tools can now be used to create simulated laboratories in which students can be guided through the discovery of basic scientific principles, practice the higher order skills of problem solving and critical evaluation, and learn how to learn. The didactic classroom, in which knowledge must be communicated verbally and abstractly, can be supplemented by laboratories that are abstractions, in the sense that they exist only on computer screens, but concrete, in the sense that they faithfully emulate real phenomena and are manipulable by the student. The practice opportunities offered by written assignments and worksheets can be supplemented by practice with immediate feedback and coaching from an intelligent computer tutor. However, the availability of these potentially useful artifacts is not enough. There must be a sound pedagogical plan for using them.

MOTIVATION

Motivation continues to be a fundamental problem in schools, and there has not been as much progress in understanding it as there has been in understanding learning and thinking However, consideration of the use of new information technologies would be incomplete without consideration of student motivation. Common sense, and the existing body of empirical research, suggest that students, like other people, invest part of their time in efforts to deal with new situations. When these efforts are highly successful, they are no longer necessary and are abandoned. When they are largely unsuccessful, they are also abandoned as fruitless. What appears to be needed is enough success to convince the student that progress is being made and enough challenge to convince him/her that more work is needed and will be worthwhile. It is possible that the level of challenge must be set differently for different students, too. None of this is very controversial, but it suggests three principles that should govern the design and evaluation of educational practices, including computer software for education.

- The context in which new skills are taught and practiced should match the student's worldview sufficiently to seem highly relevant but should contain sufficient novelty to present a challenge (i.e., to suggest that the new material is needed by the student);
- The student must be able to recognise success and progress. If necessary, the teacher or instructional computer program must help the student to identify individual successes and to recognise progress. For example, a student may not easily recognise that a revised essay is better than an earlier version or that he is faster or more accurate in solving certain mathematics problems than he was a few days ago;
- It may be necessary to vary the size of challenges posed to different students, since part of any student's experience is a sense of general likelihood of success or failure. Research by Carol Dweck suggests that some students may need to have their understanding of how successes occur challenged, since they attribute too much to luck and too little to effort.

TEACHER TRAINING

The issue of necessary teacher competence is important. We should consider whether new in-service training will be required before the emerging computer tools can be used by current teachers. More broadly, we might ask whether some of the tools now appearing can educate the teacher as much as the student. Again, the principle that learning represents the construction of knowledge must be kept in mind. The question to ask is whether the immediately apparent activities for the teacher in using a new information tool will induce the learning of new techniques for using that tool and perhaps even extend the teacher's knowledge of the domain being addressed. For example, one can develop tools for teachers that allow them to design specific problems to be solved by the students. The vocabulary that is used and the choices teachers must make in specifying problems might well teach them something about the problem solving portion of the mathematics curriculum. Thus, if a teacher must make choices that relate to core curricular concepts in order to generate worksheets for students or homework assignments, he will develop a clearer sense of the content he is teaching. We note that existing materials are often organised by superficial terms, e.g. one-digit vs. two-digit problems, rather than according to the specific strategies they teach or the specific principles they demonstrate.

Chapter 2

THE TECHNOLOGICAL CONTEXT

EXISTING INFORMATION TOOLS FOR STUDENTS

The bulk of this chapter addresses the prospects for systems that would actively teach students or provide them with a new and special kind of practice environment. However, there are many conventional tools developed for broader use that can also be used to advantage by students. These possibilities are listed in the Working Group reports, but a few possibilities are also summarised here.

Word Processing

The most immediately useful tool for students is also the most immediately useful in business environments, the word processor. In real work, we invest the right amount of labor in each communications task. If standard verbiage will do, we copy text from a computer file into a letter, for example. On the other hand, when new ideas must be communicated, we may revise our text dozens of times. In school situations, this does not happen. Because of the high cost of reading, recopying and revising texts in a paper and pencil world, there has been a continual decrease in the amount of writing students do and the amount on which teachers give them feedback, especially in non-writing subjects. The word processor can return to writing the role of shaping and refining ideas.

Idea Organisers and Hypertext Systems

Programs are appearing that go beyond text processing to allow people to structure ideas that they are developing. Some tools are very simple, mere outline development aids. Others allow text to be viewed from many different levels of detail, and a few go beyond text to handle graphs, drawings, and charts as well. The discussion below of *Notecards* gives a sense of the leading edge of this technology but less complex tools are already appearing for some common microcomputers. School children could use such tools to help develop, organise, and express their ideas in written form.

Databases

Rather than simply give students books of predigested facts to memorise, it would be nice to teach them how to retrieve and critically understand databases of texts, numbers, and other information structures. As databases begin to be distributed on compact disks and as powerful computer systems for retrieving and manipulating data structures become available, students can be given practice in skills of evaluating, understanding, and using information that will remain useful over a lifetime, rather than memorising facts that will only briefly be accepted as accurate.

Spreadsheets

The spreadsheet tools that are now widely prevalent have great potential for student use. Specific possibilities are addressed in the report of the Mathematics Working Group (Part Two, Section IV), but these tools will also be useful in science classes. As integrated spreadsheet and filing programs become more common, these can be brought into the classroom with good effect.

In summary, the marketplace is doing a good job of selecting information processing applications that are helpful in communicating and solving problems Basic education, which has problem solving and communications skills as its primary goal, must interact with these developments by providing students with chances to develop their skills while using the tools that adults use. Because the tools were initially developed for people with little or no computer experience, they (at least the better ones) may readily adapt to classroom use.

NEW HARDWARE POSSIBILITIES

Two primary new hardware technologies are emerging which provide the potential vehicles by which new forms of education might be delivered. First, there are powerful personal workstations which have the speed needed to run large artificial intelligence programs, the graphic capabilities to permit detailed visual displays (both text and pictures), and the temporary (memory chips) and permanent (magnetic disk) memory to support large-scale educational systems.

A second type of instructional delivery vehicle is the intelligent compact disk player. While the larger videodisk has not been very successful in the market, the smaller compact disk has become very popular as a means of conveying high quality audio recordings and also as a means of distributing massive amounts of data and computer programs. A single compact disk can hold over 500 million characters of information, enough for any of the following: *a)* 100 intelligent instructional programs; *b)* 7 000 pictures; *c)* 90 minutes of symphony-quality music; or *d)* 20 hours of telephone-quality voice. Mixtures of all of these on one disk are quite possible.

As experience is gained in developing educational software, it is becoming clear that much more versatility and computational power is needed for the development effort than for the delivery system on which the final product will be used. Once the strategy of developing on a powerful computer for delivery on a simpler one is adopted, it is possible to precompile images and decision tables, and further decrease the requirements for a delivery machine. One sensible approach might be to use some of the less expensive professional workstations to develop educational software and then to deliver it on a CD-ROM player designed for the consumer market. This approach is addressed below. It is important to note that even the cheap delivery systems described will be many times more powerful than the computers being used in most schools today. Because of the high cost of software development talent and its scarcity, it will not be possible to support substantial development of more advanced educational products for school machines with much less than 500 000 characters of memory and a processor of the power of the 68000 or 80286 microprocessor family.

Advanced Personal Computers for Software Development

Most of the tools needed for advanced educational software development can be found in the powerful artificial intelligence (AI) workstations now selling for $15 000 to $100 000 each. These machines are not that much more powerful than some of the personal computers now being sold. It is already possible to pay a second company to convert a Macintosh Plus into a machine that is virtually identical, in terms of basic capability (four megabytes and a 68020 processor), to the AI workstations. Although the software tools for educational product development are only beginning to appear, it seems feasible to think of software development taking place on a number of products that will sell next year for $3 000 to $5 000. To these products must be added an ability to store and retrieve video displays – at least static video. This also will be possible, it appears, as write-once video disks appear.

What is missing from this scenario is the appropriate software. Some is being developed by consortia of universities who have as their goal the design of a cheap workstation for use in college classes. However, national governments will probably have to fund the development of tools that are specially adapted to basic skills education. Nonetheless, this is at least feasible. Such systems will need to permit full exploitation of the computer-generated graphics, video, and audio possibilities that can be delivered with the type of system described below. Because of the complexity of display possibilities and the likely changes over the next decade, the development systems should support the use of object-based languages that permit appropriate decoupling of the specifics of displays from their content.

The Compact Disk Player and its Evolution

For much instructional delivery, the compact disk player seems the most sensible possibility. Driven by the audio recording market, compact disk players are becoming ever more sophisticated and powerful. Companies are beginning to think of new consumer products that would interact with the user and deliver not only audio, but also computer line graphics, and high-quality text and video displays. The user would interact via a pointing device, such as a mouse, or, if necessary, via a keyboard. Within a few years, if adequately driven by the consumer market, such systems might cost less than $1 000 each. Taking into account the basic capability likely to exist in such a system[7], it would be much more than most school computers have today, even if considered just as a computer (e.g it will have most of the capabilities of a 512K Macintosh).

Because of the market success of the compact disk player, such a product will appear by 1987 or early 1988. It will be affordable and will have most of the capabilities of the artificial intelligence workstation. Appropriate media standards are now under development. These machines, although designed for the entertainment market, will have substantial temporary memory, high-quality video and audio, and a high-speed processor. Because they are aimed at the entertainment market and a large sales volume, they will be priced initially at barely over $1 000 (not including monitor) and will probably drop to $500 by 1990 or before.

This market fact means that even less-wealthy OECD countries can count on using the new technology. The time for serious cognitive research and development is at hand. Today's prototypes will be deliverable as affordable products for the education world faster than we can design and build them.

The Economics of Educational Product Development

It is easy, and commonplace, for school officials to react to the most recent and advanced educational systems as inordinately expensive. The hardware possibilities just discussed will not solve the problem of software production costs, which will remain very high for good products. Nonetheless, such systems may have great potential for improving education where teacher quality is low or education costs unbearably high (e.g. at least for science and math education). We should fully examine the implications of the most advanced possibilities and also consider the evolution paths whereby such technology might reach school children.

The Conference rapporteur has had rather heated arguments with a US Air Force economist over this matter and has discussed it at some length with a colleague, Walter Schneider. It appears that few if any organisations (even large governments) will be able to routinely commission the development of the richest intelligent instructional systems now possible for whole curricula. This means that some cooperation will be required among organisations before systems of the complexity of *Notecards*[8], *AlgebraLand*[9] and even the Anderson *Geometry tutor*[10] can be developed and implemented in schools. If even a few such programs are widely publicised, we can expect to see numerous efforts to build most of their capability into smaller systems[11]. Every OECD country should at least be in this wave of followers and should be closely watching and talking to the leaders.

One example of the diffusion of ideas developed on powerful artificial intelligence machines involves *Notecards*. *Notecards* was first developed on a Xerox 1109 artificial intelligence workstation. Since then, many of its ideas have been moved to systems designed at Carnegie Mellon University for the IBM PC RT and to software designed at the University of Michigan for the Macintosh. Within a year, some students will be using these tools on personal computers to help organise and understand the contents of college texts and lectures.

While many routes exist whereby sound educational ideas can, once demonstrated in prototype form, be brought to the mass market, the original large-scale ventures will require funding by national or international institutions. Each of these systems rests upon a substantial body of deep cognitive theorising and task analysis. The exemplary systems just mentioned are really prototypes used to clarify researchers' broad theoretical efforts. Others that could be mentioned test current theory through the design of systems for industrial training[12]. These exemplary systems represent the quantum jump needed to move practice away from traditional formats for human-machine interaction and to develop control structures for instructional systems.

What is most likely to be successful is a sort of dialectic, in which these expensive prototype efforts from wealthy countries are confronted by the smaller and cheaper products of private enterprise and less-wealthy countries. Perhaps aspects of the space programs of some western countries have similar properties when they lead to "spin-off" products that are then brought to the consumer by private entrepreneurial efforts in other countries. Given such a scenario, the potential of new cognitive science and technology can be synthesised with a concern for cost control. It is time to give attention to the costs issue and to developing more ideas on how new potential can be successfully and economically used

EDUCATIONAL METHODS USING THE NEW TECHNOLOGY: EXAMPLES AND EVALUATION

Intelligent computer-based instructional systems, which are made possible by continuing advances in cognitive science, have two major values. As a tool for education, they permit forms of learning that are not readily enabled by conventional means. As laboratories for rigorous ecologically valid research on learning, they are a means of testing and expanding sound cognitive theory that is relevant to education.

For education, intelligent computer instructional systems afford the opportunity for an enriched extension of laboratory instruction, both in the sciences and in other subjects for which laboratories are not currently available. A second use is to provide practice in carrying out complex mental procedures, often with intelligence coaching or feedback about performance that is immediate and pertinent. Laboratory and practice experiences, as well as other forms of learning, can form the basis for educational conversations, providing a concreteness that assures that the student accurately understands what the computer qua teacher is saying and that he/she has appropriate referents for initiating his own queries and responding to those of the machine. Finally, new approaches to the description of causal relations allow the use of computer simulations that are overtly explained in ways that can be understood and that can lead to conceptual learning.

In addition to their uses in improving education directly, intelligent instructional systems are also important tools for research. First, they permit more detailed data to be gathered and more complex treatments to be applied, making them well-suited to the testing of often complex cognitive theories. Second, they offer hope of a more rigorous experimental educational psychology, since it is easier to have replicable treatments if they are administered by a machine than if they result from verbal instructions given to teachers.

These two roles for the computer, as a medium for education and as a medium for research, have a deeper interconnection. The computer affords new approaches to education and to the performance of cognitive skills that are so substantial as to require a fundamental redesign of both the content of courses and the principles of learning whereby content gives rise to curriculum. The next few sections develop, explain, and provide examples of the points made above.

Exploratory Environments (Laboratories)

Recent cognitive psychology supports the view that learning is a constructive process, that the learner constructs new knowledge in response to experience. Some experiences occur in the world of objects, some in the world of talk, and some in the world of reading. In every case, it appears that learners use their prior subject-matter knowledge and certain more general skills of learning to make sense out of their experience, to decide what changes in their knowledge it suggests. What is remembered from a text is a function of the prior knowledge the reader brings to it, and what is remembered from a laboratory experiment depends on what the learner knew to look for.

What this means is that effective learning involves taking a position on instructive experiences, deciding that they merit certain changes in what one knows or what one is prepared to do. The position taken by an effective learner should be one that is consistent with the situation he faces, his goals, and his prior knowledge. Perhaps an appropriate position will leap out at the learner immediately, but perhaps it will not. Our everyday experiences suggest that there might be value in taking a tentative position and then testing it. This suggests that learning will be most efficient when such testing can be done easily and accurately.

When an instructor speaks to a class, testing of knowledge constructed from his utterances is difficult. Generally, the need for a test arises in the midst of processing the instructor's speech, making any "thought experiments" difficult and potentially interfering with initial processing of subsequent utterances. Questions can be asked of the instructor, but with a large class, allowing all such questions would use up too much of the lecture period. Class discussions allow the development and testing to be a group experience but still involve "thought experiments". When learning is from a book, "thought experiments" are also possible, but when learning is from a school laboratory experiment, the concrete artifacts of the experiment may be more memorable, allowing more complete learning.

Of course, it is possible to create laboratory environments that permit concrete experiments rather than "thought experiments". That is, the learner reasons to himself:

> If I do *x* to object *y*, then the knowledge I have constructed leads me to expect that *z* will occur,

and he is able to test his reasoning. The ability to concretely test hypotheses provides a means for accurately constructing knowledge without having to mentally simulate exactly the material one doesn't yet understand. Presumably this is one source of the utility of laboratory experiences for learning.

There is no guarantee that students placed in a laboratory will automatically take advantage of its efficiency as a learning environment. They may need to be taught skills for learning, and they may need coaching or guidance as they attempt to use the laboratory. Because of bad controls and inadequate conceptualisation of experimental questions, not all of the experimental literature on the utility of laboratory experiences is easily evaluated. There have been a number of experiments on the utility of "discovery learning," but these have tended to be horse races in which the contending approaches were not adequately specified. There are a few results suggesting that "guided learning" is better than either didactic instruction or discovery learning, where "guided learning" seems to be more or less the same thing as coached work in a laboratory environment.

Empirical support notwithstanding, the above-stated rationale suggests that laboratory experiences may be critical to education in situations when there is high probability that the student cannot construct knowledge reliably without testing it against reality (actually, against accurate representations of the scientist's reality, the theory). Traditionally, science courses have included laboratories more or less for this reason[13]. It is an unfortunate reality that laboratory instruction is becoming less available to students even as we become more able to understand why it is important.

There are many reasons for the decline in laboratory instruction. First, it is expensive: it requires sometimes-delicate and costly equipment, while textbooks are cheap and more or less indestructible[14]. Having a lab for a course requires both money and the procedures for replacing and maintaining equipment on short notice, neither of which schools tend to have. Second, laboratories require better teachers, since a wider range of on-line handling of student inquiries is necessary, as are certain physical and cognitive skills – for doing demonstrations. Third, they are potentially dangerous in some cases. Demonstrations involving slightly radioactive compounds, bullets, and other attention-eliciting props were common in the Conference rapporteur's student days, but probably would not be acceptable in the current age of litigation

Laboratories Are Not Just for Science Courses

Fortunately, the computer can provide a variety of laboratory environments, at least in simulation form. The "what if" questions that students need to ask in order to test the knowledge they are constructing can be asked via simulation without danger. The experiments a student performs in a simulation environment are repeatable without the cost of new chemicals or the replacement of broken or melted glass. Experimentation as part of learning is no longer restricted to the sciences. For example, tools exist for experimenting with different text structures and argument forms and with the implications of different economic principles. Here are a few examples.

John Seely Brown, Frank Halasz, Tom Moran and others at Xerox Palo Alto Research Center are experimenting with *Notecards* which allows students to assemble notes into both graphic and textual representations of the arguments they wish to make. The simplest representation *Notecards* permits is that of note cards spread about the screen as they might otherwise be spread on a desk. Even for this mundane use, the system offers certain advantages, such as the availability of word processing tools for making notes, the ability to make notes of different size, and (via scrolling) the ability to put more on a note card than can be visible at one time.

Notecards allows complex arguments to be assembled into a database. Relations between assertions of an argument structure of the sort used by Toulmin (and earlier Aristotle) can be indicated explicitly between pieces of text, graphics, and other information sources. When used as a writing and thinking tool, data can be added anywhere in the relational structure, and the system can later be asked to assemble the structure into a linearised text. When used to analyze the validity of arguments, it permits gaps in the supporting structure for the argument to be noticed more easily.

Notecards goes even further, providing new tools for organising one's ideas (and even the process of having ideas). For example, each note card can contain pointers to other note cards that contain elaborations, substantiations, rebuttals, and other kinds of related information. With these links between notes established, the system can assemble one's notes into a first draft which can then be edited by the student. One can also develop an outline as a graph structure. *Notecards* will build such a structure from a set of note cards that contains linking information, and it will also create the textual note cards corresponding to any nodes that are added to such a graph. The graph becomes an experimentally manipulable object.

Conceptual Reification of Process

The capabilities of *Notecards* help to illustrate a basic capability that is built into the best computer tools for exploratory learning. This is the support for reification by the student of the processes in which he has been engaged. The idea is that components of the act of writing can be actively labeled and manipulated. It is not just that students who want to lay out their texts as a graph are provided tools for doing so. Rather, the process of editing as manipulating the relationship between complex networks of ideas and linear, running text is made more explicit, understandable, and manipulable itself as an object of thought.

The features that characterise *Notecards* as a potentially useful laboratory environment can also be seen in other environments, including some based in very simple computers. For example, Brown, Burton, and other colleagues at Xerox have also developed a prototype mathematics environment called *AlgebraLand*. This environment provides tools for simplifying equations and for understanding the process of simplification. Simplifying equations is a difficult task for many high school students. One reason for this is that their arithmetic and algebraic skills are not very strong or very practiced and they also do not understand quite what the process of simplification is all about.

AlgebraLand supports their efforts to practise simplification by giving them a menu of operations that can be performed on equations (e.g. "divide both sides by ....", "add ... to both sides", etc.). It also draws a diagram illustrating the steps the student already has taken. The menu helps remind the student what operations he has available for the problem he faces, and the diagram helps him realise what procedure he is carrying out and provides a basis for thinking about possible strategies. It also permits mental replays of recent actions, allowing the student to reflect consciously on which of his plans have worked so far.

Such displays may be a less labour-intensive way of accomplishing part of the same plans that are followed in the reciprocal teaching strategies that have been studied in recent years (e.g. Palinscar and Brown, 1984). These teaching or tutoring strategies are designed to help the student focus directly on understanding what he is noticing in a learning situation and on consciously constructing knowledge. Presumably, displays that make a concrete record of what the student has been doing can be helpful in this process. What still needs to be provided is feedback on the student's constructed knowledge. To some extent, that may be inferable by the computer from the structure of the display, just as we ask the student to make such inferences.

For example, after looking at several of his recent efforts to simplify algebraic equations, a student may induce that certain strategies are especially effective. As that student does additional exercises, the computer can determine whether his performance patterns match heuristics that are goals for the instruction. If not, it can call the student's attention to particular "instant replay" diagrams that show the utility of such a strategy or even work a few problems for the student and compare its path in such a display to the student's path. Later, it can behave less optimally and ask the student to make comparisons, so that the student gets practice in evaluating his processing activities.

Practice Environments (Simulators)

A related, but not identical, use of computers in education is as a practice environment. For certain purposes, notably pilot training, sophisticated simulators have been available for a number of years. Due to the tremendous savings in fuel costs, aircraft, and human life, these trainers became feasible very early in the computer era. They are expensive and large (many occupy whole buildings). More recently, development of practice environments that can run on personal computers and relatively inexpensive artificial intelligence workstations has become possible, making the use of the computer to support practice more feasible for less critical areas of training and education.

The initial effect of the cognitive shift in psychological theory was to emphasize understanding over skill. It represented a move away from an instructional theory built around practice to one built around initial learning. John Anderson's evolving theory of acquisition (1976, 1983) has now returned practice to the foreground, since it contains both initial learning mechanisms and other mechanisms which are driven by practice. Specifically, initial learning is seen as involving the particularisation of general procedural knowledge, the acquisition of verbal (declarative) knowledge, and the use of existing declarative knowledge by relatively general procedures. Practice, in turn, builds and strengthens more specific procedures and makes them more flexible.

The critical issue in practice is assuring that the procedure that is practiced is the correct one. For example, one reason homework is not always effective as a practice mechanism is that there is no guidance or feedback from the teacher at the time that the student is actively thinking about the problem. Initial attempts to use the computer to provide practice opportunities involved providing right-versus-wrong feedback to students after they attempted each problem in a set of exercises, along with some summarising data that sometimes permitted off-line evaluation of the student's current level. However, such feedback did not tell the student what was wrong with the incorrect performance.

The simplistic level of feedback provided by a generation of "electronic page turner" programs derived from two sources. First, there was the behavioral view that learning consisted of waiting for the student to make the correct response (or at least a response that is closer to being correct than past efforts) and then reinforcing that correct response. In cases such as simple arithmetic, where a student can often figure out why his answer is incorrect, such an approach might be sensible. When more complex conceptual learning, or even complex performances, are the target of education, the kind of feedback needed is more complex

Suppose that you were practicing tennis serves. Instead of simply waiting for good form and then rewarding it, a decent coach might make some suggestions that might help you discover how to serve with good form. Indeed, if a coach simply said "wrong!" every time you served incorrectly, you would probably not recommend him/her to your friends. We recognise that in sports, practice without good coaching is not necessarily very productive[15]. We need to have a skilled teacher look at our performance and suggest small, manageable changes that will bring us closer to optimal performance.

In order for a computer to provide such coaching, it needs to know what to say in response to performances that are at varying points along the learning curve. Put another way, intelligent coaching programs need to be able to look at student performance and evaluate it with respect to expert performance, deciding what the student can already do and what could lead the student a bit closer to expertise. This requires three kinds of knowledge: knowledge of expert capability, knowledge of how to recognise the specific capabilities of a student, and knowledge of the course and mechanisms of learning.

When we speak of an intelligent practice environment, we mean one which has these three types of knowledge. A number of practice environments have been built in prototype form, and a few have either become commercial products or have influenced commercial ventures.

Some domains, such as computer programming, contain knowledge which is acquired primarily through practice. The critical content of a computer programming course is not the small number of language conventions but rather the ability to write programs, a skill which comes through practice. More generally, intelligent instructional systems are compatible with a trend within cognitive psychology to see relatively complex procedural skills more as skills and less as bundles of declarative wisdom. This tendency has certainly been increased by two kinds of learning theories in the broad cognitive psychology world.

Anderson's theory (1976, 1983) explicitly calls for much learning to take place through practice. It is via practice that very general heuristics gain the specificity and domain-specific tailoring they need to be powerful. Through practice, conscious, temporary-memory-limited procedures are "compiled" into efficient, relatively-automatic form. The other main contender for a theory of learning, the family of massively parallel network theories, is also practice-driven. Only through practice can the specific path weightings that are distributed throughout a parallel network be properly set.

Overall, the trend toward viewing practice as a key cognitive learning activity is supported and manifested in the computer tools for cognitive practice that are beginning to appear.

Increasingly Complex Microworlds

A particularly powerful approach to the design of practice environments was introduced almost a decade ago by Fischer, Brown, and Burton (1978). This is the concept of increasingly complex microworlds. The basic idea is that from the outset, an entire skill is practiced, but in increasingly complex environments. The specific analogy offered by Fischer and his colleagues was that of skiing. Prior to the invention of the short ski, training in skiing consisted of a long period of exercises that were done without skis. This was because skiing was dangerous, and considerable muscle control and mental preparation were required before it could be done safely. Many potential skiers gave up before they ever got to the slopes. Others tried using skis before reaching the high levels of strength and preparation that were required, and ended up with broken legs.

With the invention of the short ski and the safety binding, the whole situation changed. People were almost immediately on the slopes, using progressively longer skis and attacking progressively more difficult slopes as they became more competent More people learned to ski than before, and more attained true expertise. Training time to reach a given level of skill was cut dramatically. The holistic approach, combined with carefully selected and increasingly complex practice situations, was a great success.

It also became necessary for skiing instruction to be designed more carefully, and more preparation was required before instruction could be offered. A more specific curriculum needed to be developed, and appropriate slopes had to be selected that embodied just the right challenges and prevented the need for skills not yet acquired. For example, initial runs needed to be made on a slope that ended in an uphill segment, because initially students did not know how to stop themselves.

It is now asserted that perhaps cognitive skills might be taught by providing practice in progressively more complex simulated environments, presented on a computer. For example, from the outset, students could be doing science rather than memorising its outcomes. Initially, they might be given a lot of tools that summarise data and help them keep track of their hypotheses and hypothesis-testing strategies. Later, some of these "crutches" could be removed, just as training wheels are removed from a child's bicycle. Fischer has written of the need for "cognitive oscilloscopes" to help students see the structure of complex data they may encounter in such environments (Boecker, Fischer, and Nieper, 1985). There is great promise in this concept of increasingly complex microworlds, and it is already being used in a number of laboratories to produce technical training systems (e.g. at Bolt Beranek and Newman in Cambridge, MA, and in the Learning Research and Development Center in Pittsburgh). The experience so far is that the approach is very effective but that the "crutches" must be carefully tailored to the environment. As a cartoonist recently noted, training wheels work better on bicycles than when learning to ride an elephant!

Bases for Educational Conversations

In some respects, practice and exploration are not very different. Consider, for example, medicine. Deciding what is wrong with a patient is the major activity of medicine. Accordingly, one would assume that practice environments for learning medicine would involve practice in making such diagnoses. On the other hand, a medical case (and the knowledge to which the case relates) is an exploratory environment. The student must try to account for all of the symptoms with a concise explanation derived from models of disease and of organic function. More generally, any problem solving task can be couched within an exploratory environment, where the problem space and available problem-solving operators are made explicit, to be manipulated by the student.

A critical part of the process of designing an intelligent practice environment for an intellectual activity as complex as medical diagnosis is to determine the core activity around which instruction should center. For medicine, this is the model of the specific patient (Clancey, 1986). All activity focuses on understanding the patient, given his symptoms. Another critical part of the design task is to understand the fundamental conversation forms that are part of the core activity. In the case of medicine, the fundamental conversational form is probably the consultation, in which one physician discusses a case with another, seeking and offering advice. Important current research focuses on understanding the verbal exchanges that occur when one or both parties to a consultation are trying not only to advise, but to teach (cf. Evans and Gadd, 1986).

Symbiosis of Cognitive Research and Instructional Design

In summary, the design of intelligent practice environments involves considerable cognitive psychology. The nature of instructive conversations, their verbal exchanges and the educational strategies they can employ, must be understood. The domain of expertise itself must be understood. Especially important, the fundamental cognitive activity of the domain must be identified, and theories of domain content and its acquisition must be developed, before intelligent guidance of the cognitive practice can be offered.

The primary costs and the fundamental activities in building intelligent computer-based instructional systems involve developing specific understanding of the subject matter to be taught and formally representing that understanding in the computer software.

Causal, Functional Explanations

In spite of the position taken above, not all of learning is practice of procedures. Part of education is to impart understanding. In this area, as well, there have been important advances. A driving force in this area has been the analysis of expertise (Chi, Glaser, and Rees, 1982). An important characteristic of expert performance in solving problems is that experts invest substantial proportions of their total effort in representing or modelling the problem they face. From such a representation, they then proceed toward a solution. Less-expert problem solution is, instead, characterised by reliance on superficial cues.

Work on experts' representation or mental modelling capabilities has focused on several issues, including the nature of the models (e.g. Gentner and Stevens, 1983), how they are used in cognitive activity, and how they might be conveyed (e.g. de Kleer and Brown, 1984). What it takes to understand and explain the functioning of devices is an important general issue for artificial intelligence research that goes beyond concern about instructional systems. Any expert system with a critical task will have to be able to explain its decisions and performance to humans who use it, or it won't be trusted. Furthermore, certain tasks that machines may perform, such as diagnosing failures in complex equipment, will require some amount of reasoning from basic understanding about equipment function.

When designing the knowledge that constitutes understanding of a device, there are two important levels of that knowledge, the behavioral level and the functional level (cf. de Kleer and Brown, 1984). Behavioral descriptions tend to describe individual device components. For components such as those in electronic systems, the behavioral description is an account of the input/output relations for the device. For example, the description of a resistor is given by Kirchhoff's and Ohm's Laws. It is useful for such descriptions to be organised as qualitative constraints, e.g. if the voltage across a resistor increases, the current will also increase.

A description of the behavior of each device (often all that students are taught) does not constitute an adequate description of how the total system encompassing those devices works. Knowing how transistors, resistors, capacitors, diodes, and chokes work does not tell one how a radio works. The knowledge of how a system composed of various devices works is called functional knowledge. A primary part of functional knowledge is an understanding of how changes in one part of a system affect other parts.

Powerful computer tools can be developed for teaching functional knowledge. Such tools represent a major new force in science and technology education (and perhaps other areas as well). This is partly because they provide a more faithful view of overall system function than can be provided by direct experience. Consider the task of explaining what is happening when a digitally tuned radio is tuned to a particular station. In experiencing the tuning process, the effects of pressing the tuning button are instantaneous. In reality, though, a complex cluster of changes propagates through the system. A computer simulation unfolds those changes in "mythical time," showing each successive qualitative change in a device of the system (de Kleer and Brown, 1984). The changes can be examined at various levels of grain, from individual transistor logic to large functional units. System relationships that are not viewable in the real world can still be enacted on the screen.

The verbal description of system function is not adequate for conveying this sort of knowledge, since expertise includes not only the ability to describe standard intrasystem relationships but also the ability to predict the effects of various inputs to the system, a procedural skill likely to require practice. What the computer can do is to provide a good arena for that practice, the world of mythical, but functionally accurate, time.

Even the most basic psychological research is heavily influenced by applications possibilities and requirements. Because we can now teach functional understanding better, we have more incentive, and can give higher priority, to studying what functional understanding is and how it is acquired It is likely that work in this area will be substantial in the near future. The ability to present causal information in tractable form will raise a new set of frontier questions about how else we can understand function. In subatomic physics, the simple causal account just given is not appropriate to describing certain systematic relationships. By being able to more easily teach some knowledge that was formerly hard to teach, we also set the stage for dealing with the next problem on the list, explaining fundamentally stochastic systems[16].

The Computer as Research Assistant

In addition to being an important new teaching force, the computer is an important new research instrument for educational psychology. In the past, experiments could either be done at a microscopic level in the laboratory or at a diffuse and general level in the classroom. Because artificial intelligence methods allow us to specify processes in terms of the underlying principles that describe or generate them, the treatments in computer-based educational experiments can be both more complex and better controlled. Because all of the transactions, the learning conversations, are machine mediated, a complete record of the subject's behavior is also being recorded, in machine-readable form. The result is that there is potential for a much more rigorous and much more detailed empirical psychology of education to match the more elaborate theoretical work now being done. Without this new empirical power, it is unclear that the theoretical work will progress toward clear applicability.

PROMISING AREAS OF RESEARCH AND PROTOTYPE DEVELOPMENT

As a means of summarising some of the material above from a different perspective, a few candidate topics for increased research and prototype development support are briefly discussed below. These are a well-chosen sample, but still only a sample, of the issues and concerns raised by the Working Groups.

- Intelligent tutoring systems are starting to be developed and tested. The skills needed for this development are not yet readily taught, except through apprenticeship. There is need for support of projects with specific mandates to: *i)* develop generally usable software architectures, curriculum development procedures, and programming tools for intelligent tutor development; *ii)* evaluate the effectiveness of specific intelligent tutoring methods, since the approach, taken as a whole, is too diffuse to evaluate; and *iii)* study the effects of intelligent tutor availability on the organisation and function of classrooms and schools;

- In order to provide appropriate advice to a student, a human teacher or intelligent tutor must have some representation of a student's current capabilities. Such a representation can be very diffuse and general (e.g. "the student is on chapter 5 of the text and is generally a slow student"), or it can be very specific (e.g "the student understands how to subtract in a single column but does not understand how to regroup over a zero, so he fails to do problems such as 402–2'9= correctly"). Many students seem to pass through the same basic learning states in the same order, but at different paces, so the general student modelling approach may be sufficient for some purposes. On the other hand, some students develop incomplete or incorrect mental procedures which teachers cannot easily detect. Perhaps the only way to remediate them is via very detailed diagnosis followed by highly tailored advice. While these general truisms are apparent, there is not a well-principled means for deciding how deep a student diagnosis capability must be for a particular application. Since such diagnosis is computationally expensive and difficult to design in the first place, it would be good to have some rules of thumb for when to do it;
- Clearly, we would like our children to have very general skills, so they can attack any situation they encounter. However, there is considerable evidence that competence in any domain requires considerable domain-specific knowledge. Research is needed to clarify the methods for teaching domain-specific knowledge. We need to know how to promote the abstraction of more general, transferable skills from specific learning, how to tailor instruction to the level of learning skills the student already has, and how to enhance those learning skills;
- The final topic in this sample of R&D funding suggestions is quite different, but equally important. This is the use of the most powerful educational applications of the new information technologies to teach teachers. Every major worker in the field of educational technology gives lip service to the need for teacher training, yet not enough occurs. If the information tools we have discussed are so valuable to students, then surely it should be possible to build some that are tailored for in-service education of teachers. We envision a school in which the teacher wants to use the computer for learning whenever the students are not using it. Such an environment is possible, but initial prototype and demonstration efforts must be created and funded. Organisationally, this has been difficult because funding for educational computing is aimed at students, while teacher retraining is handled by separate administration in most countries.

Fostering Co-operation between Researchers in Different Countries

One means for both spreading information about uses of information technologies in education and increasing the rate at which research and development occurs in this area is to improve communications possibilities for researchers in different countries. Academic computer networks, such as EARN and BITNET, offer important advances in this area, and it is critical that the researchers who drive technology development, curriculum development, and teacher training in each OECD country have access to these networks and maintain contacts with appropriate laboratories in other countries.

Chapter 3

IMPLICATIONS FOR EDUCATIONAL PRACTICE AND CONTENT

A FORCE FOR CHANGING CONTENT, CURRICULUM AND PRINCIPLES OF LEARNING

In recent work Lesgold and his associates conducted for the US Air Force Human Resources Laboratory, they looked at the training and the on-the-job skills of airmen who repair navigation instruments on planes. Lesgold's group found that those airmen who were doing best on the job had a clearer and more elaborated sense of how aircraft systems operate and of how faults in system components can be detected. That is, they had better procedures which they also understood better.

This requirement of skill plus understanding is common in many knowledge domains that are taught via formal schooling, and it is often not attained. Children often do not understand the meaning of arithmetic operations they perform, the rationale for writing an outline before writing a research paper, the reason for performing a chemistry lab procedure in a certain way. Auto mechanics sometimes do not understand the reasons for manufacturers' instructions on the repair of new technology, such as fuel injection systems.

Because skill without understanding is insufficient, courses and training programs tend to include both a conceptual component and a procedural component. Regrettably, these are usually treated as two entirely separate activities. The student gets some crude set theory and he also learns arithmetic, but the two are not connected. The technician is taught basic electrical concepts as well as procedural algorithms but does not understand how the two relate. One important promise of computer-based exploratory systems is that procedures can be represented and labeled in various ways, allowing them to become objects of the conceptual world as well as things to do.

IMPLICATIONS FOR INSTRUCTIONAL PRACTICE

As one reads the reports of various commissions and task forces on education in the western countries, a common theme emerges: the need for better development of problem solving and other higher-order thinking skills in our children. Rapid social and technological change implies a continuing need for flexibility and for skills of efficient learning. That which is routine, for which we can easily teach children algorithms, is a sensible target for automation. What is left for human work roles are positions requiring judgment, flexibility, and the shaping of existing procedures to novel situations. Those who hold jobs which appear to be routine in their requirements will find continuing need to be retrained to use new equipment or fill different roles. It is likely that the pattern will continue of exporting high technology jobs to less-developed countries as we come to understand how to organise "cognitive assembly lines."

This suggests that new curriculum must emerge that extends subject matters to emphasize the solving of everyday as well as technical problems, something schools have never done universally well. Those who develop the new materials and approaches may want to consider specifically how information processing tools can be useful adjuncts for teachers as they pursue this new curriculum item.

We offer one example of the way in which computer tools can dramatically change the content of a course. Many students take computer programming courses as part of the basic skills curriculum. Just as language arts courses have often succumbed to the overuse of syntax exercises instead of emphasizing writing and revising of essays and other genres, so computer programming courses tend to emphasize syntax over the design of algorithms, especially when taught in elementary or high schools. This is because the computer will reject any program that is syntactically ill formed. Efforts to help students deal with the syntax barrier to computer science sometimes compound the problem. For example, one well-meaning college taught BASIC for the first six weeks, because it has an easy syntax, and then switched to PASCAL, which is easier to use in demonstrating the structure of algorithms. Of course, the students complained because they now had to master two syntaxes.

In recent years, researchers have started to develop structure editors that permit students to write programs without knowing the syntax. In essence, the student specifies a plan structure for his program and then fills in details. The editor will not let him make a mistake and provides advice that is in terms of the algorithm being coded, not punctuation. One such editor, called *Gnome*, was developed at Carnegie Mellon University. A similar approach has been used by Jeffrey Bonar and Elliot Soloway to build an entirely new curriculum, and Bonar has built a tutor to be used as a problem solving environment within that curriculum. Students begin by specifying, in everyday terms, using a menu, a plan for solving the problem. "Gworky, The Friendly Troll" appears on the screen as necessary to provide advice. Then they translate the plan into a graphical representation of an algorithm. This graphical representation is runnable; one can put data into the input boxes of the display and watch what happens. Finally, they use a structure editor, which eliminates the need to worry about superficial aspects of program punctuation, to write a program that carries out the algorithm. Throughout, the tutor offers coaching, eliminates the distractions of programming details that are superficial but potentially overwhelming, and proceeds by starting from the student's understanding and working toward the target knowledge.

The availability of new tools in this case has led to a complete alteration of curricular goals. Instead of being arrested at the level of superficial coding of algorithms, the student receiving instruction of this new form spends most of his or her time learning how to develop and organise algorithms. The coding step, once a barrier to deeper understanding, is largely automated. As a result, the student learns a problem solving skill rather than learning the one part of the software design job that is readily automated away.

Hopefully, this is merely an early example of one role that technology can play in education, stimulating hard thinking about what the deeper goals of education might be. This will be difficult, because social agreement on educational goals, to the extent it exists at all, is rooted in people's experiences in school and their sense of which things they learned turned out to be useful. Another challenge, perhaps the ultimate challenge of new information technologies for education, is to develop, have publicly accepted, and put into use a curriculum sufficient to permit our children to thrive in the partly old but partly very novel world that is their inheritance.

Chapter 4

RECURRENT THEMES

This chapter presents a brief summary of themes relevant to educational practice and content that emerged during the Conference and the Working Group activities which preceded. Such a summary cannot do justice to the many good ideas expressed (see Part Two and General Conclusions), nor can it reflect the many nuances of similar but nonidentical opinion that were presented. Nonetheless, it is offered in hopes that it will stimulate education policy makers to the "new and imaginative approaches" of which Denis Healy spoke when he opened the Conference.

PUBLIC POLICY CONTEXTS

Since the Conference was one of educational decision-makers and experts, in many respects it was a dialectic between two concerns. First, there is the need to continue operating a complex, barely affordable system that is entangled with many other aspects of our societies. This is confronted by revolutionary technology that contains both the means for doing more efficiently what is now being done and a challenge to take on new and more complex goals. Several themes emerged in this area.

Strategy choice: Cut costs or increase benefits. To the person who must operate a school system under increasing budget pressures, who is continually asked to do more with less, the potential of the computer for cutting the costs of education must seem particularly prominent. Can we have larger classes? hire fewer science and mathematics teachers during the shortage? cut the costs of remedial education? On the other hand, there is the new challenge, not yet met, of educating all of our children sufficiently to permit success in a rapidly changing world. This calls for better outcomes as the index of productivity rather than lower costs alone.

Social effects of new information technologies. With the new tools of thinking and practice in using them, the rich child with certain home computers will have a strong advantage over the poor child whose parents cannot afford and do not themselves experience computer tools. Failure to modify the curriculum and children's classroom experiences to take account of the new information technologies may have the effect of multiplying the multigeneration influences of individual wealth and parental social status.

The obsolescence problem: Need for a tradition. No matter what schools buy in the way of information technology, it always seems to be obsolete before it is installed. Part of this problem is unavoidable: during rapid change, one must either ignore the changes until they stabilize, at the cost of not enjoying new advantages, or one must face the reality that each attainment reveals new challenges ahead. However, it is possible to minimise the disruption and waste associated with rapidly changing technology by following the computer technologies standardizations of market sectors large enough to shape traditions of stable usage. This means attending to the de facto standards in the business (personal computers and their software) and entertainment (visual media and the machines that present them) markets.

Evaluation is difficult. It is particularly difficult to evaluate demonstration efforts. Not everything new systems purport to teach has been taught before. More critical, the methodological traditions for evaluation themselves vary from the traditional to the cognitive science camps. A cognitive science approach may directly challenge the goal for which a traditional approach has developed performance standards.

Cost analysis is difficult. The above concerns make it difficult to make cost/benefit judgements. Such judgements become even more difficult when demonstration efforts do not involve "real" school systems. It is difficult to estimate the logistic infrastructure needed to move from a brilliant researcher's "hot house" demonstration to successful routine implementation. For this reason, it may be useful for demonstration efforts to involve a large enough unit of the school system to permit some estimates of the logistic and infrastructural changes that are needed to make the demonstrated programs work.

COGNITIVE SCIENCE

What is cognitive science? The preliminary reports for the Conference, and many statements during the Conference itself, heralded a new cognitive science as a source of considerable knowledge needed for development of high-quality educational uses of the new information technologies. Decision makers at the Conference expressed continual puzzlement over the exact referent for this use of the term cognitive science. This indicates a critical problem. Now that cognitive science and the information technologies are both mature enough to play a serious role, much more specific reference to precise concerns is required in an discussion about future approaches to education. We would never say simply that physics will permit the building of a new building or aircraft, even though physical principles certainly must play a role. Similarly, the science of thinking and learning has many aspects, and claims that this science will afford a specific opportunity require elaboration

Individualisation. One outcome of cognitive science research is an emerging understanding of the ways in which one student's learning activity and outcomes may differ from another's. Computer technology is especially able to permit efficient adaptation to these individual differences. By providing productivity-enhancing information tools, we can allow teachers to more readily teach all of the children in their classes. Some children may be a few years behind their classmates in reading and math skills while others may be years ahead, and the instructional approaches fruitful for teaching one child may not work as well for another. Without individualised instruction, the slow child is frustrated and the gifted child trained to be mentally lazy. With a sufficient array of instructional tools, students who are moving at a different pace can get at least some of their instruction at an appropriate level, even if there are many children in each class.

Concreteness of instruction. Lectures are inherently abstract, but cognitive research tell us that learning thrives on concreteness. Perhaps the new tools for reifying mathematical, rhetorical, and scientific processes of understanding, inference, and evaluation can permit a much more concrete set of instructional methods while simultaneously providing a chance for more children to make important abstractions. The use of tutored or coached learning environments can also help to clarify understanding and to promote analytic thinking.

Technical aids. The cognitive science view that children actively construct their knowledge forces a reappraisal of children's need for knowledge tools in their learning. If they have the hard work of knowledge construction to accomplish, it may be counterproductive to force them to deal with routine activities that can better be done with the tools that are used outside the schoolroom. Calculators, word processors, and other tools should not be kept out of the classroom just because curricula have yet to take full account of their existence. While there may be good reasons for students to learn to do things that information tools can do for them, they should also be learning to use those tools routinely.

TOWARD A NEW CURRICULUM

Curriculum is one needed component of a cognitive educational technology. We have new cognitive science telling us how learning takes place and what is learned from certain standard components of schooling. Moreover we have all around us the evidence of an information revolution that is substantially changing the skills required for social and economic productivity. This is surely a mandate for careful reconsideration and perhaps modification of the basic skills curriculum.

Adapting to a world full of information tools. Our children will have cheap tools for doing many things that people once did for high wages. These tools make possible new thinking performances that are not currently part of our curricula. We need to consider whether to teach more about how to compile larger documents now that word processing tools make this easier. Perhaps we should focus more on scientific reasoning processes, since some of the specific factual knowledge we have today will be obsolete quite soon. Perhaps even more attention to critical evaluation of arguments is needed in the era of media politics, saturation advertising, and massive contrasts in standards and styles of living among people who watch each other on television. Perhaps we need to rethink the role of arithmetic drill in the mathematics curriculum, now that [illegible] have cheap calculators.

Blending of discipli[illegible] of the Working Groups debated whether there should be more unification of the c[illegible]. The new information tools, and the skills needed to use them, straddle the bounda[illegible]ween reading, writing, science and mathematics. It would be tragic if they were sequestered into one domain or another simply to avoid the need to consider whether reading and writing, for example, might not be better taught partly in the context of science. Most of the new information tools will be useful in most or all of the four subject areas.

More research and analysis for curriculum development. Clearly, it is no longer obvious what should be taught as part of the basic skills. While our intuitions are valuable in avoiding faddish oscillation in curricu[illegible] goals, deep thinking and research is needed to clarify the specific thinking processes that are particularly hard for students to master. The curriculum should be designed to assure that learning of those critical skills is facilitated.

NEW COMPONENTS FOR THE EDUCATIONAL SYSTEM

Articulating old and new. An important concern is to articulate old and new approaches in the education system. While the teaching of basic skills is explicit and directly specified in most curricula, certain aspects of socialisation achieved through schooling are at risk if drastic changes are made. Computers, on the surface, appear to be used most often by one child at a time, perhaps decreasing social interactions during the school day. This need not be the case. Computer activities with multiple roles for multiple children can be designed and should be considered. It is important to be aware of the social and socialising changes that insertion of new information technologies might achieve. There is great potential for positive change but also the risk of losing some of what schools now do well.

The curriculum problem in the face of the new information technologies is so pervasive in the OECD countries that it is probably a fruitful issue for further international effort.

Computing and education in the home. In some ways, the new information technologies call the role of the school itself into question. In the United States, for example, a substantial number of children have been removed from the school system and are being educated at home, often with the aid of computer tools. This is perhaps the limiting case of losing the school as a socialising force. On the other hand, it points out the increasingly diverse ways in which learning can be fostered – in school, at home, in libraries, in museums and elsewhere. These opportunities should be considered in planning public education.

A rich and complete software development system. In order for appropriate and effective software to be developed for education, many different kinds of people must participate. Some roles are obvious. The subject matter expert and the learning specialist have clear roles, as might the software engineer. Other parties should also be involved, including the teacher who must use the software in the classroom; artists, who know how to draw attention to specific displays and problems; and even students who may see the screen from a different perspective.

The translation problem. It would save the OECD countries considerable expense if software could easily be translated from one language to another. This would permit each country to use the best of developments from other countries as well as its own output. However, translation is a difficult matter. While text translation is now possible via computer, translating computer interaction procedures is much more complex. Not only must the individual text displays be translated properly, but the broader intentions of the human-machine interaction, what linguists call speech acts, must also be handled. This means, among other things, translating the part of the software that decides whether the student's responses to the machine's questions are correct. Finally, the form of such speech acts is somewhat culture specific. Too superficial a translation effort can result in unintended cultural imperialism – styles of interaction being economically forced upon a country to which they are foreign.

The translation issue is a specific enough technical matter that it might well be the topic of a fruitful international seminar or conference.

TEACHERS AND THE NEW INFORMATION TECHNOLOGIES

Teachers can master technology. Whenever new information technologies for education are discussed, there is a concern expressed about teachers, who are often represented as impediments to any change. Like most of us, teachers are uncertain about the future and about the effects of information technologies on their livelihood. These uncertainties are multiplied by the economic strains on every country's education system. However, there is no reason to believe that teachers are any less capable of adapting to new things than anyone else. The key to success in bringing teachers into the information age is careful planning and design.

Some artifacts are so embedded in our culture that minimal training is required to use them. For example, few of us receive direct instruction before we successfully use a telephone or a refrigerator. This is because the knowledge needed to use these tools is culturally transmitted. Problems in training teachers come from a culture of scientists and engineers who are developing tools for another culture of teachers and principals. Just as the manufacturers of new office equipment plan their tools to be usable within the office culture with minimal instruction, so must the information tools of the classroom be planned for teachers.

Teacher training and retraining. Direct teacher retraining is probably necessary, not because a new artifact will enter the classroom but because of the changing knowledge about what and how to teach. These new insights into what to teach and how best to teach it will not improve education unless teachers currently in the field acquire facility in using this new knowledge. This facility will include skills, which require coached practice, and will be grounded in curricular specifics. They cannot be taught in a lecture of a few hours. A combination of specific workshops and on-the-job training approaches will be needed.

Computer tools for teachers. In this regard, teachers can also benefit from new information tools. Industry sources in the US report that schools are currently more interested in software for principals and teachers to use in managing education than almost anything else. They want tools just as the accountant, the manager, and the engineer do. This belies the belief that teachers cannot easily absorb technology. At a deeper level, it was pointed out during the Conference that the same techniques of computer-based learning used to train our children be used in training and retraining teachers.

INFORMATION SHARING

The final theme that emerged in this project is perhaps the most important – sharing of ideas, approaches, prototypes, and evaluations. In different countries, different aspects of the multifaceted problem of information technology in education come to the fore. The wisdom needed to address this large problem and the varied viewpoints that can lead to complete understanding of the issues our countries face are not in any one place but rather distributed throughout the OECD countries. The experience of the first research computing networks suggests that simple and inexpensive communication paths between researchers and decision-makers throughout the western world can be of enormous benefit. Networks such as EARN and BITNET are playing a critical role in helping educators and researchers avoid continual reinvention of tools and approaches that all countries need. Databases, such as ESRC-ITE in the United Kingdom, are also important. Cooperation of all OECD countries in facilitating such network interactions should be encouraged.

A FINAL THOUGHT

So far, consideration of the new information technologies for education has too often occurred in one of two incomplete viewpoints. On the one hand, we have the scientist-technologist-entrepreneur, who with his own hands produces demonstrations of powerful new educational ideas and methods. This person sees the future clearly but fails to realise how he oversimplifies his task when he ignores complexities of the education world and simultaneously assumes that all parties to the educational system know what he knows. On the other hand, we have the operators of highly constrained complex educational systems, whose jobs force them to spend most of their time keeping the current system in operation, preserving its delicate logistics, and responding to the stable needs of its people. Each of these two types of people knows many things that the other must learn if our children are to fully benefit from the new opportunities for learning that the information age affords. The project described in this book represents one effort to bring these two types of people and their two types of wisdom together. They learned a lot from each other and have much more yet to learn.

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NOTES

1. At the Conference, it was noted that the new fields of cognitive science and informatics both involve considerable vocabulary with which some educational decision-makers may be unfamiliar A glossary has therefore been made available at the end of the book, as an aid to the intelligent layman. Because the report highlights cognitive science, a new and possibly unfamiliar area, it may also be useful to consult Howard Gardner's (1985) introduction to that field.

2. I am very grateful for the co-operation of the four Working Group Chairmen, Professor Gilbert De Landsheere of Belgium, Dr. Bertram Bruce of the United States, Professor Yves Le Corre of France, and Professor Jim Howe of the United Kingdom. Without their efforts in distilling the comments of their colleagues, there would have been no conclusions for me to introduce and summarise. It has been an honor to work with them. I know that they would join me in pointing out that a number of individual Working Group members provided substantial amounts of assistance, writing portions of the reports, surveying educational computing uses in the various countries, etc. Their efforts exemplify the selfless spirit on which international co-operation depends.

3. This section borrows from a presentation by Pierre Duguet Principal Administrator. OECD Paris. I thank him for making a copy of that presentation available to me. I have modified his ideas and added to them. He should not be blamed for assertions with which the reader may disagree.

4. These problems are directly raised in Professor Le Corre's report of the Working Group on Scientific and Technological Concepts, but they seem to be general to other basic skills areas and to be implicit in the other reports.

5. For example, teachers may tell students that whenever a problem contains the word "altogether", they should add the numbers stated in the problem to reach a solution.

6. Newell and Simon called methods that did not use domain-specific knowledge "weak" methods.

7. The properties envisioned for a consumer-market, interactive compact disk player are the following.

   Audio: Plays Compact Disk stereo, but can also provide one, two or three sound channels at once. Can provide lower qualities of sound, too, allowing more storage in each disk. Sound tracks selectable and changeable during play.

   Video: Provides TV quality static pictures (256 colours) with the possibility for computer-generated graphics animated on top of video stills. Changes video images as fast as 1/second, with cuts and dissolves via two frame buffers.

   Interaction: Has a single universal control system that can output either NTSC or PAL video from the same disk. As easy to use as a phonograph. Is not sold as a computer, so is not as terrifying to the average user. Standardized character and keyboard coding to permit easy use in any country. Possibly compatible with large-format video disk systems

   Marketing: Is priced to sell as a premium-quality audio compact disk player, perhaps at about $1 000 including mouse and keyboard. Is sold as an appliance, not as a computer

   Computer power: We estimate that the power of a relatively fast 32-bit processor and about 500 000 characters of storage would be needed to achieve these publicly announced capabilities. Within a year or two, such capability will be within price range

8. *Notecards* is the trademark for a product of Xerox Special Information Systems, developed at Xerox Palo Alto Research Center.

9. *AlgebraLand* is a research prototype under development at Xerox Palo Alto Research Center. It allows students to see the structure of their problem solution paths as they try to simplify algebraic expressions. Thus, it helps students overcome the usual gap between processes and understanding in mathematics learning.

10. *Geometry Tutor* is a program developed by John R. Anderson at Carnegie-Mellon University in Pittsburgh. It shows students their evolving proofs as graphs, in which proof lines are nodes and their antecedents are links. Thus, proof is shown metaphorically as finding a path between the premises and the conclusion. Students are coached and help is available as they proceed to do their proofs. The screen display is organised to minimise the temporary memory load the student faces in doing a proof.

11. Which, given the improvements in hardware costs over the several years such efforts will take, may not be much smaller.

12. Each of the US Armed Services has several such demonstration projects underway at present.

13. There was also the desire to teach "laboratory skills," the skills of using laboratories to test communal constructions of knowledge, or scientific theories.

14. US textbook investment per child per course per year is perhaps Œto $7, and the amount spent on computers in the past few years equals the total textbook investment since the founding of the United States in 1776.

15. Gagné (Personal communication, April, 1986) tells of relating unsuccessful practice results to Harry Harlow, who thereupon posed Harlow's Practice Law: "Practice may not always improve performance, but it does always take time."

16. This may include not only subatomic physics but also certain social phenomena. For example, how does one explain how the actions of a few terrorists totally alter the tourism economics of a large part of Europe and Asia? New explanatory methods are being designed and are becoming teachable. This, in turn, poses important challenges to cognitive instructional psychology.

Part Two

READING, WRITTEN EXPRESSION, SCIENTIFIC AND TECHNOLOGICAL CONCEPTS, ARITHMETIC AND MATHEMATICAL CONCEPTS

Our thanks to Dr. Arlene W.iner, from the University of Pittsburgh, United States, for her improvements to the presentation of the four reports in Part Two.

I. READING

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The chairman acknowledges the invaluable help received from the members of the Wo Group all of whom contributed professional "notes" on specific topics covered by the reports. In Chapter 2 of the report the detailed system for classifying courseware is due entirely to Andee Rubin and Chapter 3 is entirely the work of Robert W. Lawler.

Introduction

THE CURRENT SITUATION: ILLITERACY PROBLEMS

Despite changing cultural patterns determined in part by new information technology, reading remains one of the essential intellectual skills. Admittedly, reading, writing and arithmetic are no longer the only pillars of basic elementary schooling – modern society requires a much wider cultural foundation than that – but reading has lost none of its old importance; if anything, it has gained in importance.

J. Foucambert reminds us constantly that the late twentieth century calls for a different kind of reader from that of last century. To take France as an example: in 1900, less than half the population wrote extensively. However, this minority constituted a large public for fiction and sometimes read very easily. But for most who had learned to read, reading served as a basic tool for work, communication, information and moral uplift. Messages were deciphered laboriously, word by word, mumbled or pronounced half-aloud, and usually understood at their face value. This mode of reading, aural rather than ocular, is still practised, according to Foucambert, by 70 per cent of the French population. Nowadays the flow of written messages requiring rapid interpretation by the reader, whether in the field of learning, work, general information or recreation, calls for a much higher degree of skill. The stage of mental pronunciation needs to be eliminated and the written word perceived directly as a language for the eye.

In the industrialised world – to take the supposedly most favourable example – there is hardly a country which does not complain of a rising tide of functional illiteracy. Large numbers of pupils leave primary school without knowing how to read or write. Secondary school and even university students also suffer from serious reading deficiencies. Books and articles, often argumentative, deplore the failure of the education system and clamour for a return to basic learning techniques ("back to basics!") founded on the didactic methods that had proved their worth in the past.

The figures going the rounds are certainly alarming: there are apparently 50 million functional illiterates in the OECD countries, 23 million of them in the United States (1984) (US data based on high school completion). Jeanneau (1984) calculated that per cent of the Canadian population was totally illiterate and 26 per cent functionally illiterate. In France, Alter (1984) found that a quarter of the pupils entering the lower secondary cycle could not read or write. Overall, more than 40 per cent of children aged between 11 and 12 appear to be non-readers. In 1975 Unesco put the number of illiterates worldwide at 700 million, but there is every reason to believe that this figure falls short of the mark.

The notion of "functional literacy" is ambiguous. Sometimes it is taken to mean the ability to read messages vital to survival or minimal function in society, for example, the instructions for use of a household appliance, a government form, a job vacancy notice. At other times it is defined as "being able to use language in all its forms to enlarge knowledge, clarify thought, enrich the imagination and guide judgment" (Brondy, 1980, p.114).

It can be argued that functional literacy is too modest a goal for our society. The position adopted in this respect by the United States National Academy of Education's Commission on Reading in 1975 seems unexceptionable (Carol and Chall, 1975):

> We take the position that the "reading problem" in the United States should not be stated as one of teaching people to read at the level of minimal literacy, but rather as one of ensuring that every person arriving at adulthood will be able to read and understand the whole spectrum of printed materials that one is likely to encounter in daily life. In terms of grade levels of difficulty, a meaningful goal would be the attainment of twelfth-grade literacy by all adults – roughly, the ability to read with understanding nearly all the material printed in a magazine like *Newsweek*.

For lack of a generally accepted conventional (if not operational) definition of basic literacy, the figures we have quoted have only relative significance, although this does not do away with the issue itself. It is a serious one, calling for enlightened action clearly embodied in educational policy. What is to be avoided is oversimplification of the problem It would be both unfair and simplistic to blame the current crisis on faulty teaching based on Dewey's progressive theories or inspired by "new education" movements.

Much deeper explanations can be found. First, the composition of the school population has radically changed. In Belgium, a country known for its interest in education, a bare 15 per cent of children were found by Decroly and Boon in 1921 to be benefiting from universally available primary schooling (Jadoulle, 1930, p.8); today education is compulsory up till the age of 18. The then-prevailing system of social and intellectual selection in secondary education has been replaced by another in which the very idea of "selection" is considered anti-democratic. Unless teaching methods and the means of evaluation change to meet the new situation, there can be no avoiding a drop in average school performance.

Even more fundamental explanations exist: society – or, if preferred, civilisation – has changed, altering the goals of life and education. Rather than give in to alarmism, it is better to examine the situation clearheadedly. Although the following analysis could be applied to the education system as a whole, we shall limit ourselves to our chosen subject of reading. Overall, *as concerns the fraction of today's population corresponding to the elite of the past which has always served as the standard of comparison*, the effectiveness of education, including the teaching of reading, has increased rather than diminished. As the *guiding principle* of education today is to provide all citizens with equal opportunities, each person must be given help in acquiring the appropriate skills, reading paramount among them.

The considerations which follow are applicable to four segments of the population:

- Children entering the school system, who are entitled to a high quality education;
- The low achievers at school;
- Children who have left school illiterate or relapsed into a state of illiteracy;
- Adults who have never become literate.

Ensuring that all four of these segments attain an adequate degree (a notion to be defined later) of reading proficiency is a daunting task, and one that many systems of education and teachers do not seem to be equipped to tackle effectively.

Anderson (1983, p.166 *et seq.*) identifies four causes for alarm which, probably with local variations, appear to exist in many different countries:

a) The quality of teacher intake is declining. Referring to the University of Illinois, he remarks that the weakest students now choose educational sciences. The *Times Educational Supplement* several years ago published a similar observation concerning England. The same thing may be said about the European universities;

In France, it has been noted that a career in teaching is often a fallback choice. The author found, in Belgium, that nearly all the members of a secondary teacher training class had first unsuccessfully attempted to pursue university studies. Failure is hardly the best motive for directing a choice of career;

b) The quality of school reading materials leaves much to be desired, both as to their value as texts and their level of writing. Where "readability formulae" are used, they are often poorly applied;

c) Reading is, in fact, very little taught:
Durkin (1979), after 17 977 minutes spent observing reading and social studies periods in third to sixth-grade classrooms, found only 82 minutes of teacher-led instruction in study skills or reading comprehension beyond the level of individual words;
Reading aloud is still often practised, even though it is recognised as being boring and inefficient. Silent reading and direct individual communication between pupil and teacher are the best ways of ensuring progress. Yet on average, even in these junior classes, they represented only one minute per pupil per day;

d) Teacher education is inadequate:
In most OECD countries it still falls below university level. Courses in teaching practice or special methods for a branch such as reading often depend on a particular educator defending his "turf" or his personal convictions, backed up on occasion by makeshift teaching rules.
In concluding his worldwide survey of experimental educational research, G. De Landsheere (1986) wrote:

> When will educators have at their disposal, both for their training and practice, works comparable to those available in medicine, in which, for disciplines such as reading, they can find a description and psychological explanation of the processes involved, a systematic exposition of teaching methods, along with their experimental groundwork, a study of how to predict learning potential, methods for evaluating the various aspects of learning ability, and the information needed to diagnose learning difficulties (symptomology, case background, etiology) and provide remedial treatment?

He added:

> Far be it from us to want to "medicalise" education. This language serves merely to paint a metaphor, and any other clear imagery would do just as well.

As for working teachers, they are too often left to their own devices. Anderson deplores the lack of teaching "leadership" and direct classroom aid to teachers in many schools. When such support exists for the teaching of reading, however, it is followed by positive results.
Lastly, how many teachers today have been trained to teach computer-aided reading? How many schools are suitably equipped? How many adult education instructors, including those engaged in literacy campaigns, have received adequate training in teaching how to read?

In short, in both industrialised and less developed countries, a huge job remains to be done, and traditional methods and resources seem sadly inadequate in terms of both quality and quantity.

Initially devised, as their name implies, to carry out calculations, computers were first employed in mathematics and the exact sciences It was only later that their non-numerical applications were developed These other applications are fast becoming as important as the former, if not more so.

In the beginning, particularly where reading was concerned, learning isolated words and drill and practice predominated. In terms of numbers, they still do on the software market. Although the question will be gone into later on, we mention in passing the disturbing fact that, of the few schools equipped with computers, many have equipment (which, for financial reasons, they will probably not be able to replace for a long time) that does not permit them to take advantage of the increasingly available sophisticated software.

Side by side with the so-called "closed" programs mostly connected with the lower cognitive processes, more and more "open" programs are being offered, opening the way to active construction and divergence.

Wray (1984) established a first rough classification of "open" software, as follows:

- Word processing programs, in the broad sense;
- Simulations, such as adventure games, that encourage children to make predictions, test hypotheses and consult a range of resources;
- Construction by pupils of databases for their own use;
- Knowledge displays;
- Constructive programming systems such as LOGO;
- Divergent production programs (which we consider to be a sub-category of the above point). Wray gives as an example the Divergent Cloze program exercises described in Chapter 2.

As will be seen in Chapter 3, these categories can include highly sophisticated software.

Practical considerations apart, it can be emphatically stated that the latest technology – as anyone who has visited advanced research laboratories will testify – is endowed with a vast potential. How is this potential going to be realised in educational practice so as to aid the millions of children and adults who need such help? That is the burning question.

These techniques are still expensive and they require educators capable of using them satisfactorily. It may be said with certainty that they will help in training the trainers, but no one knows to what extent.

The present report is divided into four chapters. The first deals primarily with psychology and education. This is our way of demonstrating the primacy of scientific knowledge of the reading process and of educational goals over technology. For although technology, as will probably be made clear, makes it possible to set more ambitious educational goals than previously, it must not exceed its role as a tool of informed action. It cannot be sufficiently emphasized that technology is of no interest whatsoever if all it does is to carry out poor work much more quickly than in the past.

Chapter 2 will be devoted to showing, by means of practical, working and in many cases evaluated examples, that technology can be put to use at virtually every stage of reading acquisition.

Chapter 3 is more speculative in character. It describes prototypes and types of action which are to some extent still no more than working hypotheses.

Chapter 4 concerns the impact of the technological progress on classroom practice and curriculum design.

Chapter 1

THE EDUCATIONAL CONTEXT

GOALS IN THE TEACHING OF READING

Reading and writing are closely related. More specifically, there are many connections between the teaching and learning of reading and writing. The importance of this relationship should be emphasized at each opportunity.

In our system of civilisation, reading is, firstly, an instrument of survival It serves to decode messages that are directly useful in daily life: interpreting an instruction leaflet, written notices, advertisements, or factual information in a letter or newspaper; consulting a telephone directory, etc. The message is decoded word by word and comprehension is direct. The basic definition of functional literacy corresponds to this rudimentary level of reading proficiency.

As we have seen, however, functional literacy can be given a much broader meaning. It can signify the ability to gather information by reading in order to increase knowledge, enrich the imagination and inform judgment. This, at least roughly speaking, covers a good part of the definition of basic general education.

This enables us to postulate the following goals (see also, Chapter 2 Purves' tridimensional model of reading behaviours):

- Reading to learn and, more particularly:
  - to acquire (and possibly master) specific knowledge;
  - to build up one's personal culture, defined as developing a reflective mental attitude concerning the facts of civilisation and society;
  - to develop one's intelligence or personality;
- Reading for entertainment and relaxation;
- Reading for aesthetic reasons, to discover the beauties of literary expression;
- Reading aloud for professional (e.g. radio/television announcing) or artistic (e.g. poetry reading) purposes.

Once a pupil goes beyond the stage of direct commands or algorithms for particular tasks, he is required to employ "expert" reading skills stemming from a combination of three capabilities (Lesgold, cf. Part One):

- Efficient but flexible basic routires;
- Substantial general knowledge in the relevant domain;
- Powerful strategic skills that enable him to reason beyond his current knowledge.

It is clear that the various goals do not call for the same degree of attention, of precision in registering information, or of depth of reflection Running one's eye over a newspaper to pick out the day's news, skimming through a novel to kill time on a train journey, and poring over lecture notes in which every idea may be vital for passing an examination, do not – or should not – call for the same response on the part of the reader.

Expert reading performance is determined, in fact, by the ability to vary information-registering strategy in accordance with the desired goal. One of the primary, but often neglected, objectives of the teaching of reading is to instil this kind of behavioural flexibility.

THEORIES OF READING ACQUISITION

The Contribution of Cognitive Science

Ever more rewarding applications of new information technology are in store, thanks among other things to research accomplishments in artificial intelligence and cognitive science allied with the rapid strides being made in the field of equipment and software For the first time since the beginning of the computer explosion, teaching problems are being situated at their proper level, that is to say, at the level of the higher cognitive processes. There is a will to respect the soundest theories of learning, social and emotional factors, and the findings of the most advanced educational research. In other words, the conditions seem to be ripe for a decisive step forward.

The most developed computer systems have coalesced around a theoretical model of the human mind viewed as a complex information-processing system in which information is organised, stored and operated on in ways that are only now beginning to be characterised in detail Committee on Science, Engineering and Public Policy (COSEPUP), 1984, p.24. As for the expert systems derived from recent discoveries in the field of artifical intelligence, they require an explicit representation of the highest realms of expertise.

a) The constructivist approach

During the heyday of behaviourism, attention was for a long time focussed on the outward, directly observable factors favourable to learning. Undoubted progress was achieved, but the part played by the underlying cognitive processes was too long left in the dark of the flow-chart "black boxes". This bias has been gradually corrected, so that, over the last two decades, a much better understanding has been obtained of the internal cognitive processes involved in mental operations and the acquisition of knowledge. Computer science played an active role in this respect:

> Through the simulation of human learning and problem solving, researchers have been able to verify detailed hypotheses about the mechanisms, architecture and language of the human mind, particularly as they affect highly skilled performance by experts or the mental work by which novices gain new skills. (COSEPUP, 1984, p.2[illegible])

Long before these recent advances, however, the active character of thought and the learning process had been recognised. Early in the 20th century, educationists like Dewey, Claparède and Bovet, and the adepts of the New Education movement in general, stressed the importance of action in the learning process, of learning by doing. This insight was essentially pragmatic – praxis and experience bore out the validity of their primary methodological assumption. It was left to J. Piaget to demonstrate that the intelligence forms itself through the interaction of an individual with his environment.

This thesis is directly applicable to reading. Reading is not a one-way communication process by which the reader's mind passively receives text content, like a tank being filled. Rather, the reader actively builds up meaning on a foundation of concepts elaborated and memorised in the course of previous experiences. This construction process occurs genuinely only when problems of significance to the learner are being solved Put differently, a reader always approaches a text with a purpose. A good author may modify the reader's original purpose both creating and filling a need the reader did not recognise at the outset One may, for instance, glance over a piece of text that happens to be lying about and then allow oneself to be drawn into it.

The two keys to the process are conceptual understanding and functional application. Without these, acquired knowledge and skills either are quickly forgotten or remain inoperative in situations different from the ones in which they were learnt. The capacity for conceptual understanding is obviously determined by the individual's degree of cognitive development. Research has corroborated a longstanding observation, namely that when a task becomes too complex for them to handle children tend to employ lower-level processes. In reading, particularly, this "downsliding" ends with a return to rudimentary decoding (Collins and Gentner, 1980; Rubin, 1982). It is important, therefore, to seek a careful balance between the difficulty of the task and the reader's capabilities. The Story Maker program (Rubin *et al.*), described elsewhere in the report, has this aim, among others, in view

Recent cognitive studies in the following fields are of particular importance to reading instruction:

- Memory;
- Evaluation of information-processing ability, using decision-time as indicator;
- Study of representations and their effect on behaviour;
- Study of "folk" wisdom and knowledge, i.e. prediction and explanation of events, effective in problem solving even though independent of scientific knowledge;
- Study of how individuals' knowledge affects their interpretation of text;
- Interactions between the reader's purpose and the reading process.

b) Concerning "metacognition"

Metacognitive processes may be defined generally as an individual's awareness and knowledge of how his mind works, and his ability to choose deliberately which cognitive processes to use in order to achieve a particular goal. It has been proved that metacognitive activity can play a critical part in reading. Brown *et al.* (1973) cite cases of children who achieve an adequate early degree of reading ability but who experience breakdowns later when they have to study scientific concepts from textbooks or course notes. "A closer look indicates that one reason for this is that such children do not understand that reading entails management of their own cognitive resources. They are not planful; they do not get clear on the goals for reading; they do not monitor progress in reaching these goals; they do not engage in mental review to assay whether information they are supposed to be getting is still held in memory." The key questions which a reader needs to ask himself concern his reasons for reading, the aim he is trying to accomplish, the cognitive processes (e.g. whether or not to memorise systematically) involved in meeting that aim, a self-assessment of his skills, the correct reading strategy to adopt, quality control of his learning acquisitions, and the corrective action to be taken when these are felt to be unsatisfactory (Biggs, to be published).

Briefly stated, research indicates that successful learning depends on a pupil's ability to:

- Reflect on what he is doing to accomplish a particular task;
- Check his progress towards achieving the goal in question, a goal with which, ideally, he should identify himself;

- Analyse his personal difficulties in comprehension;
- Adapt his strategy to fit the results of the three foregoing steps.

Such metacognitive behaviour presupposes systematic training.

The Emotional Component

Theories of reading acquisition have benefited from more than cognitive research. There is a growing awareness of the importance of emotional factors. In this context, the study of motivation is highly significant. It has long been known that incentives extraneous to the goals of learning have a tendency not only to subvert educational goals but also, in the long run, to be ineffective. The ideal is for the learner to adopt the educational objective as his own and find his reward in the fact of attaining it. The part played by motivation is generally decisive. We cannot but agree with Michael Canale:

> When the reading environment provides motivating purposes for reading, reading skills will normally be acquired and developed regardless of method of instruction. When the reading environment does not provide such purposes, reading skills may not be acquired nor developed to any interesting degree, regardless of method of instruction.

Another known motivating force that can be very powerful is the need for achievement. People endowed with it have the desire to vanquish the difficulty they have decided to tackle, sometimes independently of the task at hand. Someone who wants to be top of his class can learn subjects that do not interest him in their own right – the aim being to excel. Many games and computer programs provide challenges that strong achievers are happy to accept. More especially, some pupils find in them a stimulus that the school no longer supplies. It remains to be demonstrated, however, that the motivation generated by Computer-Assisted Learning carries over into more traditionally conducted types of learning.

The Process of Learning to Read

a) Ideograms and alphabetic script

Reading, as we have seen, is the construction of meaning. The process takes place in two broadly defined steps. The *first* of these is a unitary construction in which the reader decodes a word and attributes a primary meaning to it comprising a semantic nucleus (father = procreator, for all readers) and a psychological aura in accordance with the personal experience (father = rule giver, disciplinarian, example of competence). Except for the case of one-word sentences, where the steps are indistinguishable, the *second* step consists in forming units and chains of meaning from numbers of words. Whereas in ideographic scripts learning occurs through memorisation of idiosyncratic graphic structures, in alphabetic scripts a symbolic, analytical system represents the phonology of spoken language. While learning processes corresponding to the first step differ radically for alphabetic and ideographic scripts, those connected with the second step are not fundamentally different, as the study of eye movements has long since proved (Gray, 1956).

b) The process of reading alphabetic script

Aside from variations in reading behaviour linked to the aim being pursued, to which we shall return, there is a basic process involved whose character needs defining. There are two conflicting schools of thought. Here are two examples among many: Gibson and Levin (1975) define reading as extracting meaning from text, while Downing and Leong (1982) see it as the interpretation or understanding of literal, graphic or musical symbols. In reality, the two points of view are complementary rather than mutually exclusive. Before expanding on this point, however, it is necessary to outline the two theories, as they have a bearing on teaching methods.

Aarnoutse (1986) sets them out clearly in the form of two models: the "bottom-up" model in which the reader starts by analysing the printed stimuli (letters and syllables) and works his way up to the word, sentence and full text; and the "top-down" model where the reader, starting from concepts rather than stimuli, begins with hypotheses and predictions, which he then verifies by working down through the sentence to the words and finally, the letters. Strictly speaking, the first model posits a purely linear progression, practically ruling out any interaction between higher-order cognitive activity and lower-level processes. It more specifically excludes any contextual influence on the apprehension of words and letters. The top-down model, on the other hand, is essentially interactive.

Whereas the point of departure in the first model (upheld notably by Gough, 1972) is the graphic information that yields meaning step by step, the second model, though requiring a modicum of decoding like the first, supposes an almost immediate mental commitment in the shape of semantic processing at the higher cognitive level. Aarnoutse (1986, p 3), in line with Dohrmann (1955), Smith (1971, 1973) and Goodman (1976), states:

> Based on preceding information and acquired knowledge, the fluent reader predicts the next words and selects just enough information to test his hypothesis

In actual fact, these models are not mutually incompatible; they rather supplement and interact with each other. According to the stage of learning attained, the extent of the reader's familiarity with the content of his text, and the aim in view, they are employed in varying proportions. Aarnoutse (1986, p.4) goes on to say:

> In his model, Rumelhart (1977, pp.589-590) postulates a message centre and five independent knowledge sources, namely feature extraction, orthographic knowledge, lexical knowledge, syntactic knowledge and semantic knowledge. These knowledge sources provide input about the text being processed, while the message centre holds this information in store and permits the sources to communicate and interact with each other. According to Rumelhart, the message centre "keeps a running list of hypotheses about the nature of the input string". Each knowledge source constantly scans the message centre for the appearance of hypotheses relevant to its own sphere of knowledge. Whenever such an hypothesis enters the message centre, the knowledge source in question evaluates the hypothesis in the light of its own specialised knowledge As a result of its analysis, the hypothesis may be confirmed, disconfirmed and removed from the message centre, or a new hypothesis can be added to the message centre.

This third viewpoint, to which we also subscribe, is put more succinctly by Brugelmann (1985, p.2): reading calls for continual interaction between the top-down and the bottom-up processes see also Purves (1971) and Sternberg *et al* (1986). Indeed, it is impossible to construct meaning merely by accumulating atoms of language. In more analytical fashion, we can enumerate the following conclusions:

- Learning to read demands awareness of the fact that the written word conveys information;
- Reading is actively appropriating a piece of information; it is construction of meaning;

- Information is meaningful for an individual only in so far as it connects with his world, his cognitive, emotional, psycho-sensory, direct ("I was there") or indirect ("I've been told") social frame of experience;
- The first act in reading is phonological decoding to obtain meaning;
- In order to use the alphabetic system effectively, one must be able to analyse the phonic elements of spoken language. This ability is crucial in learning alphabetic reading;
- Successful learning is signified by the full internalisation of phonemic analysis. The reader goes directly from graphemes to meaning without having recourse to reading aloud or under his breath. As learning progresses, this development should accelerate. One must not forget, however, that successful reading also depends critically upon knowledge of written syntax, gender, literary convention, argument structure, etc.

c) The stages in learning to read

Chall (1979) lists a set of developmental stages in reading with an emphasis on their relation to education. We will use this classification in the rest of this paper. Ingvar Lundberg has modified the first two of Chall's five stages. Chall's classification is based on the goals of reading:

Stage 0: Prereading. For example, a child ideographically learns the name of a brand of petrol from street advertising. Lundberg divides this stage into two stages: pseudo-reading and logographic-global reading. At the logographic-global reading stage, the child starts picking out salient graphic features like initial and final letters and global word shape. Phonological factors are entirely secondary at this stage. "The child has not yet really broken the code." He tends to guess on the basis of contextual cues. He gradually infers the alphabetic principle and thus gets ready to move on to the next stage.

Stage 1: Simple decoding. Lundberg calls this stage alphabetic-analytic and defines it as the stage for which a certain level of phonemic awareness is necessary. Letter order and phonological analysis play a crucial role at this stage. The alphabetic code is broken.

Stage 2: Reading "the familiar", for practice in developing proficiency (this is not inconsistent with the functional approach). The child acquires fluency and improves his reading speed. Chall (1979) considers that adult literacy programmes often fail at this stage.

Stage 3: Reading for new knowledge, from a single viewpoint: facts, concepts, and how to do things. The vocabulary may include words unfamiliar to the child. According to Lundberg, the child is now capable of making an instant, context-free and automatic analysis of words into orthographic units. Written language becomes increasingly independent of oral language.

Stage 4: Reading from multiple viewpoints, involving greater depth of treatment and dealing with more than one set of facts, theories or attitudes.

Stage 5: Reading from a qualitative, relativistic point of view to construct or reconstruct knowledge.

CURRENT IDEAS ON THE TEACHING OF READING

Educators with an unsatisfied appetite for controversy can draw on a seemingly inexhaustible store of arguments concerning the merits of the various methods for teaching reading. With research incapable of supplying a decisive answer, one hears the old paradox regularly trotted out: children who are bright and keen enough can learn to read without a teacher, or even despite a teacher, merely by using the stimuli of their environment.

A special issue of *Le Monde de l'Education* (June 1985, p.24), devoted to learning how to read, reached the conclusion that:

> Researchers, psychologists, educational psychologists and psycholinguists feel there is little to choose between any of the methods for teaching reading. This is not because they are all equally good, but because, beneath wrappings variously redesigned to suit the fashion of the day, they are selling the same article, namely the ABC as the prerequisite for reading, at the expense of the search for meaning.

On the other side of the Atlantic Rubin and Purves, members of the Working Group, also found marked disagreement:

> Some educators have recommended that the various component skills of reading be taught and practised individually. The underlying assumption is that the student will be able to combine the mastered skills appropriately to construct meaning from a text.
> Other educators, while agreeing that a multitude of skills contribute to reading success, have emphasized that students must perform the unified act of reading, practising individual components primarily in the context of comprehending a text. An emphasis on reading as meaning-making is most consistent with this second point of view.

Mommers (1985, p.9) presented the following opinion:

> Drawing conclusions for reading instruction from research data requires caution. Yet some guidelines may be suggested. The child's fundamental task in learning to read is to discover how to map the printed text on to his existing language. This process requires the ability to deal explicitly with the structured features of spoken language. Two general kinds of language problems may therefore affect reading acquisition:
>
> - The deficiency in knowledge of oral language *per se*;
> - The inability to bring knowledge of oral language to conscious awareness.
>
> The results of our analysis suggest that phonemic or phonological awareness is a distinct kind of linguistic functioning that affects primarily the early stages of the reading acquisition process. Lack of phonemic segmentation skill may lead to difficulties in learning to read. Therefore, it seems advisable to introduce the child to phonemic segmentation before formal reading instruction starts. This can be accomplished by exposing the child to various kinds of language activities, such as rhyming, sorting objects or spoken words by their initial or final sounds, and so on.
> However, the influence of phonemic awareness is limited. The general prerequisites, including oral language skills, affect reading comprehension to a greater extent than phonemic awareness does.

Prereading

The prereading stage, thought by Chall to begin at the time of primary school entry, often begins earlier, or at least is prepared for long before:

- Some of this early preparation coincides with overall development: acquisition of the body scheme, laterality, rhythmic sense, recognition of cries and sounds, etc ;
- Certain aspects of development are more directly related to reading: memorisation of sounds and graphemes; fine visual discrimination; orientation of written characters; ability to copy graphic elements; etc. In particular, exercises leading children to discover, guess and combine sounds are extremely valuable for when they later learn to read.

Quite rightly, nursery schools generally place a high premium on games and other activities that involve using these abilities. Ideally, this form of education should also be given a functional character.

Factorial research, needed for perfecting methods for forecasting reading aptitudes, strongly confirms the above assumptions. To quote but one example, Leclercq-Boxus (1973) identifies two factors that strongly pervade eight aptitude tests. She defines the first as "intelligence applied to spatial structures, analysis-synthesis ability, perception of structures", and the second as "memory, attention and concentration capacity".

In addition to the development upon which these skills depend, account must be taken of explicit prereading activity, also often present well before the age of six The following should be especially noted:

- Activity in which the child pretends to be reading, for example, by reciting a favourite story while turning the pages of his storybook This is evidence both of motivation and of a vague but promising understanding of the relation between the written word and its meaning;
- Memorisation and naming of letter shapes that enable reading to be mimicked in a game-like way.

In this connection, Lawler (1985) conducted some extremely interesting experiments. As is well-known, LOGO provides an easy method of programming graphics, stocking them and naming them at will. It suffices to type out the chosen name to make the graphic appear on the screen. Using this procedure, "microworlds" have been created, consisting of a fixed background scene, e.g. a beach with a horizon (the Beach microworld is described at greater length in Chapter 2), and the ability to make people, animals and things (man, girl, dog, plane, etc.) appear and move against this backdrop by typing the relevant word on the keyboard. For instance, a child picking the card marked DOG types the three letters and the animal shows up on the screen. Lawler found that small children memorised the graphemes that enabled them to conjure up the image they wanted. There are ways in which this prereading behaviour resembles that referred to earlier, but there is a crucial difference: in this case, the child *builds* a project. The prereading activity involved is therefore undeniably functional. Drawing on this type of experiment, Lawler envisages a method for the teaching of reading.

Lawler and Lawler (1985) employ Kahnemann and Tversky's (1974) notion of "anchorage with variation", a process in which the subject required to solve a novel problem starts out from a known basis, or "anchor", and proceeds to vary it until he arrives at a solution. Analogy plays a prominent part in the process The process could have profound implications for reading acquisition. The familiar words learnt unintentionally by many children at the prereading stage could act as anchors. The computerised microworld could enable prereaders to acquire a set of anchors in a more highly organised way. Command of the phonological code could be achieved gradually through variations practised on the anchor words. For example, a child familiar with both the word "bob" and the letter "s" would be able to read the word "sob". In the description of the Beach microworld, the child is seen memorising words as a result of typing them out letter by letter when giving instructions to the computer.

In order to provide a reading instruction curriculum with a sound underpinning, Robert Lawler works out an optimal monosyllabic range. Although the number of possible syllables is extremely high (60 000), the critical range lies around 5 000. Following a series of statistical analyses, Lawler arrives at a figure of 550 words. If children can learn the 550 correspondences between sounds and spelling patterns, and their ability to decode others through anchoring with variation is recognised, they should be able to cover a major portion of the phonetic-orthographic correspondences of the English language. It should be emphasized that Lawler does not present his system as a comprehensive reading teaching curriculum. For him, it is a working hypothesis to be included in a broader educational pattern.

Stage 1: Simple decoding

In the prereading stage, the child may recognise words, but without doing any phonological analysis. Purely visually and globally, he decodes an "image". Later, when learning proper begins, he learns a number of tool-words (a, the, some, etc.) and others – usually monosyllabic – the same way, and for some time continues to decode them like ideograms. At an even later stage, proficient readers read so fast that it is almost impossible to know whether they are relying on a visual or a phonological code.

This notwithstanding, the key to alphabetic reading and writing proficiency lies in decoding *via* phonology. For this to be possible, the letters and their combinations must be known, and the ability must exist to analyse in explicit fashion the phonic elements of spoken language. This ability is critically important. Lundberg (1984) showed that there was a very close correlation (over +0.70) between pre-school linguistic awareness and reading proficiency in primary school.

For some time the child is obliged to oralise words if he wishes to understand them. The signal of understanding is the suddenly normal pronunciation of a word at first decoded with difficulty (the *Aha-Erlebnis*). If learning proceeds normally the vocalisation of letters and letter-groups, and finally sub-vocalisation, disappear. The spatial, visual aspect of the text is directly transformed into vocabulary. The pronunciation might be said to become mental. According to Lundberg (1985), encouraging a child beginning to read to attend to all the letters in a word may be advantageous for learning spelling.

A vitally important fact: Failure to master the typical Stage 1 skills jeopardises the reader's future. To a large extent, this failure is the probable root cause of the high rate of illiteracy and, more seriously perhaps, of failed school careers in general.

Non-proficient readers have great trouble reading isolated words, they make up for their deficiency by guessing from the context. It is symptomatic, moreover, that dyslexics experience immense difficulty reading meaningless imaginary words. It would be rash to assert that reading difficulties all derive from a problem with phonology, but its role is certainly decisive. The following two cases of research, quoted as an example, speak for themselves.

There are some pupils, normally intelligent in other respects, who experience difficulty in the early stages of reading. The hope is often expressed that "time will remedy that". What is the truth of the matter? Lundberg (1984) reports having selected, out of a group of 700 pupils finishing their first primary year, 46 conspicuous underachievers in reading and writing. He followed them through to their sixth year, along with a control group of the same size whose reading ability at the outset had been normal with respect to their intellectual capabilities. In the sixth year, half of those who had experienced difficulty in their first year still failed to match the standard of even the worst members of the control group. Eight pupils had caught up to the average level for the entire group (700). But Lundberg concluded: "We have not seen any particularly good readers and spellers among the pupils who were already diagnosed as poor readers during their first years at school" (p 8). Self-image, studied in the first, second, third and sixth years, was consistently less positive among the poor readers than among the others.

This study corroborates the one already carried out in the United States by Kraus in 1973. Kraus followed 165 children – whites, blacks, Hispanics and Asiatics – from nursery school through to adulthood (85 of the original group). He wrote:

> ... reading problems in the first and second grades must be viewed with anxiety but not with despair (...). Deep concern, however, and much thought must be given to children who, at the end of the third grade, are still presenting reading difficulties, for it is at this point that reading patterns seemed to become fairly well fixed (p.41).

Kraus further noted that the only pupils who satisfactorily overcame their initial difficulties were ones who had been aided, individually, by reading specialists. Looking ahead to the rest of this report, we can see at once what kind of role valid technological aids could play.

Stage 2: Reading for practice, but still dependent on deciphering the phonological code

This stage, which we think should coincide with the first one, consists in getting the child to read short texts about subjects very familiar to him, so that he can concentrate as much as possible on the construction of meaning. At this point, we must face up to a crucial problem on which researchers are divided.

Some, like Dohrmann (1955), hold that an expert reader constructs the meaning of a text from a minimum number of cues. The speed with which one can read an item of general information in a newspaper or a page of a fairly straightforwardly written novel would seem to indicate that the eye does not examine each letter individually but advances by leaps, even skipping several lines at a time. Film of eye movements appears to bear out this assumption: it shows a sliding movement with a varying number of pauses (sometimes hardly any) of different duration. Starting with the title or the first words of a text about a familiar subject, the reader makes assumptions about what is to follow and selectively looks for words, word clusters or parts of words even that confirm or contradict the assumptions. In the latter event, one may backtrack in order to find the correct path. This is "global" reading, a mental activity (psycholinguistic guessing game) involving the higher cognitive processes. Need we stress again the decisive role played by familiarity with the reality touched on by the text? It provides "matrices" for integrating the information.

Other researchers, including Lundberg, adopt a position that seems diametrically opposite. Lundberg says:

> A great number of studies employing a wide variety of paradigms have failed to find that good readers rely more on context for word recognition than poorer readers (1985, p.3).
>
> The skilled reader's processes of word recognition are largely rapid and automatic and thus not in need of contextual support, allowing attention to be allocated to comprehension processes at text level. (...) Poor readers, on the other hand, tend to use contextual cues (if they can) to *compensate* for their inefficient and poorly automatised decoding of word-internal information. This guessing strategy, however, even if it is successful, will leave less cognitive capacity for the text-integrative processes that are crucial for reading comprehension (pp.3-4).

It seems generally agreed that Lundberg's view is fundamentally correct. Leaps do occur, of course. In a novel, for instance, when a descriptive passage seems to hold up the action we skim through the text, checking the odd word, up to the place where the description ends. Physical cues, such as paragraph divisions, are used for the same purpose. We can also skip all or part of the account of a sporting event in order to go straight to the result. These, however, are all strategies tied to an objective and are not to be confused with the reading process itself. In reading, the fluent reader's eye scans every word. He decodes them either one by one or in different-sized groups (which may be enlarged by practice), instantaneously; he pauses appreciably only at key words, unknown terms, obscure passages or sequences which do not flow logically from what has gone before.

This second point of view in no way detracts from the importance of predictive assumptions. The stronger they are, the more speedily and easily reading will flow. "A difficult text is one with a high rate of improbability; it is often therefore more informative" (Foucambert *et al.*, 1984, p.2). We may imagine a child confronted with the sentence, "The dog is white", where the last word is relatively unfamiliar to him. The child stops after "is". There are two ways of helping him – one can ask him either to identify the first letter of the unfamiliar word, or to say what colours a dog is likely to be (assumption, construction of meaning). Then one can invite the child to check whether the unfamiliar word starts with the first letter of the word he has just suggested.

The attitude towards reading is another determining factor. Right from the beginning of learning, reading must be perceived as enjoyable. Texts read "for the fun of it" must be of high quality, not forgetting that what is good for one pupil may not be good for another. Ideally, a text should both interest the reader and match his level of cognitive and linguistic development. This gives rise to a double imperative: to understand these factors and have access to a wide variety of texts. Here, too, technology can be a valuable adjunct in diagnosing skill and classifying texts.

Recognising that there is no universal criterion of "goodness", Bruce (1978) distinguishes two features highly prized by children and often missing from school texts, namely continuity and conflict. Children appreciate it when ideas connect well with one another. They are not greatly attracted by pseudo-stories, "constructed solely to introduce letter-sound correspondences" (p.461). As for conflict, it is expected either within a character or between characters. "The cat sat on the mat" is not a story. "The cat sat on the dog's mat" *is* a story. Without conflict, there is no problem to be resolved (*ibid.*). In more general terms, "good stories" play on the beliefs and expectations of the reader.

Stages 3, 4 and 5

From stage 3 on, with reading skill acquired, reading becomes more and more a tool and less a subject of study. One of the most frequently noted defects in teaching consists in more or less leaving the pupil to his own devices. The unspoken assumption is that he will improve his skill, if the need arises, by spontaneous learning. This explains why the systematic teaching of reading is often omitted from Stage 3 on. Usually, in upper primary classes, the "reading lesson" amounts to making the pupils take turns in reading aloud, with perhaps a few technical corrections and some brisk questions on comprehension.

What remains to be done is to instil an ever clearer awareness of the various goals of reading and the best strategies for attaining them. "Word-by-word reading is always preceded by an investigation to situate the text, to situate oneself with respect to the text, to select the information one hopes to gain from it, and to organise it. This is flexible reading. To read is to choose, to have an active attitude of choice and control towards the text" (Foucambert *et al.*, 1984, p.4).

What is the best method?

There is no *single* best method. Instead, there are a number of essential transitions, as has been said. We have also seen that teachers have a choice between two major approaches, one "top down" the other "bottom-up". The difference between the two approaches is more apparent than real, in the sense that the desired objective, and the main mental processes pertaining to it, are the same. The various teaching methods that, so to speak, clothe these approaches result from an interaction between the teacher, the taught, the environment and particular circumstances. The very act of slavishly applying someone else's method is itself a choice.

We shall see that more and more educational software coming on the market addresses the teaching of comprehension at different stages. In fact, many newly-developed teaching methods address the teaching of reading comprehension and advanced reading skills concerning Stages 3, 4 and 5.

Chapter 2

EXAMPLES AND ANALYSIS OF EDUCATIONAL SOFTWARE

Today we are justified in claiming that new information technology can play a major role in the teaching and learning of reading. It can permit a hitherto unknown degree of individualised, intense instruction. Instruction is to be understood as meaning not only direct educational interaction and the creation of a situation favourable to the independent acquisition of skill, but also evaluation, diagnosis and remedial action.

Brügelmann (1985, p.5) underlines a particularly important aspect. Learning to read cannot be regarded as merely a rote process. The language experience approach has emphasized the role of meaning and the communicative value of print. The computer, for the first time, offers children an opportunity to use print, without the help of adults, as a powerful instrument with immediate feedback in a significant context.

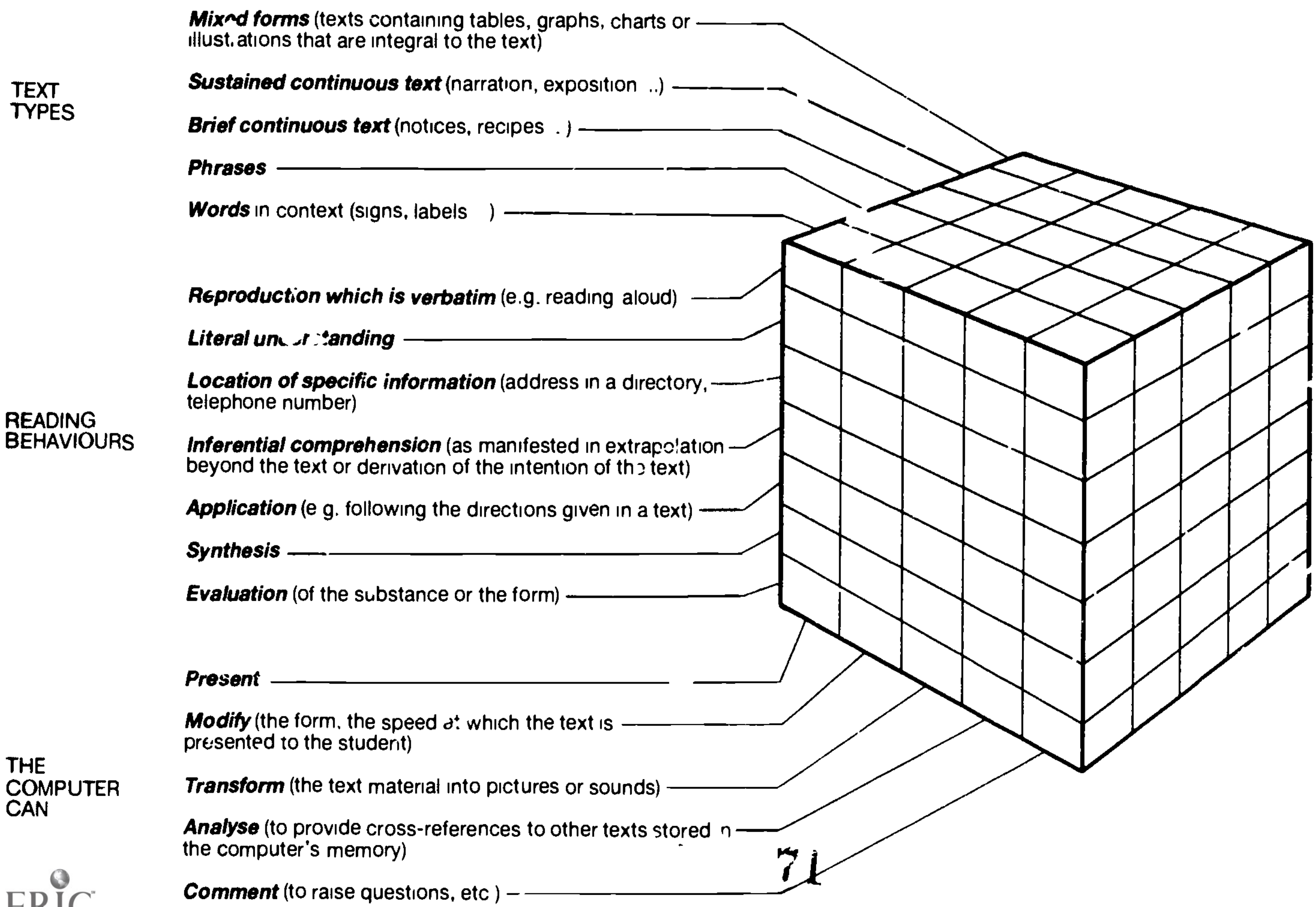
New information technology now offers a wide variety of programs covering nearly all the stages of learning. Taken in isolation, and not seen as tools for use in an educational project, many of them – even when they are materially well produced, which is by no means always the case – are of dubious psychological and pedagogical value. Instead of exploiting the computer's interactive potential, too much courseware merely offers exercises in mechanisation and artificial memorisation. These conceptually indigent programs are, however, exciting ever more vigorous protest. Computers offer three new capabilities with important educational significance (Collins, 1985):

- The creation of environments where children read and write in order to communicate;
- The creation of activity environments where children solve problems that require reading;
- The easing of reading and, especially, writing tasks.

In the hands of teachers with skill in the science and art of teaching, the new technology should stimulate decisive progress in the teaching of reading.

In this chapter we shall be dealing not with hardware but solely with courseware in its broad sense as defined by Le Corre and Schwartz (1984, pp. 61 62). "Courseware: a complete educational package for use on a Computer-Assisted Instruction (CAI) system to achieve an overall educational goal; CAI: Interactive use of the computer as an educational tool at the centre of an educational relationship between learners and teachers". In this broad sense, CAI includes both the education and the management roles. Already there are hundreds of reading courseware packages or "programs" in use in schools, available on the market or being developed in R&D laboratories. They differ considerably as regards both their aims and their psychological and educational quality, which in most cases is still somewhat mediocre.

COMPUTER AND READING



Rubin (1982, p. 6) notes that, of the 105 educational programs listed in the December 1980 catalogue published by Dresden Associates:

- Nine required the student to manipulate text at the letter level (e.g. racing with the computer to type the next letter in the alphabet);
- 85 required the student to work with isolated words (e g choosing the correct synonym);
- Seven required the student to deal with phrases or sentences (e.g. dividing a group of words into two sentences);
- Onlv seven programs presented students with a whole text

In addition, Brügelmann (1985, p.5) noted that an analysis in 1982 of 317 reading and writing programs available in the United States showed that 60 per cent of them were concerned solely with drill and practice and only two dealt with whole texts.

It is not very difficult to do better than this – provided a little more is put into the design and experimentation phases. Many of the existing educational programs barely amount to more than the most rudimentary form of linear programmed instruction However, experience has shown that they can be of some use, either in the case of a particular stumbling block in the learning process, which a highly controlled analytical approach can overcome, or when dealing with slow learners of very limited ability. Nonetheless, these advantages are themselves very minor – other than the possibility of overcoming emotional blocks and thus paving the way for learning processes that are directed more to conceptual understanding and the acquisition of higher cognitive skills.

We also have to bear in mind that the poor quality of the hardware and the computer language used in many schools almost inevitably confines them to elementary approaches. Considerable progress is being made at present in both the design and production of courseware, however, and there has been a noticeable broadening of the range of objectives and possible methods of use. In particular, there is a desire to make fuller use of the practical advantages offered by the computer: manipulation of texts using word-processing packages, altering layouts using formatting packages, question and answer sessions between students using communications networks, etc. The increasing scope for combining pictures and sounds in programs should also lead to a marked improvement in the quality of educational software.

Of the various possible methods of classifying courseware, there are two which seem best suited for our purpose. The first of these, suggested by Alan Purves, takes as its main criterion the form of cognitive or linguistic processing applied to texts by the computer. The second, suggested by Andee Rubin, is more directly concerned with the educational aspect.

Purves considers reading performance as the interaction of varying types of text, which could even be simply single words, with varying forms of cognitive or linguistic processing. His theory can be represented as a three-dimensional model.

Rubin classifies programs into four main categories. We shall be adding a fifth and a sixth.

TUTORS AND PRACTICE ENVIRONMENTS

The object of these is to improve performance and provide practice for one or more reading skills in isolation or with minimal context. Feedback, which is almost always immediate on Skinnerian lines, usually involves simply a correct/incorrect or right/wrong response or sometimes an actual "reward", i.e. the playing of a musical theme, awarding a "certifica of merit" or top marks. In some cases the program can adjust the level of difficulty to the quality of the responses. Exercises range from individual letter/sound correspondences to questions on complete texts.

Rubin divides this categ ·· of programs into those that deal with early reading (decoding and/or vord recognition) (Chall Stages 0 and 1) and those that give students practice opportunities with comprehension-related aspects of reading, from individual word meaning to integrative comprehension skills Some of these programs are single-purpose pieces appropriate for a short period in a child's development of reading skill, while others are packages incorporating a series of exercises relating to various skills that are meant to provide a curriculum useable over several years.

Most of the programs listed in software catalogues fall into this category, as most are quite like traditional workbook exercises, with the added feature of immediate feedback. With the more creative of these programs, the computer alters the speed or format of text presentation and/or the difficulties of the tasks, adapting these to the quality of the responses. It would be wrong to underestimate the services that well-made programs in this group can provide, provided they are used intelligently.

In a future scenario suggested by Rubin a student in the fourth grade who is having trouble learning to decode, plays a game on a computer for 15-20 minutes a day. The computer presents words for the child to pronounce that have been selected by a reading specialist to suit the child s particular problems; words are presented at a rate that adjusts to the child's pace. Using sophisticated speech recognition, the computer evaluates the child's performance and, if progress is made, the rate of presentation is gradually speeded up. If the child makes a mistake, the computer says so and pronounces the word correctly. Although an exercise like this is still somewhat artificial, it is certainly more stimulating than doing simple pairing tasks from book of exercises. In this case, not only is the child's activity supported and encouraged in various ways, but the tasks are suited to his particular problems.

Examples of courseware

(It is hoped they are representative,
but they are not supposed to be comprehensive)

PAREIL OU DIFFERENT (Québec)

Recognising the shape of letters: matching the letters on the screen with those on the computer keyboard.

CHEMIN DE LOUIS ETIENNE (Didaktek, Paris)

Training in the syllabification of words (transition from the oral to the written form of the language).

MAGIC SPELLS (LC, United States)

Students spell and unscramble words from 14 word lists to unlock treasure chests before the spelling demon can get hold of them.

WIZARD OF WORDS (CA, United States)

Letters are tossed into the air and have to be unscrambled and made into a word.

Guessing a word letter by letter to gain entry to a castle.

Finding shorter words hidden in a long one.

Filling in words on a puzzle.

LIS – LISONS – LISEZ (Belin, Paris)

Learning basic reading skills: perception, memorisation, comprehension Adjusts to the child's own pace.

RACER (Bolt, Beranek and Newman, Inc., United States)

Game involving decoding whole words.

It requires pronouncing words as quickly and accurately as possible 20 words are presented in each race. The comput speeds up as the student's skill increases.

Because the computer cannot judge whether the student has pronounced the words correctly, there is a second phase to the game called Soundtrap in which the student hears eight pairs of similar words (e g. moose – mouse) and has to decide which of the two was actually presented during the race.

The student's final score is a combination of his performance in Racer and Soundtrap.

ALERTE (CEDIC-NATHAN, Paris)

Speed reading training.

A "target" word is shown on the screen in the form of letters or pictures Less than a second later it disappears and is followed by a list that runs through a frame. The student has to spot the original word in this list.

WORD RACE (DNT, United States)

Each game starts with a word, six possible definitions and a counter set at 600 points. The countdown begins when the task appears and stops when the player picks the correct definition and he is awarded the number of points left. If he guesses incorrectly, he loses the number of points left on the clock.

The game is designed for both children and adults and features over 2 000 words

SKI JUMP (Bolt, Beranek and Newman, Inc., United States)

Exercises in selecting words to fit a context.

Students first read a sentence with a word missing near the end A target word is then presented in a degraded form (i.e. with only some of the dots that form it) and students must decide whether it fits the context. Initially the word is quite difficult to decipher, but on successive exposures more dots are added until it is close to completion. The object of the game is to recognise and judge the word at the earliest point possible.

DIVERGENT CLOZE (F. Potter, United Kingdom)

Instead of having to guess the original word that has been omitted from the text, as in Taylor's cloze test, the child, with the help of the language context and syntactic, semantic and pragmatic clues, makes a number of guesses that seem acceptable to him. Each of these guesses is discussed in small groups of three to six children.

The program is in three parts:

i) The child tries to guess the words while the computer helps him by providing feedback, supplying the first letter of the word, suggesting he think again, etc ,

ii) The child writes his guesses on a sheet of paper and compares these with the answers accepted by the program;

iii) The child then amends his answers, produces his own cloze test and tries it on other children.

WRITING TO READ (United States)

Reading and writing instruction system developed by J.H. Martin and distributed by IBM.

The system is based on the idea that by learning phonemes children can learn to write anything they can say and read back anything they can write.

The activities take place in a Writing to Read Center housed in a separate room so that it can be used by four to six classes a day.

The program begins in kindergarten, just after most children have mastered letter recognition. Ten cycles of computerised lessons teach the 42 English phonemes. The children move on individually to the next stage. The computers used are IBM PCjrs, equipped with a digitised voice attachment card.

Working in pairs, the children respond to the visual and auditory stimuli presented by typing letters and words, repeating sounds orally, chanting and clapping.

Each lesson begins with the colour monitor presenting the word and a picture of the subject named by the word that is being introduced and the word itself which is pronounced phoneme by phoneme *(c-a-t)*.

The computer then asks the children to type the first sound. Once this is done correctly, the computer displays the rest of the word. Then the children are asked to type the first and second sound and finally the entire word.

Each lesson ends with a mastery test and additional practice if necessary.

In addition, there are reinforcement activities and computer games that provide extra practice.

The system also includes:

- A Writing Station;
- A Typing Station;
- A Listening Station.

MEMOT (CEDIC-NATHAN, Paris)

A text is displayed on the screen and must be read before it is erased. It has to be reconstructed like a jigsaw If a mistake is made, the text is flashed on the screen again. Twelve mistakes are allowed and clues are provided.

The program can be modified by the teacher.

READING COMPREHENSION (PDI, United States)

Logical problems where the student must pick out the word that does not fit.

LLOG (MEN/CNDP, Paris)

Spotting the logical connection between ideas.

IRIS (by J. Schnitz *et al.*, WICAT, United States)

A system to teach reading comprehension for grades three to eight.

> *Making inferences.* Children read a short passage and then choose which of several inferences can be made. They must then point to the words in the text that best justify their answers. The system then lists both the students' words and the computer-preferred words for the students to compare It also gives the reason for its answer to the inference question,

Recognising inappropriate sentences. Students have to edit articles in a fictional newspaper. When the student decides to delete a particular line, the program will explain why he is right or wrong.

Analysing arguments. The first paragraph of an argument is displayed and students are asked to identify what position the writer is taking. The next paragraph of the argument is then displayed and the student is asked whether the author is arguing his case well; this procedure is repeated for the subsequent paragraphs.

ELMO 0 (French Association for Reading)

ELMO 0, which J. Foucambert had a major hand in designing, does not claim to provide a complete curriculum but simply a programme of daily 10-15 minute sessions to help in teaching children to read, whatever particular method the teacher himself may use. The overall methodological approach, however, is unique: active and always meaningful learning, and therefore involving functional use of basic skills.

The programme is made up of four modules:

- A module for building up and enlarging a library of several pages, and allowing several of these libraries to be used simultaneously. Texts are entered as required by the teacher or the students using a word processor;
- A module designed to extract the utmost benefit from the texts in memory by compiling a dictionary and regularly updating this, by displaying on request each word in the context in which it was used, and by providing printouts;
- A module comprising five reading games (Mastermot, Loto, Mot-numéro, Pigeon vole, Mémoire);
- A module providing 13 different exercises, which use texts in the library and which therefore can be regularly renewed (the results of these exercises are also processed by the computer):

  1. Sentence building game ("consequences");
  2. Series D: rapid spotting of a word in a context;
  3. Tool words: exercises on the meaning imparted by these words;
  4. Unscrambling: reconstructing a paragraph from jumbled phrases;
  5. Graphemes: spotting words with letters in the wrong order;
  6. Cloze: supplying the one word out of five that is missing;
  7. Chase: training in increasing reading span using a text that is progressively erased;
  8. The written word: spelling exercise;
  9. Wrong order: unscrambling the jumbled words of a phrase;
  10. Spelling;
  11. Text reconstruction;
  12. Flash words: training in instant recognition;
  13. Phrase completion: filling in the missing gaps.

ELMO 1 (French Association for Reading)

(J. Foucambert, *ELMO: Un didacticiel d'entraînement à la lecture par ordinateur*; Paris, Association française pour la lecture, January 1984.)

The pace and presentation of this training program adjusts to the requirements of the individual student; it provides roughly 100 hours' work (sessions of 10-20 minutes spread over four to six months).

There are six types of exercise dealing with either texts or words. Each type of exercise relates to a specific library of texts, arranged in order of difficulty; the earlier sets of texts are easier than the later ones and contain more common, everyday words. The wide range of difficulty covered by the program makes it suitable for use with adults as well as eight-year-olds.

Each library has its own routine for inputting and processing new texts, so that subject matters can be chosen to suit specific needs, e.g. users' particular interests, specialised training for adults, etc.

There are two variable functions that determine the speed of operation:

- The speed at which the written items are displayed or erased;
- The length of text spanned with each eye fixation.

The exercises and texts form a unit which is accessed via a student-management program. Each newcomer is dealt with individually and his progress is controlled by the microcomputer on the basis of his results, the sequence of operations being as follows:

- The parameters for the first series of six types of exercise are determined on the basis of an initial test. Then a second series of exercises is administered using the same parameters as at the culmination of each type of exercise during the first series;
- At the end of this stage (six sessions at invervals of two or three days), a fresh test is administered to determine the parameters for a further first series, followed by a second series, and so on;
- The training comprises a dozen such paired series separated by reassessment tests. Each test is designed to measure the student's reading ability on the basis of his speed and level of comprehension, and the parameters used in administering the first series of exercises are determined by his overall proficiency. While the actual exercise is in progress, the computer adjusts these parameters to the student's replies.

Purpose of the various exercises

Series A: To develop a broader visual field for each eye fixation and at the same time increase familiarity with the basic vocabulary.

Series B: Practice using these eye fixation points, but this time whilst actually reading a text.

Series C: To improve the ability to discriminate

Series D: To develop speed in scanning a text

Series E: To improve anticipation.

Series F: To oblige the student to read a text faster than a set minimum speed.

J. Foucambert lays great stress on the fact that these exercises are designed to improve functional reading, the only type of reading that is important

INTERACTIVE LANGUAGE ENVIRONMENTS

The object of these is progressively to increase the student's reading ability through contact with meaningful texts (Chall Stage 2). The ideal is that the reader should read for his own pleasure or to find the solution to a problem he wants to solve (if only to understand a written message he has received). In general, these activities provide an environment in which the student's goal is to communicate through written language. The role of the computer here is to provide support for the successful completion of a reading/writing task Thus, the computer may actually perform some subtasks critical to the completion of the language activity (e.g. filling in words and phrases in a text), leaving to the student those tasks which she is most capable of accomplishing herselt. *Story Maker*, for example, provides phrases for students to choose to construct a story, managing the word choice, spelling and punctuation for the student. Because these activities deal with the integrated experience of reading and writing, the computer is unable to provide much explicit feedback The student gets feedback in the form of the quality of the environment he manages to create (e.g. the quality of a story constructed by successively selecting phrases from those suggested), the pleasure he derives from reading, or the reaction from others with whom he communicates

In this category of programs learning to read is seen from the broader standpoint of an active mastery of the language, hence its close linking with the written word In general the exercises involve communication via written language Rubin points out that programs of this type have the potential to change our definition of reading, as they use the computer to alter significantly the experience of getting information from the printed page. The most extreme of these is the set of programs developed at Brown University that explore the Hypertext notion (Yankelovich *et al.*, 1985). These take advantage of the ability of computers to link together pieces of text in multiple ways to create a "web" of connected information that a reader can explore according to his own interests, unrelated perhaps to the way anyone else reads it. While this system has been used primarily at the university level, it has important implications for the skills students will need to learn in elementary and high schools

Examples of courseware

(It is not always easy to decide whether a program belongs to this second category or to the previous one)

THE BEACH MICROWORLD (Lawler, 1985a)

The idea of micro worlds was suggested by S. Papert in *Mindstorms* (1980). The expert endeavours to devise the simplest possible models, that will, as it were, open the door to broader knowledge. These microworlds will constitute a genuine source of learning only if the provide elements that children will want to use in order to achieve certain meaningful objectives.

Beach is a LOGO microworld for learning the alphabetic language. Lawler (1985a) states that this microworld helped his three-year-old daughter to learn to read with minimal direct instruction. In addition to the familiar turtle, the TI LOGO also has "sprites"; a sprite is a video-display object that has a location, a heading and a velocity, but no drawing capability. There is a maximum of 25 different coloured shapes which these sprites can "carry"

TI LOGO has a second graphics system that can provide a coloured background with a number of static shapes against which these sprites can move.

The system can create scenarios such as a plane crossing the sky, a sunrise or a sunset, etc. The *Beach Microworld* vocabulary includes, for example, *objects* (beach, bird, boat, boy, etc.) and *actions* (up, down, move, etc.), most of them words of one syllable.

Since, with LOGO, the user can define and name procedures, it is easy for him to call the procedure that creates a yellow ball on the screen "sun". The child is thus involved in defining objects that will form part of the world, and their characteristics and the actions they will be expected to perform. He thus *constructs* his own world. In order to play, the child has cards, each of which has a word written on it. When the letters of one of these words are typed on the keyboard, the object appears on the screen. The child soon learns to recognise a particular favourite word by sight and in the end is able to read it when he sees it on its own or amongst other words. At the same time he learns to write it since he has to type it out each time.

The interesting feature with a system like this is that the child does not interact with the microworld in an artificial classroom context but in order to create the effect that he wants.

Initially the learning process is implicit and Brügelmann rightly regards this type of implicit learning "as one of the most powerful aids we can offer to children at any age" (1985, p. 5). Lawler does not consider the *Beach Microworld* as a universal model; other children might find other microworlds more suitable.

INTERACTIVE TEXTS

Steve Weyer (1982) of the Xerox Palo Alto Research Center in the United States was the first to develop a dynamic book by putting a textbook on a computer. The reader can call up part of the text on the screen, at the same time the computer displays a table of contents and a subject index. If the reader selects the topic in this subject index, this section of the text is automatically displayed on the screen. Similarly, the text changes as the reader browses through the table of contents.

Interactive books would seem to have considerable potential. Collins (1985, p.13) lists some of the advantages of an interactive book:

- It can ask questions to make sure readers understand what they have read and, if necessary, explain things in simple terms;
- The text can be written at several levels of difficulty or detail. The reader could choose the level of difficulty or detail he wants or the computer, after asking questions to assess his level of ability, could select the most appropriate version;
- The reader can ask for an explanation of a word or a phrase (in some cases, there is an on-line dictionary).

STORY MAKER (Bolt, Beranek and Newman, Inc. United States)

This program requires the child to follow a logical sequence in building a story and makes him aware of his selection of episodes.

The student has a choice of several story trees from which he can create a story. If he wishes, the program will set a goal for his story. He then proceeds by making a series of choices among story parts that fit together to form a story; each choice constrains the next set of choices. Since the computer prints the story as it is being constructed, the child can see the consequences of his decisions. As he does not have to worry about writing and spelling, the child can concentrate on the task of creating the story and its conceptual content. When the story is finished, the computer makes a printout, which the child can compare with those his friends have done, take home, etc. At the end, the program will tell a student whether or not his story meets the goal he has set for the story.

For example, if the child chooses the Haunted House story tree, he may be asked to write a story in which the heroine meets some skeletons. If the child's story does not include this incident, the program can tell him so. Feedback in this case therefore takes the form of a direct reaction to the student's performance.

STORY MAKER MAKER

This program is a variant of the previous one, but requires more input from the students. At certain choice points in the story construction process, students have the option of writing their own segment, rather than choosing one of those provided by the program. This segment, in addition to being added to the story they are constructing, is permanently added to the story tree, where it is available as a choice to the students who subsequently use the tree. Students can actually create an entire story tree of their own by starting with an empty tree and using the option A.

This activity combines reading and writing in a particularly effective way, because students are involved in reading when they are using the program and they understand that the story segments they write will also be read by students constructing their own stories. Thus, *Story Maker Maker* provides both an active component for their reading and an automatic audience for their writing.

INTERACTIVE TEXT INTERPRETER AND OTHER INTERACTIVE TOOLS
(Interlearn, United States)

These interactive tools provide a dynamic system of support for reading and writing. Writers take an active role in creating stories, poems, letters and newspaper articles. Once written, these texts become useful materials in the reading process.

Interactive tools are arranged in a sequence from maximum support to minimum support. Beginners receive the most help, making selections of material from fixed choices. As confidence and skill increase, the support provided by the system diminishes, until students do all the writing while the interactive tool offers suggestions about what to write and how to proceed. Completed poems, stories and newspaper stories can be printed, displayed on the screen and stored on disks.

Interactive tools currently available include: letter writer, poetry prompter, expository writing tool, narrative writing tool and computer chronicles (for writing newspaper articles).

LANGUAGE TOOL KITS

This type of program is designed to provide an active method for learning about the structure of language: the student is required to devise, build and test models of language. The feedback consists in comparing what actually happens with what the student expected the model to do. These activities come closest to programming. In fact, many can be done in LOGO without additional special software.

Few of these programs are available commercially, since they do not fit with most traditional curricula. However, they represent a truly innovative use of the computer and one which cannot be duplicated with pencil and paper. They make substantial use of the symbol-manipulation capabilities of the computer.

Examples of courseware

GRAM (Sharples, United Kingdom)

Gram actually has three parts:

- Gram 1 is a random word generator;
- Gram 2 generates sentences from a simple grammar;
- Gram 3 generates sentences of words which match in meaning.

Gram 1, for example, simply requires a student to create a dictionary of words, specify a number of lines and the number of words in a line. The program then creates a "composition" which is a random selection of words from the dictionary.

Gram 2 requires the student to assign a part of speech to each word in the dictionary. The student then specifies a pattern and gets a "sentence" that corresponds to the pattern. For example, the pattern "article-adjective-noun-
verb-article-noun" might give rise to the sentence "the hungry cat eats the meat".

Gram 3 is the most sophisticated program of the three. It augments the capabilities of Gram 2 by adding some simple semantics that make it possible to specify that a noun and adjective must "match" on some descriptor. Thus, using this program, a student guarantees that his pattern will generate the sentences "a lion is huge" and "a mouse is small", but not "a lion is small". By defining suitably complex patterns, the student can create poems and paragraphs and begin to experiment with the structure of language at this level.

GOSSIP (Bolt, Beranek and Newman, Inc., United States)

A similar program, written as an extension to LOGO, is Gossip. The simplest version is a single program that generates a single sentence of the form "who does what?" In this case, "who" may be one of several names, while "does what" is one of several verb phrases such as "giggles", "talks your ears off" or "likes smelly feet". After being introduced to this simple version, students proceed to complicate the definition of gossip; a first complication may be to add the pattern "who does what to whom". Working with this intrinsically interesting language genre allows students to discover more about the structure of simple sentences. With a few more simple extensions, students can also write interactive jokes and arithmetic story problems.

COMPREHENSIVE ACTIVITIES AND TOOLS

The object of these programs is to train students to use language to accomplish general tasks and, in particular, for problem solving. Feedback consists in either the achievement of the original objective or the user group's reactions. Some of these programs are made for home use. Those that are made for school use are relevant to more than one curriculum area.

Many of the general-purpose computer tools used by the public have important applications in language arts education. In particular, they support educational projects that involve aspects of several disciplines, uniting them in the pursuit of information and action – much as a person does in his everyday life outside school.

Databases, graphics programs and, more obviously, word processors all require some facility with language. In addition, the kinds of problem-solving skills they demand are closely related to strategies for finding and using information in text.

Some educational software packages typify this philosophy of "language in use". Generally, they set up some non-language-related goal that requires language use for its fulfilment. Andee Rubin envisages a situation where the communications network enables students in a particular class to communicate with one of their number who has had to stay at home because of illness, to read a story that was invented in another classroom or in another country, to consult the catalogue of the Library of Congress, etc.

Networks and other communications software also have as yet unused potential in education. Several forward-looking projects at the University of California at San Diego have demonstrated the possibilities of long-distance networks. The Intercultural Communication

Network links classrooms in the United States (California and Alaska), Japan, Mexico and Israel. Students can ask one another questions (e.g. "Is the moon full where you are today?") and get quick answers, build joint databases and carry out co-operative research projects – all with significant use of language (and often several languages).

Examples of courseware

ICE CREAM PRICE WARS (Bolt, Beranek and Newman Inc., United States)

These Ice Cream Price Wars combine a communication environment with a competitive economics game. Students discuss their strategies through an electronic mail system and attempt to persuade other team-mates that their approach is best.

CSILE (Computer Supported Intentional Learning Environments) (M. Scardamalia and C. Bereiter, Ontario Institute for Studies in Education, 1985)

The object of this prototype program is to develop higher cognitive and metacognitive skills and the principle on which it is based is considered to be applicable from elementary up to higher education level.

- A unit of subject matter is provided to the students via a computer or a book (the authors consider other methods of presentation, but these are of less direct relevance for our purpose);
- The students make some conceptual response in the form of a comment, question, summary, etc. This response is keyed into the computer and enters a database that is used in subsequent steps;
- The computer provides procedural support for students in improving their conceptual responses. Typically this involves self-evaluation by the students;
- Via the database, students can compare how other students, and experts, responded and evaluated responses to the same subject matter. They can also comment on and evaluate one another's responses and answer one another's questions (anonymity can be safeguarded, if desired).

The general aim of this group work is to enhance the quality of the thinking about the subject matter.

The CSILE can be linked up to an expert system. So far, this prototype has been tested only in higher education

COMPUTER ASSISTED TESTS

Tests are included here as a fifth category although, strictly speaking, they are not part of the process of instruction as such nor therefore of educational software; they do, however, represent an important and integral aspect of the curriculum in the present-day sense of this term. From the educational standpoint, we shall be differentiating between predictive tests, achievement tests and diagnostic tests. From the language standpoint, we shall be dealing solely with readability tests. Although several of the programs included in the preceding categories incorporate testing procedures, this fifth category covers programs concerned solely with testing.

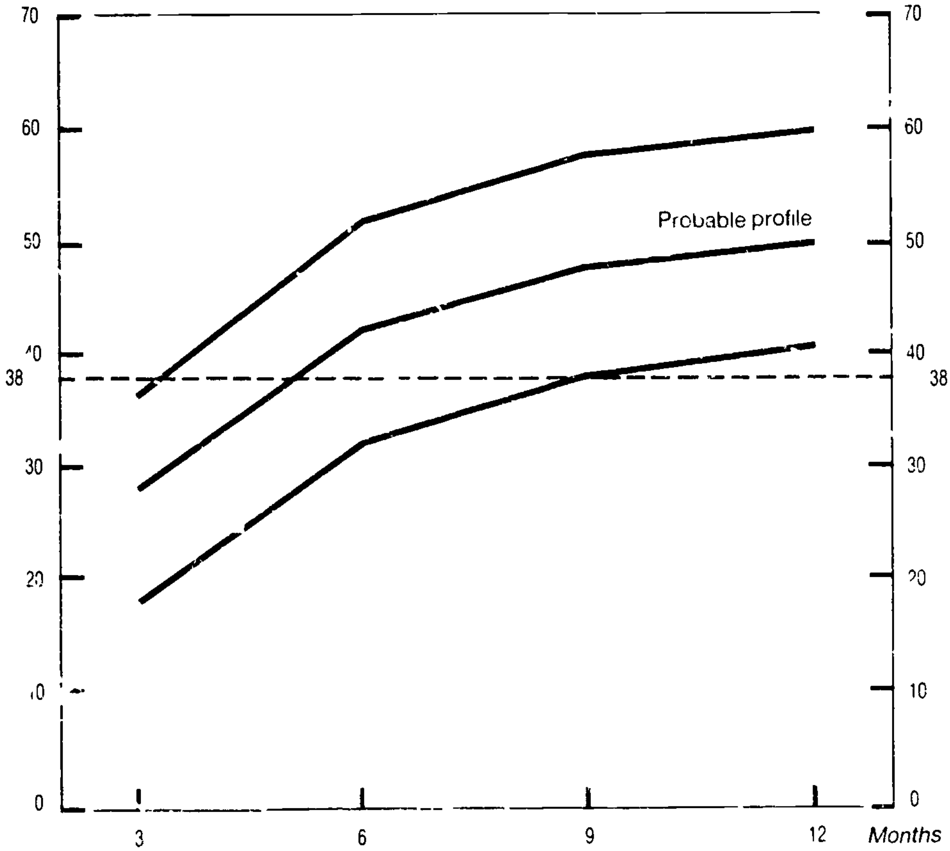
Generally speaking the computer, in the same way as it is making it increasingly possible to individualise instruction, will also help to individualise assessment, either at the level of a particular student, a class group what are now termed "special groups" (e.g deprived children, certain types of handicapped children, etc.). It is likely that in the near future computer managed banks of questions, tailored testing and flexible or branch testing will be performing a major function.

Productive and Diagnostic Tests: Examples of courseware

PREDIC

Predictive test of reading ability (E. Boxus, Laboratory of experimental pedagogy at the University of Liège, Belgium, 1973).

Based on the measurement of eight predictive variables (copying and reproducing from memory Rey's complex figure, the little man test, Goodenough's test, Horst's sign-elimination test, Kohs' cube test, pronunciation test, drawing recollection test, age) and with the aid of an operational reading ability benchmark (a score of 38 in the Inizan Test), the computer, which is reprogrammed to suit the method of teaching used, predicts each child's expected



reading progress after three, six, nine and twelve months of instruction. Thus, right from the start of the first primary grade, the teacher has a probable profile for each child, showing the statistically acceptable margins.

Performance is evaluated at each stage and, if need be, a detailed diagnosis is made of any difficulties in order to decide how to remedy them.

This basic procedure does not rule out the use of spot checks on progress during the learning process. Moreover, it is always pointed out to the teacher that the profile is not a target to be achieved but rather a standard to be improved on.

TEXT WINDOW (Lundberg, Sweden, 1985): a diagnostic tool

This system, developed at the University of Umea and implemented on a microcomputer, is designed to study reading in real time. To restrict immediate vision of the text, a moving window is simulated on the computer's screen. The window then moves through the text.

Two basic modes of operation are available for collecting data:

- The reader himself controls the speed and direction of the window;
- The reader is required to perform one or more subsidiary tasks as the text is read; how and how fast the reader responds to these tasks is recorded.

The effect of a window moving through the text is created by defining a basic string length and adding characters periodically to one end of the string while taking them away from the other end. The tasks that the reader has to perform while reading the text include, for example, answering short questions presented in temporary window areas at the bottom of the screen.

The data are analysed statistically. This system can evaluate reading proficiency in a matter of minutes and provide certain types of diagnosis.

Readability Tests

There are four main methods of evaluating the readability of texts:

- Direct observation of cursive reading behaviour;
- Evaluation of the difficulty of texts through the answers to comprehension questions;
- Evaluation of the difficulty of texts through the results of cloze tests;
- Indirect evaluation, using statistical formulae constructed by multiple regression analysis in order to determine what variables predict most accurately and simply the score that a reader should obtain in type *b) or type c)* comprehension tests for a given text.

The computer-managed techniques include:

a) *The computer managed system of text presentation*, developed by Lundberg (1985) to study the individual reading process (see above).

Lundberg considers that the speed at which a reader can grasp the content of a text is a more valid way of evaluating readability than indirect statistical methods.

b) *The cloze test*, devised by Taylor (1953), involves deleting one word in five in a text. The reader has to fill in the blanks.

De Landsheere, in his general analysis (1973), confirmed the validity of this test. Having to supply the word originally used in the text and not just a synonym, involves more than mere comprehension. The reader tends to fill in the gap with the word most frequently used in that particular context: that is to say, he tends to take the steepest probability slope. Depending on how far the word the author has chosen to use in the text deviates from this probability, the reading process will be slowed down, i.e. readability decreases.

De Brogniez (University of Liège, 1984) has devised a French language microcomputer program for generating and printing various versions of cloze tests for the same text. In addition, in France there is the CLOSU Program (MEN/CNDP, Paris) software for creating cloze tests

c) *Automatic measurement of readability*

First generation programs for calculating readability indices, using traditional formulae, are already available on the market.

Example: MECC: FINDING READABILITY LEVELS (MEC, United States)

This program, which can be run on an Apple type microcomputer, calculates readability indices by taking samples of 100 words and using the Spache, Fry, Dale-Chall, Raygar, Flesch and Cunning-Fox formulae.

d) *G. Henry's readability formulae*

In the case of the French language, the most significant work in this area has been done by Ph. de Brogniez (1984) (Laboratory of Experimental Pedagogy at the University of Liège), who has devised programs that can use the second generation readability formulae developed (in the same laboratory) by G. Henry (1974). These are the first formulae specially designed for the French language.

G. Henry's work differs from that of others in that he proposes different formulae for three key educational levels, i.e. the end of primary education, the end of lower secondary education and the end of upper secondary education.

The program devised by Ph. de Brogniez comprises two diskettes: the first contains the analysis program and part of the dictionaries (Basic French and a Dictionary of Concrete Common Nouns), while the second contains the rest of these dictionaries and a simplified word-processing editor. The texts to be analysed have also to be recorded on diskette. The processing speed is roughly ten minutes for 300-400 words.

In Canada, a program using G. Henry's simplified formula has been devised by G. Fortier (University of Montreal, 1979, unpublished). Fortier uses the "vocabulary of students in secondary grades I and V on Montreal Island".

It must, however, be emphasized that readability analyses have their shortcomings; they do not always reflect the true difficulty of texts and can not be used directly for text adaptations (Rubin, 1982; Rappaport-Liebling, 1986)

INFORMATION TECHNOLOGIES AND PERSONS WITH SENSORY AND PHYSICAL IMPAIRMENTS

It seems that more and more often the education of physically and mentally handicapped persons of all categories can also benefit from new information technologies. This issue is however so broad and specialised that it exceeds the scope of the present report. One can note, first of all, with Mommers (1985) that, for the handicapped people, "it is vital that educational materials activate as many senses as possible, thus increasing the probability that the given information has been received and understood correctly. Mommers indicates a set of techniques which can be synthesized as follows:

For blind and partially sighted people, the devices to assist them in reading tasks can be classified into five categories:

- Printed text to voice (e.g. The Kurzweil Reading Machine);
- Computer text to voice;
- Automatic translators from texts to braille. Much existing software provides for text editing and voice output;
- Automatic print enlargement for partially-sighted people;
- Translation of printed material into raised vibrating print readable by touch (e.g. OPTACON; OPtical-to-TActile-CONverter).

For the hard of hearing:

- Computer-based remote communication;
- Manually coded means of communication;
- Lip reading;
- Vocalising exercises. The teacher pronounces a word into the microphone and the computer displays its length, tone, stress... The deaf person then repeats the word and compares its visual image with the word model;
- One could also include that the Laboratory of Experimental Pedagogy of Liège University has developed a software prototype for teaching sign language. The ...m was a microcomputer with interface to a videotape recorder with random access.

Concerning motor impaired people, by definition they do not have primary impairments of cognitive or sensory abilities, but these are often associated with the initial handicap. Micro-electronics offer such cases considerable range of possibilities. Within the motor impaired group those with non-verbal motor handicaps require special attention. They tend to be extremely isolated as they can understand the language but cannot use it to communicate with others. For those who have not learned to read, symbol-based communication systems have been developed. For example, the well-known Bliss system includes about 1 400 conceptual symbols which children can use, by pointing to those representing what they want to say. Blissapple is a set of programs devised to facilitate the use of the Bliss system with the aid of microcomputers.

Chapter 3

PROMISING AREAS FOR RESEARCH AND THE DEVELOPMENT OF PROTOTYPES

R.W. Lawler recently conducted a survey into the prospects for research and development in the new information technologies for education. (The survey was conducted by telephone conversation with more than thirty prominent members of the education and technology research community in the United States. Some notes on the process and a list of those respondents and their affiliations is at the end of this chapter). The questions were essentially concerned with two issues: what forms of technological progress would exert the greatest influence on education and what research in the field it would be most useful to support over the next five years. Today, technology is driving the development of informatics for education. But if the transmission of values is the quintessence of education, we must ask how the two can coexist in a manner productive both for learners and for society. The following notes take their shape from the interplay of these two themes of technology and values. They are organised into major sections with these headings: the environment, materials design and research frontiers.

THE ENVIRONMENT

Hardware

Major computer vendors share an interest in development of multi-media learning stations. Such systems are now typically thought of as a sharable reference facility more than as devices for individuals. The IBM HANDY system will become a standard. (The system's developer, Nix, has displayed and demonstrated a prototype at computer, psychology, and education conferences). The Personal Computer controls multiple output devices (audio tape playback, speech generation; videodisc output can be flexibly overlaid by computer generated images) with an object oriented language in which new scripts may be written. Apple will compete directly with this potential IBM product. Control Data will place more emphasis on centralised mainframes to support satellites with the computational power of current AI workstations. Major AI workstation vendors (Symbolics, Lisp Machine Inc., Texas Instruments and Hewlett Packard) are moving in essentially the same direction. They expect to produce powerful laptop lisp machines with huge memories and integrated optical digital discs for software and applications delivery.

The education market in US schools will suffer growing inertia from a large installed base of Apples and IBM PCs. New hardware sales will require more effective marketing of benefit-justified systems. There are two implications here. First, with their more aggressive marketing force, hardware vendors will dominate textbook publishers as the primary influence in school-centred education technology. Second, economics of scale will promote system packages which will have satellite learning stations connectible to a primary reference "library" system. If this is the most likely intermediate term configuration in organised centres, it is almost certain that the gap between the "haves" and "have-nots" will widen considerably. Within school systems, if such learning station clusters are sold to the secondary schools, existing stocks of micros may well be released for use in the earlier grades.

Such second-hand hardware will be "costless" for use by younger children or require only maintenance and software. Will they be kept in some sort of service as used cars are? Will these computers be stashed away like old toys? Will they remain an unexploited resource? Oliva of Texas Instruments (TI) emphasizes the unexploited potential of technology now available "off the shelf"; he notes that the Speak and Spell line of products have built-in "personality software" which would permit their tailoring for use in different languages and cultures – but this has never been used. In the last 1960s and 70s, hardware stabilisation developed around the IBM 360 series in the business world. The US microcomputer market is stabilising now to dominance by the Apple II and the IBM PC. The main line of development will not be around the technically best systems but around those most widely dispersed and familiar to the most people. Good hardware and software products have already failed because they did not attain sufficent "market share" to be taken seriously by consumers uninterested in the technical details of performance, and who, not knowing what is best for them, buy what others have bought before.

In the longer term and in other places, other media will circumvent this configuration. If cable connected digital TV is widely accepted in the longer term, its built-in processors will have such memory and processing capacity that they will be "costless" competitors to stand-alone computers. They will also have the network available for centralised software distribution. Another pathway for such service will develop when the broad band width of fibre optical transmission is made available to the "twisted pair" of communications networks now connected to private dwellings. A significant minority view holds that networked microcomputers will have a major impact by opening new application possibilities. (Counted in their number are Dwyer, Koulakoff, Lawler, Levin, Mohl and Ridgley; Shafto cited Lesgold's interest in networks of powerful micros as well).

Conclusions about Hardware

Over the next five years, the two main developments will be wider dispersion of compact disc technology and a breakthrough in the price/performance ratio for laptop computers. The impact of enhanced communications will be in a second wave. *Compact disc technology* (digital optical disc) with its massive storage capacity, will be used primarily for distribution of software and textual materials. Secondarily, it will provide ancillary video to enrich the textual environment with animated sequences of digitised images. Videodisc will continue to provide works (movies and image data banks) for analysis and as material or instruction The essential limitations of these technologies – their profound lack of user modifiability – will restrict their successful use. Effective use of *very powerful small computers* will require for their cost-justification significant software advances, the occurence of which is uncertain at best. In default of breakthroughs in the creation of accessible, flexible, exploration-supportive software, specific function packages will come to dominate the installation of new systems. Clusters of learning stations will cost a lot of money; they will be justifiable in wealthy communities and in prototype installations primarily through arguments related to teacher shortages in technical disciplines. *The gap between the possible and the feasible will widen significantly*

Considerable agreement exists on the following major points. There is little valuable education software; what exists of value is the exception that highlights the poverty of the remainder. The problem of developing good application software is seen as the primary bottleneck limiting the potentially beneficial effect of technology in education.

Today's most developed prototypes of future systems are ITS, *Intelligent Tutoring Systems* (see Sleeman and Brown, 1982, for a classic text; see the section Materials Design for a further discussion). They can be seen as expert system for education applications. Such ITS have three primary functions: the embodiment of domain-specific expert knowledge, diagnosis of a student's performance, and the selection of an instructional treatment for subsequent presentation. The ideal of such a system is "... the moment-by-adaptation of instructional content for the student" (see Yazdani and Lawler, 1985, for a current assessment of the state of the art). The optimistic hope is that there will be a breakthrough to general productivity in this area within five years. Some researchers report impressive results; for example, that students tutored by their systems test as well as those taught by human tutors (see Anderson, Boyle and Reiser, 1985). Critics argue that *Intelligent Tutoring Systems* are not intelligent, and that their impressive successes are limited in scope and extensibility. A significant minority believes this majority view is over-negative. Beside Brown and Burton, pioneers in such systems, others in the cognition research community known to favour such work, although not part of this survey, are Anderson, Clancey, Ohlsson, Sleeman and Soloway. From fundamentally different perspectives, Carey has been impressed by the success of Anderson's teaching with his mechanised tutors, and Austin, Feurzeig and Lawler recognise the power of Brown's demonstrations and metacognitive focus and look to future extensions of such work.

The immediate hope for progress is the creation of powerful development tools both for software creators and for non-programmers. And yet, if new tools typically appear as generalisations of facilities developed for limited purposes in specific domains, this projection may be more hopeful than promising. Hardware vendors are now focussed on and even committed to "tool-provision" and "enhancing usability". What they are leaving to others is application system development. Less common but still optimistic observations are that we can hope for smarter software at all levels and that "Lisp-on-a-chip" machines will lead a breakout of intelligent software tools More *sceptical views* were at least as well represented as the former. Typical comments are that "the software will be done wrong before it is done right" and that the development of necessary software will delay widespread deployment of multi-media learning stations for at least five years. The pessimists hold that standardization, although it would have profound benefits for developing good materials, will be impossible because it limits the relative advantage of one product over another. Undercutting this view are recent attempts to establish a common object-oriented Lisp language standard through vendors sharing source code (Xerox and Symbolics) and the Phillips-Sony compact disc implementation standard for the consumer electronics market announced at the CD-ROM conference (see Bruno and Mizushima, 1986).

One alternative to the "tool-kits" approach is to develop modifiable interfaces. In such a system, the user would receive a functioning system but one which would be significantly enhanced by his own tailoring with a powerful general language or menu-modification scheme. Lawler's Word Worlds (described through - exemplified by the *beach* microworld in Chapter 2: "interactive language environments") offer a simple illustration of such facilities: they provide enough structure to show what goals are appropriate, along with simple, functioning programs which can be copied and modified. Further, because the programs are a system of procedures functioning at the language level, any user's modifications or additions can be usefully mixed into the system without requiring extensive integration into controlling programs written by someone else. The LOGO and Boxer programming languages have tried to put such creative initiative in the hands of the user An initial difficulty users found with LOGO derived from its generality. Because it could be used for nearly anything, people couldn't figure out what it was for. Whether Boxer will escape this difficulty remains to be seen.

A second alternative, advocated by Feurzeig under the banner of "intelligent microworlds" extends the microworlds strategy of presenting materials through creating domains for exploration by building intelligence into the facilities of the microworld so that each may be at need either a simply executable function, an explainer of its functioning, or a coach to help the user in learning how to better solve the problems on which it works.

Dealing with the values implicit in educational materials is a crucial but difficult issue. The pessimistic believe that if computer vendor software dominates schools, it will be bad for teachers and possibly harmful to the children: think of Saturday morning TV! This dimension of software design, although difficult to grapple with, is one that merits significant attention.

Technical problems needing solution are the indexing and browsing of massive databases (see further on *Research Frontiers. Computational*). Issues at the frontier of research are in organising and manipulating portions of digitised images.

McClintock (1986) argues that the essential reason for the "poor quality" of software in higher education is the very lack of machine encoded knowledge accessible through the informatics medium; he continues that this lack is a direct consequence of underinvestment in education. His cogent argument, based on rough but sensible estimates of the information content explored in courses, reminds us that the fanciest systems for accessing information will be ineffective if the database itself is relatively empty (as compared, for example, to the content of 20 books).

Conclusions about Software

If one made a "wish-list" of the features desirable in systems for education, it should include at least the following systems characteristics:

- A uniform systems appearance;
- A general purpose language with:
  - simplicity: no lower threshold of accessibility;
  - expressivity. appropriate high-level primitives for various applications;
  - extensibility: the capability of compounding primitive functions into new, invocable procedures;
  - power: no ceiling to its serious application;
- Seductiveness: leading users to learn more about it naturally.
- A coherent formulation of four primary informatics functions
  - text processing: character (string) manipulation;
  - simulation: modelling facilities;
  - database applications: record manipulation;
  - communications: information passing over arbitrary network
- Control of rich and diverse I/O systems (multimedia potential):
- Vast stores of information both available and worthwhile accessing;
- Cross system portability: vendor independence

Reasonable expectations, based on past history and the dynamics of the market economy which will produce the products, are that we will have

- Package and domain fragmented systems appearances: because first, standardization is contrary to competitive advantage and second, too few good ideas exist, in consequence of which new materials will be developed piecemeal by people with a highly specific focus and little breadth;
- Coherent formulation for two-out-of-four main functions: because at least two systems will exist integrating text manipulation and functional languages; the limit is two functions because there is insufficient attention to integrating database and communications into a unified systems appearance with text processing and simulation;
- Fragmentary multi-media control: because I/O is expensive and systems will be sold piecemeal by various vendors;
- Only locally dense collections of machine encoded information, typically concentrated in domains where timely information can be of significant monetary value, such as economic and market data; such databases will be available to the education system but will not be developed *for* the education system.

In respect of quality, one should hope for zero defects and all the productivity and usability aids possible. A reasonable expectation is that software will be variable by supplier. Most packages will gradually congeal to a kludgey, slowly changing, decently functioning system for already developed user materials; such are usually hard to understand at first and require people to invest significant time and energy in learning how to use them. (Current commercial operating systems and application packages can represent such facilities). This seems an inescapable outcome, because as market breadth increases, producers serve more various users with a single system Each user takes a degree of freedom with some specific clever use, which he desperately needs, till eventually nothing can change. A few systems will be of a more dynamic character; such as exist today often have cross version incompatibilities which limit their use to *aficionados*.

MATERIALS DESIGN

Existing Prototypes

The purpose of prototypes, *created as such*, is generally to establish that some system is crossing the threshold of viability for a specific application. In a second sense, a novel application can be taken as a prototype for a new genre of applications. The first fruits of the informatics medium have been direct exploitations of basic capabilities: programming languages, word processing, and electronic communications. The impact of these capabilities can be profound. Word processors do help people write better. Computer simulations can help people understand material that society demands they master Electronic mail is a new medium of personal and group communication in its own right. It may enhance international communication and cross-cultural understanding. A striking medium-use proposal is to apply computers and communication links to establish multi-site, long-distance joint-school projects. One example produced by the Intercultural Network project of Levin and his colleagues is a school newspaper with contributions from Alaska, California, Hawaii, Israel and Japan.

When materials developers attempt to exploit a medium for a well established application, such as teaching reading, what one sees initially are a series of re-creations in the new medium of materials found appropriate in earlier experience. Typical examples are using computer games to teach letter and word recognition. (Several such games are described and evaluated in the articles "Growing up Literate" and "Preschoolers Learn at Home", *Creative*

Computing, October 1984). Such replication of old functions in a new medium is useful in integrating the novelties of the new medium with society's previously established practice. But even here, where there is an appearance of sameness, the new technology provides room for novelty in reorganising the learning situation. Consider this contrast. A commercially available product teaches children to recognise words by presenting them with one of three digraphs (-ar, -og or -in) representing the end of syllables and offering the child the chance to create words by prefixing a letter representing an initial phoneme; when the child creates an actual English "word", the program makes the word flash and music play, then shows an animated graphics display. *The reward is in the machine response.* In contrast, Lawler's Word Worlds assumes the essential reward is in an approving relation with a human being. Child and caretaker are called on to create scenes using words for objects which they will probably recognise in a simple image. When they are successful in creating a scene, *the reward is human approval*, either the learner's self-approval or that of some caretaker, not machine gyrations. Although the content may be, in some sense, "the same", the pedagogical situation is significantly changed because the user can mix in his own modifications bit by bit without changing the original procedures. This user modifiability opens up the possibility for systematic development of the material by others (see Lawler and Lawler, 1985)

It is only when new dimensions of utility are discovered or invented that one can believe a technology is ripening. What stands out about Intelligent Tutoring Systems is their new ambition: to make regularly available to the learner the services of an expert and sensitive tutor. This is something long desired, the hope for the realisation of which lies in embodying both expertise and sensitivity in an intelligent machine. This is an aim whose achievement would be revolutionary less in its novelty than in its anticipated effect. The results reported in technical areas with talented audiences (for example, Lisp programming by engineering students) promise effective extension to subjects of broader concern and accessible to a less selected audience. Critics, despite admitting the power of specific demonstrations, argue that generally such efforts are not convincing either in their attempt to embody the teacher in the machine or in their attempt to comprehend the mind of the student; but it is only fair to admit that such efforts are extremely ambitious and should be expected to take time to become generally effective.

More striking uses of the informatics medium are those which create possibilities not available before. Several prototypes are exploiting the computer primarily as a flexible, multi-media controller. Such systems attempt to return to the user some of the diversity and richness missing from pure text, whether in book form or on a computer display. From a programmable personal computer, IBM's HANDY system controls the following output devices: videodisc, graphics display (pictures and text), audiotape, and speech generator. The script-like programming language is designed to be accessible to young children. More ambitious systems addressed to mature audiences are those of Englebart (*Augment*), Nelson (*Xanadu*), and VanDam (*Intermedia*) which attempt to integrate vast pools of machine readable, restructured text, the richness of graphics, and the flexibility of intelligent machines. Such can generally be referred to as multi-media hypertext systems. (See the review *Hypermedia* by Young 1986). They present forcefully the view that technology has brought us beyond the age of print into an environment of integrated media controlled with the aid of programmed intelligence.

Compact disc technology is now spawning a new genre of multi-media prototypes. This technology offers itself as one delivery vehicle for the popularisation of multi-media hypertext. The Microsoft *Multi-media Encyclopaedia*, demonstrated at the first international conference on CD-ROM (Compact Disk, Read Only Memory) exhibited the following functions:

- Simultaneous presentation of text from several articles in separate computer-screen "windows";

- Retrieving for presentation an article cross-referenced by the primary one;
- Retrieving for their definitions uncommon words used in an article;
- Pre-programmed, graphically-presented simulations; for example, tracing the developing migration path of whales throughout the year;
- Manipulable images of solid objects which can be viewed from any angle.

This integrated functionality may make encyclopaedia knowledge more accessible than it has ever been in the past. But there remains the question of interesting a potential user in what the system has to offer. Cornyn (of The Record Group, Warner Communications) proposed at the CD-ROM conference a multi-tiered form of presentation with a "seductive" level similar to a film clip which, when stopped at any point, would contain active links to articles presenting information about elements appearing in the still image. Such a system would be capable of offering textual, graphical and functional "footnotes" to a dramatic video presentation. Reading with such a system will be integrated (as a deepening technique) with other modes of making sense of a richer experience than books have been able to make available.

Systems with the most potential for profoundly affecting the developing mind are those which aim to affect *how* a person thinks more than *what* a person thinks. As Papert tried to change how children think about maths with his LOGO *Mathland*, Brown's metacognitive objective is to change the way people think about text. *Notecards* is the name of a prototype writing aid which embodies ideas described by Brown as *Annoland* (Brown, 1985) – a computer-based facility for aiding a writer in the collection, interconnection and manipulation of scraps of text, ideas and objectives. In effect a word processing super-system, the specific objective of Brown's *Annoland* for writing is to present the user with tools for organising preliminary composition notes and simultaneously to articulate a representation for such materials that will aid the user in organising them into a sound text. If the user adopts the system's representation of the material as his own, he will develop a view of text that is less serial and more hierarchical than is common when text is viewed as a static, printed thing. Reading will never be the same, because the changed tools for writing will change the perception of reading. Appearing less ambitious at first than hypertext systems of greater scope, Notecards-like systems may have more direct impact by opening the way to more general hypertext availability. Lawler suggests that the most likely path for the dispersion of hypertext capabilities will be through the dissemination of machine-readable text from central databases over communications facilities to individuals whose initial uses of systems such as *Notecards* begin with a "writing" focus.

Promising Ideas

Survey respondents suggested some specific future applications for development. The expensive multi-media systems with immense storage online almost propose themselves as classroom libraries. Publishers will soon discover the value of having authors write books with accompanying software for modelling and simulation keyed to the text. More striking was Borning's suggestion that in the future we will develop online image-banks, comparable to current databases. Imagine not merely an encyclopaedia text on a videodisc, but the entire photographic collection of the *Smithsonian* or of the *National Geographic Society* with digitised images accessible, transmissible, manipulable, and reproducible at remote locations. In the shorter term, a significant improvement in the creation of videodisc materials would be to decouple the design (image selection and organisation) and production processes for videodisc as has been done for integrated circiuts with VLSI technology. The importance of the graphics frontier is also emphasized by Schwartz.

Two new network-oriented applications have been suggested. One sees the network as a tool whereby a group of people through simultaneous, multi-site simulation discover a set of constraints operating in a system beyond the ability of any of them to engage singly Dwyer advanced this general type of application and gave as an example the situation of multiple air-traffic controllers simultaneously managing the heavy traffic at a major airport. Koulakoff proposes that online knowledge, accessible through networks, can help introduce the next major advance in democracy. In his scenario, groups of people approach a common problem, either in person or through a network; when they have need of help or additional information, experts, databases, and simulations will be available to aid in achieving the most intelligent consensus possible. As a social process, such a scenario has been successful (Koulakoff mentioned the Puget Sound Coalition, 1969, and the Metroplex Assembly in St. Louis). The role of technology in this case will be to make such a process more common and more effective. (This suggestion appeared in a general form years ago in an article by MacLuhan "At the Flip Point in Time"). The general promise of such ideas suggests that they could play an important role in the development of reading skills in the broadest sense as well.

Tools for presenting textual analysis, when made easier to use, will lead to a deeper appreciation of short literary works, as reports of VanDam's experiments with *Hypertext* indicate (see Young, 1986). It may be more effective for most students to share and compare their peers' interpretations than to be directed solely to more scholarly textual analyses. Triesman (1986), documents the importance of peer-based problem solving to improving college students' performance both in solving calculus problems and in interpreting how specific maths problems define the limits of applicability of ideas and problem-solving methods Similar results should be obtained for interpreting and appreciating the meaning of texts. (Further, examining the role of interacting peer interpretations of art works might be one method for exploring the general problem of the meanings that graphics may have). The application and adaptation of expert systems for legal reasoning could lead to better articulation of arguments and evidence presented in complex intellectual works, and to an advance in textual comprehension. For example, a restructuring of assertions and examples may clarify both the structures of argument and their bases in application Such support may be very valuable for improving comprehension of complex arguments based on extensive and deep knowledge.

Suggestions for Improved Design

Any information technology should present a consistent and self-explaining systems appearance to the student. Users should be able to express their knowledge in various ways to their computers, so that programs do not assume people are stupid who prefer some mode of thought or representation different from that assumed by the programmer. More broadly, the dominant suggestion proposed was to open up one's vision to the potential of information technologies to affect values of modern society; values are implic in education materials, and they should direct development. To the extent adults are the guides and intermediaries in transmitting the knowledge children develop in their own minds, more attention should be given to developing facilities to help caretakers or teachers than has been done in the past.

Diverse methodological suggestions for future work have been advanced. A novelty of the WNET Learning Laboratory proposal (see Salyer and colleagues, 1983) is introducing a production-team organisation, similar to what one finds in movie making, into the creation of electronically-presented education materials. Lawler suggests developing an instructional modelling facility to permit the articulate specification of the cognitive structures, conceived of as models of experiences, which one wants learning to produce in students' minds One would use that collection of models for guidance in the creation of sharply focussed and variously related exploratory learning environments. Taylor advocates the online integration of graphics and text, possible with his First Programming Language, to permit the exploration of modes of communication which have not been so well served by the print technologies of the past.

A core strategy for creating new applications was articulated by Taylor: look for limitations in current instructional media then fill the gaps with new informatics applications. Lawler's Word Worlds provide a concrete example of this strategy put into practice. Written words have previously not had appreciable functions for pre-readers Now they can Computers are powerful machines that can be controlled by typed words. This *control function* of typed words is new. Simple systems built around the pre-reader's selection of single words can provide him an experience where *his* purposes can be served by mastery of the written word. Such activities are intrinsically engaging and invoke profound motives for pre-readers to begin learning the written language. This new functionality of single words makes learning to read one word at a time both more useful and more enjoyable. By enhancing word functionality for pre-readers, information technology can have a significant impact on developing literacy

Complaints about Intelligent Tutoring Systems (ITS) yield pointers to new directions of research. Dwyer notes that ITS appear to have run into some sort of barrier on their complexity, and that one needs to define that barrier to circumvent it. In his view, ITS are based on an educational model where the teacher is posited as the expert provider of an optimal lesson plan. This ignores the progressive quality of education that begins with practice under guidance and goes on to independent exploration. For him, the preceding inadequate view of the education process is the barrier to be circumvented, the circumvention can be found by group problem solving in domains too complex for individual action to resolve the relationships. An example might be the simulation of the world's economic relations by the separate decisions made by a network of students who could in no way be able to comprehend the system of linear equations that might more formally represent their relationships

Goldenberg adds a compatible, different note in the instructional situation, the teacher's strength is in circumventing inadequate material. The use of technology in education has pushed a mass of inappropriate and untested materials into the teacher's bailiwick without his adequate instruction and familiarisation with the materials. It is simply not fair or correct to blame the teachers for resisting and rejecting such materials. One could conclude that there has been too much emphasis on the direct users of the educational systems, the learners, and not enough on making systems resources and tools for teachers (in their function as instructors more than in their function as classroom administrators) An example: if teachers had at their finger-tips a library of functioning procedures represented by manipulable icons, which they could assemble into simulations, their ability to present to students simple, tailored examples would be significantly enhanced. Goldenberg (with Feurzeig) has proposed extending the LOGO language to make such facilities available to teachers Julia Motz holds that only when control over the technology is placed in the hands of the teachers will it begin to be used with the flexibility and creativity necessary to achieve its promise. She might ask: When will a computer be able to assess the look on a child's face, however brilliant its diagnosis of problem-solving sequences?

The primary tactical suggestion, in a formulation advanced by Cole, is to adopt a bi-level structure for materials design, where one gives instruction both in basic skills and higher level problem solving strategies, with the former subordinated to the latter. Even more importantly, the call for simultaneous, multi-level focus is a contribution to dealing with the problem of values implicit in instruction. One must think about both the lesson of the moment and what the student is learning about society's values from the instructional environment.

Most agreed that developing domain independent "tool-kits" was desirable where possible and that additional computational power would permit more realistic and fruitful simulations. (This was a primary point for Ridgley; he argued that while everyone observes how the price of microcomputers is falling, few note that the price of mainframes continues to decline at least as rapidly. Today it is possible to have a Control Data mainframe for the price of ten IBM workstations.).

Conclusions on Design

The pervasive position behind these suggestions is that new ideas for communicating important skills, strategies, and values through technology are needed. And yet, there seems to be enough richness of vision with practical goals to achieve significant progress. *How* and *how fast* that progress will occcur through the concrete embodiment of ideas is a debatable point.

Against the general belief in the value of "powerful tools", others contrast the important specific roots of effective ideas. The sharpest contrast appears to be between the powerful abstraction of a high-level programming language and specific, purposeful applicability to problem solving. Intermediate between these poles are extensible microworlds, which provide guidance for the novice, with environment specific primitives and examples, by showing what is possible and desirable. For such extensible systems, the importance of the high-level programming language is two-fold: first to permit user extension of application-specific high-level primitives and second, to open up those high-level primitives as explainable composites of the functions of the general purpose language.

If new ideas develop primarily from solving problems in very specific domains, after which widely usable tools can be created by generalisation from facilities made for specific purposes, the likelihood of a "breakthrough" in software is not so great as that of an evolutionary, possibly accelerating, process of improving accessibility, expressiveness, and power of existing facilities. To the extent that effectiveness of educational software will depend on the *quantity* of information online, the "knowledge entry" problem will limit the speed with which intelligent technologies will affect education.

RESEARCH FRONTIERS

Computational

Research in indexing schemes and algorithms for massive data bases is essential to progress in the use of optical storage technologies. Coping with graphics will be the main challenge. Research in graphics manipulations is an important frontier because images will become much more engaging if and when they can be manipulated by system users. For example, one would like to be able to extract a component object from a scene (and have the system fill in the previously occluded areas), construct a three-dimensional model of the object, modify the model then re-insert some different flattened representation of the modified model back into the scene. The occasional need for the computational power to model objects in three-dimensional space would make desirable the ability to off-load such computations to a more powerful locally available host; one can imagine a "host window" in the local system which could be served by the computational power and burst transmission of the mainframe at need.

Evaluation of Technology

There is a common belief that information about the cognitive results of computer experience is needed, and that of a dependable, not merely anecdotal, sort. Two methodological proposals are to use more intensive, long-term studies of learning to get deeper results (see Lawler, 1985a) and to use combined methods of classroom research. This was articulated as a research goal by Clements. The extended and child-focussed studies by Bussis and colleagues (1985) could serve as a prototype of this genre of study. Higginson is now planning a long and detailed study of this sort. An example of such a study might employ learner-focussed case studies in both technologically altered and in more traditional classroom settings. Specific recommendations are to ask what radical changes in cognition, if any, new technologies do in fact promote. Pea attempted to address such questions in his past research and has discussed in public undertaking such a study in the hope that such effects can be found in the impact of Brown's *Annoland*. Burton advocates developing a theory of evaluation which will be more useful in respect of high-level cognitive skills; he argues that the most effective way to improve an educational system is to improve the criteria by which it is judged externally.

Materials Development: Cognition Research

If information technologies' impact is to be broader and more profound than skills-oriented training, better understanding of the processes of learning must be a primary goal. Several researchers judge it to be so (see Brown, Greeno and colleagues, 1984) The central argument is that the changing logistics of information manipulation and transfer will change the quantity and kinds of knowledge people can control. Mohl's example of this point is lucid and accessible: multiplication was possible using Roman numerals, but the process was so cumbersome that multiplication never became a common accomplishment until the Roman representation scheme was supplanted by Hindu-arabic numbers. To what extent this is true and precisely how such changes take place are central scientific questions. Answers to such questions would have a profound enabling effect for the design of superior education materials. Particular core issues for future information technology media studies might be:

- What general effects does computer experience have on development?
- How is meaning constructed from fleeting experiences?
- How does electronic presentation affect appreciation/use of text?
- What does graphics mean and how is it interpreted?
- How are the interrelations of natural language and other representations of knowledge changed by more graphics-rich, less necessarily-serial media?

Given the likely development and marketing of "learning stations" for technology based education, one should study the impact on cognition of presenting materials through a uniform interface – as opposed to the typically heterogeneous experiences of everyday life.

Materials Development: Application Research

One major purpose for applications research is providing feedback to materials designers. They face in concrete form the very general questions of how you teach people what they want to know in a short time and how you help them go beyond skills to mastery. The most prominent candidates for progress in this area are attempts to develop well-articulated principles of instructional design and the advancement of Intelligent Tutoring Systems and Feurzeig's proposed intelligent microworlds. There is hope that a synergy will develop between these two previously distinct approaches for using computers for instruction (see Yazdani and Lawler, 1985). To the extent that the primary interface to computers has been lexical and will remain so, one should probe the significance of new functions for reading and writing in the electronic medium.

Socially-oriented Research

Knowing one's place in the world is a central theme of education. The social context into which information technologies fit, both in the senses of how they can be used to access resources and how they will interact with other forces in shaping society, should be foci of research. But which specific research issues can be addressed productive is unclear.

More local questions, useful to explore nonetheless, are the following. How does participation in an electronic mail community contrast with other forms of interaction and group membership? Studies of this sort are beginning to appear (see, for example, Carley, 1985). Can education reform, such as might be represented by shifting focus to high-level problem-solving skills as opposed to basic skills, be effected by testing organisations' adopting measures of such strategic skills, as advocated by Burton? What resistances to technology adoption by the education community exist; are they more or less justified in terms of the communities' goals and the needs of the instructors and students? Surely there is no single answer to such questions as these, but case studies of successes and failures in different social contexts may indicate the proper balance between conservatism and temerity as a function of the educational alternatives of the different populations

Essential Research of Uncertain Value

Some issues are so important they should be studied even if one can't tell ahead of time how the studies will turn out. Exploring technology's impact on society is one such risky but essential study. Computation and communication, the informatics medium, can and probably will take us into MacLuhan's age of the global village. We need to explore the range of promise, the danger and the controllability of this new world-environment with the deepest and most careful thought we are capable of. If one outcome could be a breakthrough into a new age of consensual democracy, as in Koulakoff's scenario of conference communications and instant access to expertise, others are less hopeful. Orwell's sombre vision is not any more frightening than that of nuclear annihilation brought on by the capricious play of brilliant but irresponsible pranksters breaking into defense command and control systems.

The primary challenge of education in an environment where intelligent machines will represent a major component of experience will be the development of an ethical and civic sense. An important means of developing an ethical sense is to recognise one's own place in the world through comparison with the situations of others. Placing oneself in the world is important, whether the individual's focus be on what he can get from the world or what he should contribute to it as a matter of civic responsibility. One possibility worth consideration is exploring the use of video to articulate the values and problem-solving techniques of different countries, cultures and subcultures. For example, a suggestion proposed by Lawler calls for the distribution of cameras and film to children and others of various countries so they can make an enormous collection of 35mm slide pictures of what is important to them and how they solve the problems of their daily life. Participating cultures and other groups could present "their story" to the world. With a multitude of such culture-specific video collections which could be made into videodiscs, people in these cultures would be better able to portray for others and appreciate themselves their place in the modern world The ultimate educational benefit would be that different people could begin to see what others value in their own cultures and how others' ideas and resources could help them cope with their local problems.

Restructuring Society

Telephone and auto and air travel have reduced the dominance of *place* in people's lives. If the establishment of communication-supported distributed communities of interest, subcultures in fact, will be a frontier area of social development during transition to the electronic world of the future, one should explore the role and effects of electronic communication and personal interaction in the development and functioning of such groups.

What does a "civic" sense mean in a world of distributed communities supported by electronic communications? It is possible that ubiquitous and unlimited computational and communication resources will permit people to develop a new relation to the world in this primary social sense: most people today see themselves as citizens of a place; people of the future may come to see themselves as "Citizens in Time", connected into various subcultures by electronic communications. If *when* becomes more salient than *where*, such a radical reorganisation in the structure of communities throughout the entire world will be the most significant revolution in human history since the founding of cities.

Survey Respondents

The people contacted for opinion are colleagues I have come to know and respect through their work or through introductions arranged by such colleagues. Most of the reports of opinion here are based on short telephone interviews; some few comments are based on conversations and presentations heard at public meetings. To most of the respondents, I initially sent a letter, including a description of OECD published in the *Christian Science Monitor*, with the request that they think about the two questions of technology future and worthwhile research, with the notice that I would try to contact them by telephone during subsequent weeks. Several people sent me materials to read. Most were willing to discuss the issues. Several responded out of respect for the OECD and its work. I thank them all for their help and hope I have not inadvertently misrepresented ideas they were willing to share.

Howard Austin	Knowledge Analysis, Inc., Concord Massachusetts
Alfred Bork	Educational Technology Center, Irvine, California
Alan Borning	Computer Science, University of Washington
Barbara Bowen	Apple Education Foundation
John S. Brown	Xerox Palo Alto Research Center
Richard Burton	Xerox Palo Alto Research Center
Susan Carey	Psychology, MIT
Douglas Clements	Education, Kent State University
Michael Cole	Psychology, University of California, San Diego
Andrea DiSessa	Education, University of California
Joe Druzzi	Director of Education, Lisp Machine, Inc.
Thomas Dwyer	Computer Science, University of Pittsburgh
Wallace Feurzeig	Bolt, Beranek and Newman, Inc. (BBN)
Paul Goldenberg	Lincoln-Sudbury High School, MA
Wm. Higginson	Queen's College, Kingston, Ontario

Wm. Hoffman	New Product Marketing, Symbolics Inc.
Alan Koulakoff	Academy for Educational Development
Hal Lamster	Businessman, Past ACM Chairman, New York
Robert Lawler	Fundamental Research, GTE Laboratories
James Levin	University of Illinois, Urbana
Robert Mohl	Video Consultant, Paris and New York
Andrew Molnar	Director, Advanced Technology Programs, National Science Foundation
Julia Motz	Video producer and Consultant, Exxon Foundation
Don Nix	IBM Research, Watson Labs
Ralph Oliva	Texas Instruments, Product Development
Patrick Ridgley	Control Data, Educational Product Development
Stephen Salyer	Director, WNET Education Division
Judah Schwartz	Education Technology Center, Harvard
Michael Shafto	Office of Naval Research
Brian Silverman	Chief Engineer, LOGO Computer Systems, Inc.
Robert Taylor	Columbia Teachers College
Stephen Weyer	Hewlett Packard, Artificial Intelligence Laboratory

Chapter 4

IMPLICATIONS FOR TEACHING PRACTICE AND CONTENT

Although the primary object is specifically that the pupil should master a fundamental cognitive skill, teaching reading is in the first place teaching itself. This means that it should not only have a clearcut place among the ultimate aims of general education but should also proceed from the most reliable possible understanding of psychology and reflect the most reliable educational principles. Except perhaps in a situation calling for a desperate remedy, it would be unacceptable to reduce the ambitions and procedures of education to what technology allows.

It has to be recognised that during the first years of microcomputing, educational software packages were designed more in terms of what the technology could do (and, often, in non-expert hands) than of what was really desirable. There was some anxiety that the outcome might be a pedagogical regression, especially as increasingly numerous and therefore heterogeneous school rolls have produced, in the unfavourable conditions prevailing, a decline in the average performance. For some, the situation called for a return to educational practice based on lower cognitive processes and rote learning.

Today microtechnology and, even more, the educational reflection accompanying it, are emerging from their first severe growing pains. In particular, with help from discoveries in artificial intelligence, they are opening up hitherto unsuspected possibilities for stimulating the development of higher cognitive skills – critical attitude, flexibility, problem-solving, etc. – which man will increasingly need in a world where robots will perform most of the simple or repetitive tasks. Setting out along that avenue makes one newly aware of the importance of 20th century psychological and pedagogical discoveries, such as the construction of intelligence in interaction with the environment, the decisive importance of the functional character of learning and therefore of its significant character for the individual, the key role of emotion and the social context.

Technology itself is producing new advances in psychology. For example to build an expert system requires a very deep understanding of the knowledge and skills necessary to work in a specific area.

> Construction of such systems requires a complete theory and symbolic representation of all the components of an overall skill. However, it also requires: *a)* a theory of how those subskills are mislearned that accounts for observed student mistakes; *b)* a theory accounting for student modification – e.g. shortcuts – of formally taught procedures; and *c)* a model of the "noise" in the students' execution of the skill. (COSEPUP, 1984, p. 25)

Briefly, after over-exclusive (though probably inevitable) focussing on technical development, leading specialists in educational technology are attaching increasing importance to the contributions of fundamental research in the human sciences, particularly in the educational quality of curricula.

Brügelmann (1985, p. 7) proposes a set of pedagogical principles that computer-assisted teaching to read should respect. He summarises them as follows.

"– Infants should be encouraged to activate their personal experiences with print in everyday life and to build on these naïve concepts when learning to read and to write more formally;
- Children should understand what they learn, i.e. they should gradually extend and differentiate their individual concepts of the (social) functions and of the (technical) structure of print rather than additively acquire isolated skills and bits of knowledge;
- They should be allowed to experiment actively with print, i.e. to learn from their own reading and writing attempts without being restricted to correct solutions, and they should experience respect for intermediate stages on their route to literacy – in spite of the way still to go;
- Children should work as independently as possible and increasingly control their work on their own even when practising skills (e.g. through selecting the type and amount of exercise by themselves);
- Situations should often be offered where children can use print effectively and for purposes that are significant for them personally;
- Tasks should be designed in such a way that children can work together and learn from each other so that they learn to evaluate diverse solutions and to accept different approaches to the same problem;
- Learning together does not mean doing the same; the type of tasks should allow for different ways of using print and for utilising individual strategies of reading and writing;
- The material should stimulate multiple kinds of activity, activating several senses and, in particular, involve children in hands-on manipulation of letters, of words, and of equipment for their production."

Within these broad principles it is also important to recognise the obligatory stages, the critical aspects of learning and of teaching to read. As mentioned above, the idea is not to suggest some one and only method with all the virtues, but clearly to recognise the skills which must at all events be mastered. Even in the teaching of something apparently so technical as reading, the teacher as an individual will be pursuing particular objectives with particular people in particular circumstances. For example, adult education calls for special procedures imposed by the learner's own needs, personal experience and psychology. How will technology take its place in the informal education process?

New curricula for the teaching of reading will have to be developed in the light of the new horizons being opened up by the information technologies. On the periphery/centre pattern of curriculum development, their methodological component might take the form of detailed scenarios as the only way of demonstrating, hypothetically or if possible from a real-life experiment, the evolution of a full period in learning and teaching to read, e.g. the first two primary years (Chall stages 1 and 2). The word scenario is systematically substituted here for methodology in order to avoid any normative connotation, since what is being described is not the best way but one way which, preferably, has already been shown to work.

There are very few fully developed curricula – curriculum being defined as a set of actions planned to convey instruction; it includes the definition of teaching objectives, content, methods (including assessment), equipment (including textbooks) and arrangements for adequate teacher training (De Landsheere, 1979). The obvious reason is that developing a proper curriculum requires such a large stock of knowledge (which going over to the computer often involves extending) and so heavy an investment in time and money that it is hardly realistic to expect the private sector to produce one.

The concept of teaching is no longer dissociated from that of formative, diagnostic assessment permitting continuous correction and adjustment. Systems are now coming in which also make use of research into artificial intelligence and the cognitive processes to offer the pupil an environment which helps him to discover how to solve problems more efficiently, by recording and reproducing every step he has taken in trying to solve the problem. This is a kind of new technology of recorded spoken thought. It enables students working simultaneously on a problem to compare their respective approaches, and the instructor to set tests.

With Norton and Resta (1986) we conclude that:

> It seems evident to the researchers that computers have the potential to play an important role in support of the reading curriculum. However, that role may not be of service to the "traditional" skills curriculum. The traditional curriculum has tended to view the reading process as the accumulation of discrete bits of information and the mastery of specified, often sequenced, skills believed to add up to a whole. Conversely, gains in achievement made by those using problem-solving and simulation software suggest reconceptualising the reading process as fluency with cognitive and problem-solving strategies, particularly when they are applied to specific, increasingly complex, knowledge or idea domains. The computer will have its most important impact on the reading curriculum when educators seek new uses of this new technology rather than using it as a new medium for accomplishing the "traditional" curricular goals associated with reading instruction.

HARDWARE

It seems increasingly probable that the kind of testing mentioned above together with the complex courseware now appearing will require much more advanced hardware, which as the previous chapter showed will itself soon be available. In particular, tomorrow's most attractive hardware will probably consist largely of learning stations connected to a central or "library" system.

Schools and other educational institutions should be taking account of this rapid and crucial development in their hardware policy. But authorities who have already spent heavily on poor quality hardware may be reluctant to discard it until it has worn out. If so, Computer Assisted Learning might congeal at the lower cognitive level, even though development efforts seem to be increasingly geared towards the higher processes. However, it would also be an error to believe that only highly sophisticated and very powerful hardware makes sound educational treatment possible.

SOCIAL ASPECTS

Attention must be drawn to one direct socio-economic aspect of the above considerations. In first-generation microcomputer provision, differences among families and schools in wealth and awareness have already distorted equality of opportunity. This will surely remain a problem if frequent, large-scale reinvestment is required to benefit from major technological advances. Democracy cannot in principle tolerate a division between schools for the rich and schools for the poor (a point that applies to all countries).

Inequality between the sexes, to [illegible] in favour of boys, has been a very early criticism. The imbalance is less serious in the field of language than in science but is nevertheless there. In the social domain as such, Andee Rubin points out that the social context of reading and learning to read has not received enough attention from researchers or courseware designers, and that there are also various forms of cultural bias.

Is the social context of the classroom liable to be disrupted by large-scale use of computers? On the unfavourable side, there are grounds for concern that a middle-class child initiated early into computers through having one in the home may be at an advantage in the power structures and negotiation processes which can considerably influence learning within the class as a group. A reverse social process may also occur, since it is not unusual for a child from an underprivileged background, underachieving in ordinary lessons, to pull suddenly ahead in the new field of technology with, apparently, every prospect of success, in which case the power structures could change to his benefit.

Another question has been whether the individualised teaching that the new technologies make possible may deprive children of the benefits of interaction that are a feature of the group situation. The outcome is by no means clear. Working with a computer often involves two or three children solving problems together and providing one another with feedback. It has also been seen that computers linked up into networks can facilitate communication not only among members of the class group but also with the nearer and remoter outside world. Some programs, moreover, have been specially designed for group work. In short, there is every prospect for more rather than less interchange among learners thanks to the new information technologies.

TEACHERS

Rubin and Bruce (1986) confirm the observations of De Landsheere (1984) and emphasize that the teacher has far more influence than the software on the child's educational experiences. Recent courseware has moreover become increasingly "open" so that teachers and children can contribute personally to their implementation.

The introduction of computing into education is a twofold source of innovation. It provides new ways of using traditional methods; at the same time, the power of technology provides an opportunity for changing methods. For example, expert systems to teach reading set the child a task, record his replies, assess them, provide feedback and offer individual help. In short, they simulate teaching (and may on that score be used for teacher training). The danger is that the systems might be regarded as authorities rather than as perfectible tools.

The phenomenon of resistance to innovation has long been known. In particular, owing to the ineffectualness of teacher training methods (discussing psychology and pedagogics instead of practising them) the younger teacher, at a loss when embarking on actual teaching practice, will reproduce the educational patterns he interiorised during his own schooldays. Attitudes handed on from generation to generation are thus reinforced and, as a result, very resistant to change. So various decisions are made about method or content once and for all. As the COSEPUP report points out (1984, p.28):

> Analyses of educational change have identified a set of basic pedagogical techniques and curricular contents that have been particularly resistant to change. Cognitive analysis suggests that, in many cases, these are precisely what must change if improvements in the quality of learning for all students are to take place.

Introducing the new information technologies into the classroom, with all the flexibility they make possible, may reveal new types of learning activity and exert a motivating influence on the teacher. In short, new learning systems may align classroom practice more closely with contemporary advances in cognitive science. The more easily the actual effects of such innovations can be assessed, especially the effects upon cognitive development, the likelier they are to become accepted.

In particular, teaching/diagnostic expert systems may exert a decisive influence:

> Cognitively-based learning systems can be used simultaneously to teach professional courses in education, to engage teachers in the same kinds of activity-based learning experiences that they will use with students later on, and as objects of study about underlying cognitive processes. (COSEPUP, 1984, p 28)

Such considerations bring us back to a constant theme in relations between the new information technologies and education. The leap forward in education, both desirable and necessary, will surely be less a question of technology or of specifying methods for using it than of people, of teacher recruitment and training. There are four possible hypotheses:

a) A significant rise in the level of teacher recruitment, ...tial and refresher training, so that institutions can be staffed with real "professionals" i e. people who have received the highest level of scientific training so that understanding and using scientific aids are second nature to them·
For many countries this kind of an advance seems rather unlikely, not only because of the cost it would involve but also because they have large numbers of established teachers more or less in mid-career in whom rapid change would be dfficult to promote;

b) After the present enthusiasm, for lack of powerful enough hardware or of enough good software, computers are dropped and forgotten about, rather as with the audio-visual techniques, in which case the pedagogical advances achieved will not be very significant;

c) As with teams of scientists, we might see poles of excellence arise in the teaching world, with genuine two-way communication between technology as it opens up new avenues, exerting a formative influence on the educator, and the psychological and pedagogical contribution from trainers to advancing technology;

d) Schools unable to evolve sufficiently to meet society's needs have their field of action limited, with new kinds of parallel educational institutions or pathways alongside to deal with the kinds of education which the school no longer seems able to provide efficiently.

None of these hypotheses will probably be fulfilled distinctly or exclusively but they can all be expected to come about to varying extents.

INVESTING IN RESEARCH

Research and development, properly balanced, are obviously essential aspects of applying the new information technologies to education. But two aspects are perhaps less clearly perceived although they are essential if the process is not to be haphazard, with dead-ends or sterile decisions. First, the importance to be attached to fundamental research. Second, the essential need for long-term, longitudinal research No reasonably well-known research leader has much difficulty in funding a short-term project, even though policy-makers and businessmen ought to realise that short-term projects yield the smallest profits. But to fund a really serious project, such as a longitudinal study over twenty years or so, there is practically no one to whom he can realistically turn.

The danger we warned of two years ago at the OECD is still a threat. Waste on an incalculable scale or massive forgone earnings are still in prospect unless facilities can immediately be provided for long-term research on technologies which are going to change mankind's destiny. At all events, scientists of the calibre to do this essential research will not be forthcoming if they can only be offered precarious status and pitiful resources.

RECOMMENDATIONS

- Cognitive science research should be pursued to continue to develop new models of the reading process, new assessment techniques and new teaching and coaching techniques. Educational software designers should work with cognitive scientists to translate research findings into effective software whenever possible;
- Educational software in reading should be designed with the awareness that reading and writing are closely connected, not only as linguistic processes, but as subjects in school. In fact, treating reading and writing together as "language arts" and emphasizing the social relation between author and reader has the potential to improve learning in both subjects. In this respect, people doing research and development in reading should be in close communication with those in writing. Future OECD efforts in this direction should plan for discussion between reading and writing experts;
- Emphasis should be placed on the development of software that focuses on reading comprehension. There is still an imbalance in software in this area, with many more programs existing that deal with early reading (decoding) than comprehension and inference in reading;
- Investigation should continue of new technologies that are likely to affect text presentation and communication in the near future. In particular, CD/ROMS (Compact Disk – Read Only Memory), speech recognition and production, networks (both distant and local-area), parallel machines and integrated (multi-media) communications are all likely to effect the teaching in general and teaching reading in particular in two different ways:
  a) by changing the definition of reading and text, e.g. through the availability of spoken versions of text and/or the inclusion of multi-media adjuncts in text;
  b) by making expertise in reading and/or subject matter available to novices – either through networks or using storage media with large capacity (e.g. CD/ROM);

  OECD should track these developments as they affect reading instruction;
- A software exchange should be created that would avoid the duplication so common in educational software. Alternatively, OECD could facilitate Member countries' access to experts who had already developed software in reading, so that new efforts could gain from previous ones, even if they are in different languages and thus may have significant differences;
- Evaluation of software for teaching reading should continue, focussing especially on the software in use: the classroom and school context, the curriculum and teacher training;
- In current reading research two basic but closely-related aspects of reading are distinguished: *i)* decoding (involving word recognition and syntactic parsing); and *ii)* interpretation of the written message. By now it is quite obvious that computers can serve as powerful educational tools in promoting the development of rapid, efficient and automatised decoding skills which gradually become encapsulated in processing modules requiring a

minimum of mental resources. The other aspect of reading, involving active interpretative and constructive strategies, inferencing, schema utilisation, prior knowledge activation, etc., is generally not explicitly taught at all in conventional education. The present report has provided rich examples of creative possibilities of using computers for promoting the development of interpretative and metacognitive skills. However, hardware and software do not in themselves guarantee improvement of reading instruction. Training of teachers must include the development of a sophisticated theoretical frame of reference concerning various aspects of the reading process;

- Research on teacher training in using language arts software must be expanded. For software that has any flexibility (and this includes most software) its educational effectiveness depends mainly on the way the teacher integrates it into the curriculum. Thus, we need to spend significant effort understanding how teachers adapt software for their own classrooms;
- Research must be undertaken on the obstacles to individualisation. Since many decades ago, at a time when the role of computers was not discussed, methods and technologies of individualisation have been experimented and validated. For what reasons have teachers not applied them? What are the new factors today that could change this situation? Is the existence of a broad range of educational software the only factor?
- It would be desirable to organise workshops (lasting a minimum of three to four weeks) in order to actively initiate teachers to individualised or semi-individualised teaching. The follow-up of the teachers trained should be done in their own class. Finally, a renovated curriculum for teaching reading and written expression should be developed.

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II. WRITTEN EXPRESSION

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Introduction

This report concerns not one, but two streams of innovation in education The first concerns the impact of new information technologies on teaching and learning. The second, which might seem far removed from the realm of information technologies, is a radical reconception of the role of writing (by which we mean "written expression") in education and of how it should be taught.

This report focuses on the confluence of these two streams. Despite initial impressions to the contrary, we suspect that information technologies may have a gre   if not their greatest, impact in the area of writing.

New Information Technologies

The general outlines of the information technologies revolution are already evident. Computers and allied information and communication technologies make possible significant advances in several areas. First, the computer as a tool enables learning by doing. In the area of writing, especially, computers facilitate learning by fostering success and making the task more meaningful. Second, information technologies provide new environments for learning, e.g. communication networks foster writing with clear purposes to real audiences. Third, they make language itself an explorable domain. Students can discover for themselves the patterns of language through games, simulations, and constructive activities. Fourth, they now promise not just machine-based or programmed teaching, but truly intelligent tutoring systems. Fifth, by making the learning process more visible, they make research on learning more feasible and teaching better informed . Sixth, and finally, they are changing our conception of what needs to be learned. Facility in the use of new information processing tools is becoming an increasingly important aspect of what it means to be skilled in a given area.

These are exciting possibilities for the near future, but the hopes for what information technologies can do for teaching and learning must be tempered by the realities of present-day educational systems. We must critically examine the promise in the light of what we know about educational expenditures and equality of access. Moreover, we need to understand better how information technologies can actually be incorporated into existing schools. These issues, as well as the promise, must be studied seriously.

New Perspectives on Writing

A rethinking of writing instruction has coincided with the rise in the use of information technologies for education. Writing is increasingly being seen as a tool for acquiring knowledge, for developing thinking and for real communication. Conventional methods of teaching writing, which have emphasized correction of student products, are giving way to approaches that emphasize process: significant interactions between reading, writing, speaking, and listening; a focus on meaningful communication with real audiences; and ample opportunities for feedback and revision in a non-linear writing process.

This shift in the teaching of writing has been fostered by extensive research on writing in recent years (Hillocks, 1986), which has challenged the assumptions underlying conventional approaches. The research has tended to stress one of two perspectives:

- Writing as a social act, as a basic skill for learning and survival in a literate society;
- Writing as a cognitive act, as a tool of thought.

Neither of these strands supports a focus on mechanics (grammar, spelling, punctuation, capitalisation, etc.), or an exclusive use of the writing assignment, a task usually separated from all other aspects of learning.

When writing is viewed from the *social perspective*, understanding the purpose and the audience become paramount (Bruce, Collins, Rubin and Gentner, 1982). In all writing situations the basic goal of writing is to convey some message to the reader. The message may vary according to whether the writer's purpose is to inform, to persuade or to express feelings.

The social perspective leads us to see the production of text as a typically collaborative act. Most adult writing is embedded in social settings. The writer, however, produces a text without the direct co-operation of the reader. This distinguishes writing from conversational interaction. Since a writer cannot have immediate feedback, the text has to anticipate and address possible responses (e.g. lack of interest, comprehension difficulties, memory difficulties, objections, criticisms). Extending Grice's notion of the co-operative principle for conversations (1975) to writing, we can say that the writer and reader are bound by mutual obligations: the writer is obligated to write a clear text, while it is the reader's task to read the text and interpret it with due regard to the writer's presumed purpose. Expert writers are therefore not just expert at putting words to paper, but at listening to others, interviewing, discussing, arguing, analysing, synthesising, and, generally, engaging in collective as well as solitary intellectual work. Questions need to be raised: How are these skills learned? How well do schools prepare students for writing in adult contexts?

When writing is viewed from a *cognitive perspective*, it is seen as an immensely complex act, one essentially inseparable from general thinking and learning (Gregg and Steinberg, 1980). From the cognitive perspective, understanding of the writing process becomes paramount. During the writing process writers must generate and collect ideas, then organise, prune, and revise them. Moreover, they must produce text with attention to all levels from individual word choice to overall text organisation. To complicate things, text production and idea generation are not easily separable, for ideas arise during the process of creating text.

The cognitive perspective studies the knowledge and processes of competent performance. What makes a person a good writer, or even an adequate one? In simplest terms, good writers (in a given domain) know more – more words, more ways of expressing ideas, more forms of text organisation; they are more skilled at applying the knowledge they have; and they have better strategies for putting everything together, even going beyond what they know. It is this third capability, having strategic skills, that brings the cognitive and social perspectives together. Expert writers have experience in various kinds of writing situations; they have written on a variety of tasks and topics for varied writing purposes and audiences. As we examine new technologies for teaching writing we will need to keep in mind these aspects of writing expertise.

New Information Technologies and Writing Instruction

Technology can be used to change writing instruction in a variety of ways. Computers can aid at places where teacher time and attention are insufficient. They can make prewriting activities more feasible; in particular, they can stimulate the processes of generating ideas and organising text. With the aid of a text editor, revision of text is highly efficient and more rewarding. They can comment upon features of written texts. Unlike teachers, computers can give feedback at any convenient moment. Most important, computers can provide new opportunities for the introduction of effective teaching strategies.

Computers can increase the student's time-on-task and can help lessen the teaching load. They can thus create time and opportunity for teacher involvement with essential aspects of writing processes that are beyond the reach of the computer.

New technologies can also help to realise a more functional way of teaching writing. Ideals of "writing across the curriculum" – teaching writing in connection with all subjects, rather than only as an isolated course – may become more feasible with the support of computers. By means of computer networking, communities of student writers can be established. Real audiences and meaningful goals can stimulate the development of competency in written communication and enhance motivation

With the aid of computers, students can draw on knowledge bases that contain information on spelling, punctuation, grammar, and style, but also on factual data and models of texts and the writing process. Texts written by students can easily be be stored and retrieved later in order to analyse errors and growth in writing. Aspects of the writing process itself can also be made visible to the learner and the teacher.

Outline of the Report

In this report we examine the teaching of writing, new technologies of today and the future, implications for education, and recommendations to bring about significant and cost effective change in writing instruction.

- Chapter 1 discusses the pedagogical context: in particular, goals for instruction in writing, followed by what is known of how writing develops and how teaching can best facilitate its growth.
- Chapter 2 describes technology to date, focussing on the use of the computer as a tool for thinking and composing, communicating, and exploring language.
- Chapter 3 examines promising areas of research and prototype development. Some of these are natural extensions of the work described in Chapter 2, while others are exciting new possibilities.
- Chapter 4 covers the implications of these developments, both the actual and the potential ones, for instruction.
- Finally our recommendations conclude this report.

Chapter 1

THE PEDAGOGICAL CONTEXT

In this chapter we consider the three aspects of the pedagogical context: *i)* the goals of writing instruction; *ii)* how writing is learned; and *iii)* the teaching of writing.

GOALS OF INSTRUCTION

Written language has always played a dominant role in the school system. Typically, the acquisition of literacy is considered to be one of the most important tasks of the school, for it forms the foundation for all subsequent learning. Writing is an essential component of literacy.

It should be recognised that the school is the first and most important writing community in most children's lives. In this community, writing should be defined broadly, to include all forms of composition, from the most basic levels of functional writing to the accomplished use of written language for reflection and learning. It is the school's central task to guide the student to write for different communicative purposes on a wide range of tasks and topics of various degrees of familiarity. One has to recognise that the school may play a greater role in the teaching of writing than in the teaching of reading, or even of foreign languages.

Writing has several functions, among them: *i)* the acquisition and recitation of knowledge (writing to learn); *ii)* the development of logical thinking; and *iii)* communication within a social context. In many school systems these objectives are restricted. In some, only communication is emphasized; in others, logical thinking. All school systems tend to stress the recitation function of writing. Differences do exist, however, in whether the aim is to learn content through writing, to integrate knowledge, to repeat given knowledge, or to reveal one's own knowledge by writing. In post-industrial societies citizens require increasingly sophisticated writing skills of all these types.

The teaching of writing is also connected with a more general educational goal: socialisation through language. To a certain extent this goal has been accepted in all school systems. This leads either to direct transmission of cultural heritage (the "heritage model"), or to induction of society's norms and values through linguistic interaction (the "competency model"). In some school systems the development of an independent, creative mind is also a general objective. This is facilitated by rich linguistic interactions and a curriculum that concentrates on students, their needs and their emotional and psychological growth. Students express their ideas and emotional needs in writing; teachers provide the materials and guidelines for the students' development.

In the past few years we have learned much that provides a solid base for the educational application of new technology. Investigations of the past two decades have advanced our understanding of the growing mind of the child. While the causes of changes in developmental status over the life span are not entirely clear, there are some generally accepted principles emerging. The developing child is viewed by present-day cognitive scientists, as an active organism interacting with the environment. This interaction is crucial to the development of intelligence and world knowledge.

We know that the roots of formal linguistic expression are embedded in early speech development. Speaking and listening skills are integral to, not just precursors of, written literacy. A rich experience in all aspects of linguistic expression is vital to the child's verbal construction of the world.

Verbal expression has both cognitive and social roots (cf. Vygotsky, 1978). The very young infant is known to move in synchrony with its human environment. Interactions occur in bursts and pauses, and even babies soon learn to take turns. As spoken language develops in the first years of life, the communicative value of language serves to stimulate, and in turn be enhanced by, the intellectual and social growth of the child.

To support this learning, rich intellectual, linguistic, and social stimulation is necessary. along with the opportunity for the effective exercise of developing skills. Learning by doing is especially important. The toddler learns language best by using it in a warm, supportive, stimulating context. The child also begins to encounter the utility of language in print, and begins to experience the importance of decontextualised representation. Environmental print is incorporated in experience, and the reciprocal processes of writing and reading commence. The maintenance of a social and cognitive environment that supports communicative interactivity is critical at this time.

The likelihood of having something he or she wants to communicate increases if the child inhabits an interesting environment. As in the development of early speech, activities in early reading and writing must make sense to the child.

The growing child's capacity to express the world in writing provides us with a valuable window on a developing cognitive and linguistic world. Children have impressively complete "scripts", or mental representations of events, at an early age (Cameron, Linton, and Hunt, 1985; Cameron, Linton, Hunt and Shred, 1985). One task of a writing curriculum is to assist children in making these representations communicable, available for contemplation and examination, and the source of further psychological development. The formal representations of written language require the coordination of a host of cognitive skills, strategies, and knowledge, and that coordination is accompanied by the growth of metacognitive awareness, i.e. the ability to reflect on one's own knowledge. Budding metacommunicative skills have been documented with preschoolers, but their refinement takes a lifetime of communication experience. Whether writing promotes metalinguistic development or the reverse may be immaterial to pedagogical practice; the point is that the relationship between writing and metalinguistic development is strong.

A useful model of the writing process might mirror recently hypothesised models (e.g. Sternberg, 1985) of the development of intelligent problem-solving, which identify such components as: deciding the nature of the problem to be solved; selecting the problem-solving processes to be employed; deciding on an organisation of information; choosing a strategy for combining the processes of components employed; deciding the allocation of attention; monitoring the solution; and maintaining sensitivity to feedback. Increased experience in both writing and problem solving results in "automaticity", or enhanced control over the planning, selecting, monitoring, and revising processes, and consequently, in the complexity of the content amenable to such processing.

For the purpose of this report, we distinguish five activities: *i)* getting ideas; *ii)* organising thoughts; *iii)* composing; *iv)* editing and revising text; and *v)* obtaining feedback about one's writing. We also distinguish the specific activities that lead to text production (*i-v*) from the encompassing activity of communication with others. Finally, we identify a special category: language exploration activities. This decomposition should not be taken to imply that writing is a linear process. Studies of the writing process have shown that the writing process is recursive; there is no straight line from conception to completion. Planning, formulating and revising occur at each stage of text production (e.g. new concepts emerge on the basis of created text).

Skilled writing differs significantly from novice writing, and theoretical analyses of how skilled writers go about writing can provide expert models of the writing process for students to emulate. Instruction and material support in getting and organising ideas, composing, getting feedback, revising, and publishing contribute to the development of skill. Most important, writing is not a process to be segregated in a language arts curriculum. The content that can be expressed in writing is as broad as the whole curriculum. Students must write in all school subjects, and their writing should be evaluated throughout their school years.

To summarise, we know that good writing depends on a rich environment that teaches knowledge of the world and skills to represent and manipulate that world symbolically. Furthermore, we know that development of expertise in writing is enhanced through social interactions at home and at school. Today's technology gives us additional capabilities to put this knowledge to work. It provides new tools for social interaction, new environments for language learning, and new methods for teaching.

TEACHING WRITING

Teachers of writing today are confronted with many problems. Since the 1960s there has been a rapid expansion of educational systems in many countries; many more students now participate at high levels of schooling. Teachers of all subjects must take into account the needs of new kinds of students; they must adapt traditional curricula to new circumstances and at the same time they must try to maintain standards of achievement. For teachers there is the special problem of transferring literacy skills to growing numbers of students for whom the language of the school and the language of the home differ. Ideally, a substantial portion of the school day should be devoted to writing. Progress depends upon opportunities to write and frequent practice. Individualised instruction is needed, in order to pay attention to the specific needs and competencies of individual students.

But teaching load and teaching time have not kept pace. New subject matter claims part of the teaching hours originally devoted to basic literacy development. Growing pupil numbers and decreasing resources for education only worsen the situation. Within this context the teacher of writing needs help.

Quasi-experimental studies have yielded important information on effective teaching strategies. Various prewriting activities, i.e., activities focussing student attention on text organisation, idea generation, problem-solving categories and rules for systematically treating a subject, have shown to be effective. The best-known, and sometimes too rigid, prewriting activity is discussing a composition assignment before writing, but there are other ways to focus the writer's attention on content and organisation. Specific instruction also enhances the act of formulating text. For example, sentence combining exercises appear to have a positive influence not only on sentence structure, but also on the general quality of written text. Research has also found peer evaluation and revision after comments by the teacher to be effective teaching methods.

Unfortunately, much of the teaching of writing has yet to be influenced by current research. One problem, alluded to above, is that the amount of time invested in the teaching of writing is small. On average, in the United States, little more than one hour per week is devoted to writing instruction. This would not be so unfortunate if writing were truly integrated with other aspects of learning. But, when writing is isolated, the scant instructional time means there is little opportunity for feedback, conferences, or revision.

There are other factors beyond that of time limitations (Krashen, 1984). Prewriting activities are rarely encouraged; in general, writing is unprepared and triggered by short assignments or essay titles only. Exercises in isolated grammar, punctuation and spelling still predominate. Generally, only the teacher, and not peers, gives feedback on writing. The feedback that is given is seldom used to revise text; first drafts become final versions. Linear procedures for writing are often taught; the recursive nature of the writing process is not recognised, much less reinforced.

It will come as no surprise, then, that the writing instruction does not accomplish its goals. In many countries "functional literacy" constitutes a major goal of education. Yet various assessment studies in a range of countries have shown that many students fail to reach a level of writing skill that enables effective participation in society. Students are not able to express themselves in writing in a variety of situations, with various audiences and goals.

It is clear that changes are needed. Students need more writing instruction. They need more effective writing instruction. They need opportunities for writing that are more realistic and challenging. They need to write with real audiences and goals in mind. They need room for planning activities throughout the writing process. They need opportunities to revise their work without the drudgery of recopying text.

Chapter 2

TECHNOLOGY TO DATE

In this chapter we review technologies for addressing problems in the teaching of functional and creative writing. Two trends, in particular, represent important advances over earlier applications of technology to writing instruction. The first trend is recognition of the importance of *tools* for teachers and students. Tools include, for example, communication networks, aids for planning a written composition, and programs that write other programs.

The second trend is awareness that applications of technology require carefully planned computing systems that are integrated into the curriculum, school, and community – not just one or two terminals thrown into a classroom. The development of tools and integrated systems promises to free students and teachers from tedious tasks and to adapt instruction to the varieties of human needs, abilities, and experiences.

In parallel with these technological trends, we have learned more about the process of writing. Recent empirical research on writing has revealed much about the nature of expertise in writing, in particular, the way people use top-down and bottom-up thought processes in writing. There has also been substantial research on writing development and on societal differences in the uses and functions of writing. These findings provide a rationale for uses of technology.

We first discuss issues of hardware and general software development. Then we review software aids specifically for writing, including explicit tutorial programs, but focussing on the computer as a tool for writers. This review has three sections: information technologies as aids to composition, information technologies as environments for communication, and information technologies for language exploration. Finally, we discuss evaluation of current software. Because so few substantial evaluations have been done, we describe only three, considering one in detail as a possible paradigm for future work.

HARDWARE AND SOFTWARE DEVELOPMENT

Educationally relevant technology today includes much more than computers. A broad range of computing hardware, software, and courseware is available, but we also have new storage devices, such as videodisks and compact disk read-only memories (CD-ROM), and new means of delivering information, such as cable television and videotex information services. Furthermore, the data base resources needed to make use of new delivery methods, such as on-line dictionaries, thesauruses and encyclopaedias, are reasonably well developed. In addition, many networks allow communication within and across national boundaries – some of these are accessible to the general public. Hence, technology to date includes a broad range of communication devices and resources The term *télématique*, perhaps better than any other, represents this wide range of technologies. Plans to apply technology should consider all these resources.

Computers are being used by students in a wider range of educational activities than ever before, including tutoring, testing and diagnosis, exploratory learning, communication and games. Today, students can use technology to learn from direct instruction, from examples, from entertainment, from advisory systems and from browsing. Teachers have available many administrative and record-keeping aids. Hence, today's technology makes it possible to address the needs of writing teachers, students, administrators, testers and researchers, and to satisfy the requirements of most educational philosophies

Hardware

Developments in optical character reading, speech recognition, and speech production have broadened the range of senses for communication via technology. One no longer need type at a keyboard to activate a computer ... speech is enough. In addition, the tedious typing of text into a computer can be simplified with the aid of optical character readers that not only read what is written, but speak what they read. The sense of touch, for those with limited vision, can be used more efficiently when assisted by computer Furthermore, touch-sensitive screens can be used to simplify data entry.

Input technologies include optical character readers, in wide use for the blind, which read aloud the text that is given to them; however, this technology is expensive. Graphics tablets are inexpensive devices that can be used effectively with children. Voice recognition can now be done reliably by restricting vocabularies and by training the computer to recognise individual voice characteristics. These new technologies promise application for very young children, the handicapped, and for computer-naïve users.

We see few relevant limitations in hardware technology. Reductions in costs and increases in functions continue to outstrip predictions. Since 1970, memory densities have quadrupled about every four years. Processor technologies have developed at the same rate It is estimated that within ten years it will cost about $100 for a small machine with the computing power of 100 MIPS (Million Instructions Per Second), 1 million characters of random access memory, and 4 million characters of program memory. This is the equivalent of today's large and expensive computing machines.

Output technologies have also improved greatly, including various colour systems and dot-matrix and laser printers. These new output devices have been especially important for non-alphabetic languages, such as Japanese. They come in various price ranges, many affordable for home or school use. Videodisks are also in use and not too expensive, although they are expensive to develop. One commercial videodisk system allows multi-user access to over 6.5 million records in the United States Library of Congress shelf list. Compact disk technology is just coming into wide use. It is possible to store, on one CD-ROM (compact disk/read-only memory) disk about the same information as contained in 275 000 typed pages. Such a disk weighs about 150 grams and costs only a few dollars to produce. Currently available CD-ROM disks contain such information as multi-media encyclopaedias, the complete 1984 Olympic statistics and, on one demonstration disk, 8 800 public domain computer programs.

How soon these new technologies will be affordable by most school systems is still difficult to say. A complete system with software and input/output devices may be beyond the reach of many for the next five years.

Software

Progress also continues to be made in the development of general software (such as course authoring systems) and in the development of specific applications Search techniques are improving; some computer systems search 30 000 words a second. However, courseware development, i.e. specific instructional packages, continues to be an expensive bottleneck. It takes about 1 000 hours of labor to develop an hour of instruction. (This is one of the reasons that recent work has shown a shift towards using the computer as a learning tool, rather than as a tutor.)

Thousands of educational software programs exist, and they have improved steadily over the years. But quality is still a problem: educational software must be selected cautiously. Although significant advances in industry have occurred in the development of software tools and methods, the fruits of these development tools have yet to be felt in the educational marketplace. Still, new technology for quality software development can be used to educational advantage. More resources should be devoted to producing high-quality software that can be used on many systems and developing shared methods of software testing and evaluation.

Technology is also unevenly developed throughout the world. One cannot help notice the insularity of nations developing new technologies. Technologically advanced countries should establish methods of sharing effective software with other countries, through demonstrations, international interest groups, and joint ventures that transfer technology to other cultures. Exemplary hardware and software should be adapted for international use.

Regulation and co-ordination of new technologies are major international concerns. Internationalisation of an operating system, for instance, demands that it be adapted to differences in local customs (dates, abbreviations, decimal delimiters, and so on). International differences in character representation create problems for table lookup, and linguistic differences, such as whether a language is read from right to left or from left to right, create problems for text scanning and filtering commands. In addition, system interfaces must use words and allow responses in the user's own language. Finally, paper documentation must be translated. Because of these problems, international standards are necessary.

Without standardization, gains by one educational group are unavailable to others. Support should be given to open system architectures, in which information can flow, without hardware or software incompatibilities, across different computer systems. With such sharing, educational advances in one part of the globe can be transmitted instantaneously around the world. Most important, for the future of international hardware and software, is the creation of products with modular components that can be easily changed to adapt to the character representations and languages of different countries. International groups can work together to build such architectures.

Many kinds of data bases, including the world's literature, need to be transferred from print to electronic form. Support should be given for converting this information in ways that facilitate later use. For instance, the *Oxford English Dictionary* is being transferred to compact disk, thus making available tremendous lexicographic information in a computer readable form at a low cost. But the coding of the information is too simple. Sophisticated linguistic and semantic searches of the dictionary will be awkward without better support facilities.

In the next three sections we review software aids for writing, mentioning hardware, network, and other facilities where appropriate. Our intention is to give some flavor of the range of applications that software provides, with the understanding that the usefulness of a particular resource can be determined only in the context of a specific classroom. The emphasis here is on new technologies as *tools* for composition, communication, and language exploration, for it is the tool capacity that has proven most useful in current applications. In the following chapter we look at other uses of new information technologies

SOFTWARE AIDS FOR COMPOSITION

The review here is organised in terms of the five activities of writing mentioned in Chapter 1: *i) getting ideas; ii) organising thoughts; iii) composing, iv) editing and revising text;* and *v) obtaining feedback about one's writing.* Again we emphasize that this organisation is in no way intended to imply a linear writing process.

Getting Ideas

Expert writers spend most of their time thinking up ideas and organising thoughts. The act of putting those thoughts on paper hardly reflects the intellectual struggles that have gone before. Activities in which one invents things to write about can be especially difficult for young children or for those whose knowledge of a topic is *weak*.

Several software programs have been designed to help with the tasks of planning and generating ideas (see also Pea and Kurland, 1986). Those mentioned below are inexpensive and designed to run on common home computers. One program, called *CAC*, offers children advice about composing persuasive text. The premise is that young children can write better if the computer prompts high-level cognitive decisions. The child can request computer help using a special key. This creates a menu of items from which the child can choose. For instance, advice might be sought about choosing the next sentence. The computer suggests actions based on keywords it finds in the preceding text written by the student. A program called *WANDAH* (Writing-Aid AND Author's Helper) has a subprogram that turns off the screen when text is being entered, so that the student is not distracted by the visual image of what is written. (This technique is called "invisible writing.") Invisible writing is intended to keep students from editing text prematurely, interfering with the flow of ideas. *WANDAH* is now offered commercially as the *HBJ* Writer (Harcourt Brace Jovanovich).

Burns, in the United States, developed programs to guide college writers in inventing topics for persuasive, journalistic, and exploratory writing. *Invent* is a suite of programs based on Aristotle's 28 enthymeme topics (*Topoi*), Burke's rhetorical pentad (*Burke*) and Young, Becker, and Pike's tagmemic matrix (*Tagi*). The objective of the programs is to stimulate writing appropriate to different genres, based on research in rhetoric and language instruction.

Idea generation activities are included in many other programs, such as: *Quill* (D.C. Heath), an extensive program that also includes activities of organising, composing, and revising text; *Prewrite* (Boynton/Cook) (for high school students); *SEEN* (H. Schwartz), a literature-oriented program for high school and college students; *Writer's Helper* (Conduit), which includes eleven different programs (one, called *TREE*, displays the tree of ideas developed by the writer), integrated with revision programs (grades six to college); *Writing Workshop* (Milliken), which includes three prewriting programs (grades three to eight); and several other special purpose programs, such as *Writing a Narrative* (MECC), which is a tutorial on narrative structure and point of view (grades seven to nine).

Activity disks for prewriting also exist. Some are reminiscent of teachers' activity plans, but they offer more student guidance and greater flexibility. These include: *Complete Writer* (Learnco), which creates three writing environments enabling students to take on different writing roles (grades six to twelve); *Writing Activities and Language Skill Builders* (Scholastic), which offers many different prewriting activities (grades six to eight); and *Writing Skills Bank* (Scholastic), which also offers prewriting activities, but for the lower grades (grades four to six). These activity programs all require the *Bank Street Writer* (Broderbund) word processing program.

Dozens of interactive stories and story makers are available that might be included under the rubric "getting ideas," because they stimulate writing partly by providing context. These include *Adventure Writer* (Codewriter), which allows creation of dialogue-style adventures (high school), and *Interactive Toolkit* (Interlearn), which allows creation of interactive stories.

Databases of information should be included among prewriting resources, since they make it possible for students to browse text as a method of stimulating their writing. These would include dictionaries and the host of information facilities available from videotex services, such as those offered on Prestel. There are also many microcomputer-based databases, such as Australia's *Bushrangers* (KnowWare), which allow students to explore new worlds of information.

One might also include adult database management programs, for instance, *PFS: File* (Software Publishing), *ZyIndex* (Zylab), or *Fulcrum* (Fulcrum Technologies), in the storehouse of software that might aid writing through literature access. However, these are not integrated so that a student could easily have access to them all immediately at one terminal. Integrated systems require more sophisticated computing resources than early home terminals provided. Research systems, such as the *ZOG* database system from Carnegie-Mellon University, and the *Hypertext Editing System (HES)* and *File Retrieval and Editing SyStem (FRESS)*, from brown University, suggest useful directions for today's small but powerful desktop computers.

Organising Thoughts

Organising one's thoughts is a second important activity of writing. The computer offers the capability of moving text around in various ways and of viewing it from different vantage points. Some outline generating programs, such as *Framework* (Ashton-Tate), create empty, numbered outline structures within a word processing program. Programs like *NLS* expand and collapse outlines. Using *NLS*, a writer develops an outline by adding levels to a hierarchical structure with headings such as 1, 1a, 1a1, and so on. Lower levels of information in the outline can be hidden from higher levels; thus, the writer can move about at different levels of text. Related programs include *ThinkTank* (Living Videotex), *MaxThink* (MaxThink) and *Freestyle* (Summa Technologies). These programs have such intellectual potential that they have become known as "idea processors." Prices for such programs range from less than $100 up to $700.

Another technique for organising thoughts is to use notecards. Several programs are designed to help with the notecard function, including *Executive Filer* (Paperback Software International), *Thor* (Fastware), and *Notecards* (Xerox PARC). *Notecards* includes a multi-windowed display that allows a writer to create individual notes that can be linked to other notes. Any note can be shrunk to an icon and a writer can browse through the network of icons, perhaps changing its structure. Notes can contain graphic images, text, or both.

One program, included in the *Unix Writer's Workbench* (AT&T Bell Laboratories), strips away all text except headings and the beginning and end of paragraphs, giving the author an uncluttered view of text transitions. Similar features in *Writer's Assistant* (Interlearn) allow the user to see only the first sentence of each paragraph, or to flip between a sentence by sentence format and the conventional paragraph organisation.

Composing

Technological aids that support the composing process include programs that help expand ideas in a text, which might exist in only outline form. Previously mentioned programs, such as the *Hypertext Editing System* from Brown University, can be much more than outline programs. Electronic hypertext documents are networks of related ideas that can be gathered to expand what one is writing. For instance, a person reading an article about cars has a choice of how much detail to see about the history of cars, their manufacture, their relation to the rubber industry, and so on. Movement through this connected text can be controlled by a pointing device called a "mouse", rather than keyboard. Hypertext still requires large computers, but its principles are reflected in programs such as Xerox's *Notecards*.

Many other programs exist whose function it is to build poetry or other text. These range from general purpose computer languages such as LOGO which can be used to create random poetry, to poetry generators such as Marcus's *Compupoem* (University of California, Santa Barbara) or Levin's *Poetry Prompter* (Interlearn).

Rubin's (BBN Laboratories) *Storymaker* program (1980) allows students to create and manipulate text units larger than the sentence. Story structures are represented as a tree consisting of nodes connected by branches. The nodes contain sentences or paragraphs. The student first creates a story by chosing branches to follow; the program adds its text segments to the story as the child chooses.

Any literary database could be grist for students' composing. It is accepted practice, in the teaching of composition, to have students use the writing of famous authors as models for their own writing. Not only style, but content can be imitated. Parts of a student's own compositions might be copied to build new text. Access to the world's literature would be a fine resource for imitation. There are over 350 vendors of on-line and time-sharing search services worldwide, with databases in virtually every academic domain. There are over 600 major electronic databases. Many useful literary databases, however, are in private hands or located in universities and colleges around the world.

Editing and Revising Text

There are hundreds of word processing programs that allow children and adults to enter and revise text. Some, like *Bank Street Writer*, present menus of functions from which the author chooses, thus making it easy to learn and to use the system, but with some sacrifice of flexibility. There is some evidence that young writers function most effortlessly with more powerful word processors (Cameron, 1985; Levin, Boruta, and Vasconcellos, 1982). Many authors, especially adults and professional writers, want to control details of text format, and they need footnote and indexing functions. *Nota Bene* (Dragonfly Software), is a powerful program aimed at academics and sophisticated writers. The program has been endorsed by the Modern Language Association. It is a word processor, but it also permits access to indexed notes and has capabilities for tables of contents, lists, footnotes and endnotes, bibliographies, and indexes.

Several commercial keyboarding programs have been created to help children and adults learn typing skills. However, the need for explicit instruction may not be necessary during the early school years (Bruce and Rubin, 1984a; Cameron, *et al.*, 1985).

Obtaining Feedback About Writing

Research has shown that computer programs created to assist students with the revision process improve student editing skills. For instance, *Writer's Workbench* includes over 40 programs that provide feedback on spelling, diction, style, and other text characteristics. An interactive version of the program works within a text editor; it suggests correct spellings for words, and will automatically replace them if the author desires. A writing laboratory has now been designed based on trials of the system by the English Department of Colorado State University. Smaller programs, which perform some functions of the *Writer's Workbench* system, are also available. The *Writer's Assistant*, developed for young children (by Levin, Boruta, and Vasconcellos, 1982), checks spelling and other features, and allows students to try out various sentence combinations. IBM's *Epistle* system, under development, has a parser that detects complex linguistic problems, such as subject-verb agreement. Thesauruses, such as the *Random House Electronic Thesaurus*, provide word alternatives that stimulate student text revision; hence, students learn from them even though programs are advisory rather than tutorial.

Feedback about many other features of writing could be given. For instance, with little effort records of progressive drafts of a paper can be kept and used to provide writers with a trace of changes made in the process of writing. Document tracking systems exist today, but mainly in research and development laboratories.

INFORMATION TECHNOLOGIES AS ENVIRONMENTS FOR COMMUNICATION WITH OTHERS

The importance of social interaction argues against the use of computers as isolated machines. It is through social interaction that human qualities develop, and social interaction is an important component of writing. It is by feedback from others, by whatever means, that writing skills develop. Peer tutoring has been shown to promote writing development. Several writing programs, such as the *Quill Mailbag* and *Library* facilities, allow writers to share their products (Bruce and Rubin, 1984b). The Computer Chronicles News Network (CCNN) allows children to share news items from around the world. Current work with the Intercultural Learning Network (Cohen and Miyake, 1986) is exploring the use of electronic messaging for learning.

A variety of computer conferencing systems exist that might influence writing at adult levels. They include the Swedish National Defense Research Institute network (COM), which is a worldwide electronic mailbox, Turoff's Electronic Information Exchange System (EIES), and various networks, such as ARPANET, BITNET, EARN, USENET, CSNET, MAILNET, and JANET. These and other research systems have developed the technology for conferencing systems, such as NOTEPAD, eForum, and CONFER. A system developed at MIT, *Newspeek*, creates personal newspapers. Readers use keywords to describe their interests, and news stories from wire services are filtered according to each reader's list of keywords. Newspapers that are tailored to each reader can thus be produced.

One important element in the popularity of computer text processing systems is the ability to format text to achieve communicative goals. Technology can provide students with the ability to publish their own newsletters, papers, or books. Desktop publishing, at modest cost, is here. For instance, the *MacPublisher* software, which allows various formats and integration of text and graphics, costs about $150. Publishing compositions can be intrinsically motivating for students.

Other programs create communication environments modeled upon those used widely in the adult world. *Newsdesk* (Cambridge Language Arts Software) is a computer-managed simulation game in which the players take on the roles of newspaper sub-editors. The computer acts as a teleprinter giving news updates, and also offers screen-editing facilities. *EDFAX* (Tecmedia Ltd.) is a "Teletext (Videotex in the United States) Emulator" – a micro-based version of an information display and retrieval system such as Prestel. It allows users to store, edit and display pages of text and graphics. It is particularly useful for creating an electronic newspaper or bulletin board.

INFORMATION TECHNOLOGIES AS TOOLS FOR LANGUAGE EXPLORATION

Students learn most from activities, such as games, that are meaningful to them and promote active involvement (especially when abilities are challenged, but success is attainable). Programs such as *Gram* (Sharples), *Interactive Toolkit* (Levin, 1982), and *Iliad* (BBN Laboratories), allow students to explore language by playing with its syntax and semantics. *Interactive Toolkit*, for instance, contains a high-level language that redefines what the computer can do. Using it, a writer can create programs with new functions, for example, to provide templates to guide letter writing.

A host of language games are commercially available. For instance: *Crossword Magic* (Mindscape), allows teachers or students to create crossword puzzles. The activity encourages exploration of word meanings and relationships, as well as spelling. *Developing Tray* (Acornsoft) is a game based on the cloze procedure. Readers adopt predictive strategies in order to uncover a text in which all but the punctuation marks have been left out. *Adventurer* (Chelsea College, London) is a suite of programs which allow users to create their own text-based adventure games. *Talkback* (Acornsoft) is a version of *Eliza*, the simulation of a non-directive psychotherapist, in which the user can create his/her own bank of match-words and responses. It allows the user to make one computer "personality" have a conversation with another.

Sharples (1980, 1985), developed several programs, including *Gram*, which generates text using rewrite rules. Another program, *Tran*, allows students to write their own transformations using pattern action rules. Children learn characteristics of grammar through such programs, but more important, they develop a sense of the rule-governed aspect of language in general and develop their own ability to create and solve problems. Application of the programs to everyday composition needs to be explored.

EVALUATION

Very little of the existing software for teaching writing has undergone a formal evaluation. There are several reasons for this. Software changes rapidly so that new versions appear in less time than one could carry out an evaluation of the existing version. Publishers, and even governmental research agencies, are often more interested in the next product than in analyses of existing software. Adequate evaluations are difficult, time-consuming, and expensive. Many schools still do not have sufficient hardware for the necessary in situ studies. And, perhaps most importantly, new technology is never more than one component in a complex system that includes inter alia teachers, teacher training, existing curricula, school schedules and procedures, testing, and maintenance of equipment (Michaels, 198 , to be published; Michaels, Cazden and Bruce, 1985).

Nevertheless, there are promising initial studies. One example is the evaluation of *Quill* (D.C. Heath), which was carried out in 1982-83 (Bruce and Rubin, 1984b). It is presented here in some detail, both as an example study, and, because *Quill* represents a composite of features present in many other systems, i.e., the *Quill* evaluation can, with some qualification, be taken as representative of an evaluation of an approach to the use of information technologies in the teaching of writing, not just that of a particular piece of software.

Quill

Quill (D.C. Heath) is a set of microcomputer-based writing tools and writing environments. The software can be used for writing on any subject in grades two to twelve. Integrating reading and writing skills, *Quill* encourages students to create written products through planning, drafting, revising, and sharing.

There are four components of the *Quill* software: *Planner* helps a writer generate and organise ideas before writing begins *Writer's Assistant* (Levin, 1982) is an editing system that is accessible whenever students enter or revise text. *Library* is an information storage system that allows students to produce texts for other students to see, index them according to keywords, and retrieve them as one would information in an encyclopaedia. *Mailbag* is an electronic message system that encourages students to communicate via computer with the teacher, with other members of the class, or with students in other classrooms.

The *Quill* Teacher's Guide explains how to use the software and suggests activities that integrate *Quill* with instruction in language arts, science, social science and math. It also contains the "Cookbook", a series of lessons for introducing *Quill* and the writing process to a classroom. In addition, a detailed plan for training teachers to use *Quill* has been developed and field tested.

a) Quill and the Writing Process

Quill activities encompass the planning, composing, revising and publishing aspects of the writing process. Prewriting activities include the use of *Planner* to help children generate and organise ideas for composition. A teacher, for example, might hold a brainstorming session with his or her class to list categories relevant to a topic (e.g. reviews of popular games) and record the results in a *Planner* which students could use in developing their ideas for texts.

Reading, writing and spoken language are integrated throughout the prewriting stage. A child might create an interview form using *Planner* in order to conduct research on a topic. When the child is ready to plan a composition, *Planner* is used to formulate main ideas and details, structural organisation and point of view. Children are encouraged to work in small groups or pairs as they conduct their research and plan their compositions.

Students can compose and revise their drafts using a text editor, *Writer's Assistant*, which enables students to delete, add to, or rearrange their text easily. Children find revision more enjoyable and less tedious when the amount of recopying is reduced

Quill provides two types of communication environments, *Library* and *Mailbag*. *Library* is an environment in which children store their writing using the complete title of the piece (rather than a six letter file name), their full name, or names, if they work in pairs, and keywords, which tell what their writing is about. Students can create encyclopaedias of expository prose as well as collections of narratives or poetry. *Mailbag* is an environment in which children send electronic mail to others. It helps children realise the communicative function of written language. Messages can be sent in letter or memo form and can be addressed to pen-pals, to the teacher, to friends with secret code-names, to special interest groups, or to an electronic "bulletin board."

Revising, like planning and composing, can be a process of sharing. The *Quill* Teacher's Guide suggests ways to use drafts and planners as tools in writing conferences. *Library* and *Mailbag* encourage students to comment on one another's writing, so that revisions can be made that respond to audience reaction. Children can use a printer to produce copies of their texts to give to peers, teachers and parents. Having final copy that looks good and is correctly formatted encourages students to publish their work so others can read it.

b) Field Test Results

A field test of the *Quill* system was conducted in Massachusetts (a rural site), Connecticut (an inner-city site), and New Jersey (a suburban site) during the 1982 academic year. Students in the five field test classrooms ranged from third through fifth grade. Pretest and post-test writing samples of *Quill* classes and matched control classes were scored using a primary trait scoring system. This system measures the effectiveness of writing in terms of the primary goal or trait of the writing assignment. Though the quality of all the students' writing improved in the course of the year, the writing of students using *Quill* improved significantly more than that of students in the control classes in both expository and persuasive genres. Details of this field test can be found in Bruce and Rubin (1984a). A summary follows.

On an expository writing pretest in October of 1982, *Quill* students scored an average of 1.96 (on a scale of one to four), whereas students in control groups scored an average of 2.05. In May 1983, the same students took an expository writing post-test. *Quill* students scored 2.60 while control students scored 2.21. For each grade level (three, four and five) *Quill* students achieved statistically significant gains as well as gains above the conventional standard of 0.33 standard deviation (SD) units. In contrast, two of the control groups did not demonstrate either statistically-significant or benchmark (0.33 SD) gains.

Similar results were obtained for persuasive writing. *Quill* students progressed from 1.97 to 2.69 on the 1 to 4 scale. Control students on the other hand, progressed from 1.72 to 2.09.

A second analysis of the data demonstrated that for both persuasive and expository tests, the differences between post-test scores of *Quill* and control students groups were statistically significant in every case, while only one of the cases (third grade, expository) showed a significant difference on the pretest. Moreover, for four of the six cases the differences on the post-test were greater than the 0.33 standard deviation benchmark. Thus, the *Quill* and control groups had not differed at the beginning of the study, but the *Quill* group had superior scores at the end of the study.

Students aged nine to eleven who used *Quill* improved their ability to write well in two specific genres: exposition and persuasion. These genres are characteristically the types of writing required of students in post-elementary grades, as well as in post-secondary education. Improved ability in these areas addresses one of the most critical need areas in education.

The field test results indicate that the effects of *Quill* are educationally important. *Quill* has helped students to understand the purpose of an assignment, and to communicate their ideas effectively. Other evaluations of *Quill* have shown improvement in students' expressive writing as well (using a primary trait scoring method). In one study *Quill* students' post-test writing samples were almost twice as long as their pretest samples.

Teachers, administrators and parents of students using *Quill* all described marked changes in student attitudes towards writing, and improvement in specific skills and general writing ability. *Quill* students wrote more often, both in school and at home. Teachers observed students successfully applying rules of punctuation and capitalisation while at the computer. Teachers reported a greater tendency in students to revise their work.

Additionally, *Quill* students learned to use software tools modeled after real world applications. Familiarity with such tools contributes to computer literacy, perhaps more effectively than simple programming does.

Quill was approved for dissemination by the US Department of Education for grades three through five, but has been used with students of all ability levels in grades one through twelve. It is now in use in approximately 2 000 classrooms.

c) Limitations

There are, however, many unanswered questions. Results such as those described here reflect only one facet of learning to write. Many of the most intriguing effects could not be measured in such a design. For example, in some cases, revision occurred not just because the text editor facilitated the mechanical act of editing, but because *Quill* catalysed changes in the social organisation of writing, e.g. more collaboration (Bruce, Michaels and Watson-Gegeo, 1985). Moreover, in many school systems it would have been difficult to implement *Quill* as successfully as it was in the field test sites. Recent research is beginning to unravel some of these complexities.

One observation has been confirmed several times. The teacher makes the major difference between success and failure, whatever the success criterion used (Michaels, 1985, and to be published; Michaels, Cazden and Bruce, 1985; Rubin and Bruce, 1986). The construct of a *writing system*, which embodies the norms, beliefs and values surrounding the act of writing, is now being used to emphasize that information technologies are at most one piece of a large puzzle. Learning, in general, is a complex social act, and writing, in particular, must be viewed as the communicative, social act it is if we are to understand how to bring about change.

Writer's Assistant

Writer's Assistant (Interlearn), the text editor in *Quill*, was also evaluated independently. Again, this evaluation is limited, but it can be taken as one piece of data on how the use of text editors might affect writing.

Levin, Boruta and Vasconcellos (1982) worked with two classrooms, one using *Writer's Assistant* and one not. Students generated pre-computer-use and post-use samples of writing using pencil and paper. In the experimental (*Writer's Assistant*) class, there was a 64 per cent increase in writing sample length versus 4 per cent in the control class. On a four-point holistic scale, using blind ratings, the experimental group's scores increased from 2 to 3.09 after the four-month period of use of the text editor. The control group decreased slightly, from 2.27 to 2.24.

As in the case of the *Quill* evaluation, we believe these results should be viewed as tentative, but worth further exploration. We need to know how, when and why the use of information technologies aid growth in writing.

Writer's Workbench

The *Quill* and *Writer's Assistant* evaluations were done with children; a similar study was done at the university level at Colorado State University, using *Writer's Workbench*

(AT&T Bell Laboratories) (Frase, Kiefer, Smith and Fox, in press). The results in this study did not reveal statistically significant differences in writing gains between the control and experimental groups, because all the students showed significant gains in writing. There were, however, several other positive findings. Students who used the computer were reported to have a more positive attitude about writing: they progressed more rapidly; and they averaged one more revision on each paper. Teachers found grading and responding to papers easier because of uniform formatting and typing. Perhaps most importantly, students began to look at their writing in a new way, asking questions they never asked before. Frase *et al.* suggest that these indirect consequences of using a computer may be as important as the direct effects.

Chapter 3

PROMISING AREAS OF RESEARCH AND PROTOTYPE DEVELOPMENT

Here we discuss basic research that is necessary in order to use new information technologies effectively. This discussion is organised around six major categories of their impact on the teaching of writing: *i)* as tools for composition (most of the software examples in Chapter 2 fall into this category); *ii)* to create environments for communication; *iii)* to enable language exploration; *iv)* as writing tutors; *v)* to improve our understanding of the writing process; and *vi)* as they create a need to redefine writing and writing instruction.

NEW TOOLS FOR COMPOSITION

One approach to using information technologies for writing instruction is to remove the emphasis from the teaching component and instead provide computer-based tools that can assist the writing process. Toolkits are becoming commonplace in the business and academic world, and the task is to adapt and develop them for more general use. The maxim is: Beginners Need Powerful Systems. Learners have just as wide a range of problems to solve as experts, but they are less skillful at presenting their needs clearly and unambiguously Consequently, the computer system should not only offer powerful problem solving and writing aids; it should also be helpful, able to deal with errors such as spelling mistakes, and capable of explaining its actions.

When computer toolkits are used to aid writing, they function both as facilitators of writing and as devices to enhance the learning of writing. We have identified several characteristics of such a toolkit, which builds on current technology (see Chapter 2), and could lead to immediately useful computer-based writing tools.

Composition Assistant

In recent years there has been a spate of projects to develop computer systems to assist writers in the production of conventional articles and books, or to create "electronic media" such as databases, text file systems, and on-line encyclopaedias. Many such projects were discussed in Chapter 2 (for useful overviews, see also Meyrowitz and van Dam, 1982; or Yankelovich, Meyrowitz and van Dam, 1985). Although powerful systems already exist in some forms, the research in this area is still in an early stage.

This work is leading toward a general purpose *Composition Assistant*, which would offer help throughout the writing task. It would allow writers to work at the idea level, sorting ideas into categories and then arranging them into a pictorial "concept map". This map would then serve as a guide to the writer, who could specify further constraints, of style and layout, to the system. The system would then monitor the text as it was being typed, to ensure the constraints were satisfied It might perform many of the functions of a proofreader, correcting spelling, tidying headings, references and quotations into a consistent format, and indicating repetitions.

The system would also offer a writer the opportunity to specify the presentation of the document, either by giving layout directions or by directly manipulating chunks of text on the screen. It would also have a stock of pre-defined layout formats – headings, column widths, typefaces etc. – for particular applications.

Because writers often need to collaborate, the *Composition Assistant* would include aids for commenting on another's text. As with *Notecards* (Xerox), authors could make marginal notes, give reasons for changes, ask questions, and suggest alternatives. There would also be multiple representations of the same text: as a network of paragraphs, as a set of headings, as a collection of ideas linked to actual text passages, and so on.

It is important to consider not only the quality of the authoring tools, but also how these tools relate to one another. At one extreme there might be a number of applications packages, one each for creating text, diagrams, tables, etc.; the final document would then be pieced together from the product of each package. At the other extreme is a fully-integrated system. As the author moved to a diagram within the document, picture editing functions would be available, moving to a table would activate table editing functions, and so forth. New techniques of "object-oriented programming", in which each element (a sentence, a table, a diagram) is an active object with its own rules of style and presentation, offer the best means of designing such an integrated environment.

Aids for Special Needs

Computer-based writing tools could address special needs in several categories: adult illiteracy; hearing impairment; survival writing. Some programs have already been written primarily for the disabled. The *Iliad* program is aimed at deaf children, as is a suite of programs from Hull University (Ward, Sewell, Rostron and Phillips, 1983). The term "survival writing" is used to describe those types of writing needed to get by in a literate society: filling in tax forms, applications, and surveys; writing job applications and reports etc. If the content of the document is sufficiently circumscribed then a program might offer advice not only on grammar and style but also on content. Such "expert systems" are already under development, for example to assist with welfare benefit claims and tax forms; they could be extended to other areas of expertise. Expert systems are, however, costly to develop, requiring detailed analysis of users' skills and knowledge.

Major research issues concerning the computer as a tool for composition include:

- Analysis of how such tools can best be integrated with other classroom activities;
- Exploration of developmental trends in the use of such tools;
- Assessment of the social, cognitive, and communicative consequences of the use of such tools.

NEW ENVIRONMENTS FOR COMMUNICATION

Electronic mail systems already span the world and the links between sections of an electronic book could be similarly stretched. Systems are now under development that allow multi-media messaging and conferencing; users have the capability to send not just text, but images, graphics, spread sheets, voice and ultimately video (e.g. the *Diamond* system at BBN Laboratories (Thomas, Forsdick, Crowley, Robertson, Schaa., Tomlinson and Travers, 1985). We know little today of the full possibilities of such systems for enhancing communication.

International co-authorship and readership bring both possibilities and problems, arising from differences in technology, language, and culture.

A priority for the future is to ensure compatibility between electronic mail systems, so that mail transactions can be made as swiftly and efficiently as telephone calls. As for the language barrier, machine translation systems are already in daily use, for example in translating documents produced for the EEC. They are not particularly effective and require a human to tidy up the grammar of the resulting text, but they may be sufficient for international electronic mail. Simpler aids, such as on-line multilingual dictionaries would also help communication across borders.

A step toward overcoming the greatest barriers, those of culture and race, can be made by regular, useful, communication between people. An exciting development is the "electronic newspaper". This has no publisher, printer, nor editor. Contributors send in items under specific headings by electronic mail to a central computer which automatically collates them and distributes to subscribing machines. Such "Newsnets" could be extended to link and inform people with common interests, regardless of nationality.

Even among the community of researchers and teachers who have been interested in information technologies and writing, the importance of communication environments has been underestimated. Much of the work to date has been on text production. Research is needed to explore how technologies can enhance sharing of those texts with real audiences.

NEW WAYS TO EXPLORE LANGUAGE

The preceding chapter showed how students can use existing information technologies to discover aspects of language. Language exploration software is still rudimentary, lacking adequate documentation, project material, and the presentation necessary for general distribution, but is a promising area of development. A language exploration package could allow a learner to discover the patterns and processes of writing, to improve his idea gathering and planning abilities, and to extend his repertoire of writing styles and techniques.

Recent research (Flower and Hayes, 1981; Gregg and Steinberg, 1980; Scardamalia, 1981) stresses writing as a cognitive process, open to conscious inspection and control. A general awareness of thought and language is necessary, but not sufficient. The child, or adult, also needs to understand the particular processes of writing, the patterns and forms of language and the relationship between writer and reader. From the research perspective, there is still much to be learned about these patterns and forms.

Some language exploration programs, such as the *Interactive Toolkit* (Levin, 1982) and *Iliad* (Bates, Beinashowitz, Ingria and Wilson, 1981) are complete packages. Others are extensions of LOGO. The LOGO programming language (Feurzeig and Papert, 1969; Feurzeig, Papert, Bloom, Grant and Solomon, 1969) and "turtle geometry" (using LOGO to command a "turtle" – a small motorised cart – to draw shapes) has been successful, with appropriate environmental support, in enabling children to explore shape, space and direction and to learn the skills of modelling and problem solving. We need an equivalent "turtle geometry for language", that could help children to understand the forms and processes of writing. *Phrasebooks* and *Boxes* (Sharples, 1985) are two additions to LOGO that that allow children to classify words, create their own dictionaries and phrasebooks, devise a quiz, write a program that will converse in natural language or build their own "Adventure Games".

Over the past decade computer programs have been written to reproduce many aspects of language production and comprehension – generative grammars, parsers, translation systems, information retrieval systems – and some of these are now being adapted for use by learners. They offer an environment for creating generative grammars, looking at patterns in language, exploring the bounds of meaning and syntax and understanding the process of idea creation and planning.

Language exploration need not be confined to exercises designed to shape well-understood skills. For instance, a common practice in language instruction is to have students copy the writing styles of expert writers. With tools that now exist, some feedback could be given to students, by computer, on features of experts' writing that are missing from their writing. Such activities could be the basis for group interaction and problem solving in the classroom.

Important research issues concerning language exploration include:

- What skills should be targets for language exploration tools;
- How computer-based language exploration can be integrated into classroom activities;
- How general algorithms for educational activities can be developed for use in new educational software.

NEW WAYS TO TUTOR WRITING

One part of learning to write is the development of procedural skills: procedures for spelling, punctuation, style, organisation and presentation. Some of the current writing software is designed to teach these skills explicitly, but the programs are severely limited by a lack of knowledge about writing and the student. Recent research in Artificial Intelligence and Intelligent Tutoring Systems has addressed such issues (cf. research on arithmetic and algebraic procedures discussed in the report on mathematics).

The first requirement of an Intelligent Tutoring System for any task is that it should have some ability to perform, or at least discuss articulately, the task in hand. This demands explicit knowledge of the task. Thus, a spelling tutor should be able to correct misspellings and to identify them as instances of general spelling rules. Two other important requirements are a knowledge of teaching methods and representation of the student's current knowledge, so that opportunities can be seized to teach in the most appropriate way and to diagnose misconceptions.

Providing an Intelligent Tutoring System (ITS) for rule-governed aspects of writing is a difficult problem. Not surprisingly, little of the software reviewed in Chapter 2 fits in the ITS category. Nevertheless, the problem appears tractable in principle. One ITS is *Iliad* (Bates *et al.*, 1981). It contains a sentence generator which is capable of syntactic variations of a core sentence. For example, from the sentence "John ate the apple"; *Iliad* might generate:

Did John eat the apple?
What did John eat?
Who ate the apple?, etc.

The tutoring component asks the child to carry out similar transformations and comments on the result.

Iliad could be extended to allow children to design their own transformation rules, either using a simple grammar notation, or by using example. Thus a child might propose:

Which apple did John eat?

as a new transformation of "John ate the apple" and then test it on other sentences The child might type "Mary sees the cat" and the system would use the rule to produce "Which cat did Mary see?".

The process of writing calls for procedures far beyond the following of grammatical rules. But the criteria for these procedures are, unlike those for subtraction or algebra, partly subjective. An important research issue thus emerges. Can Intelligent Tutoring Systems, which have shown such promise in domains like mathematics and science, be applied in teaching aspects of writing? Or does the act of writing differ fundamentally from these other areas?

To begin with, it is by no means clear that tutorial systems are appropriate for all students. Many adults prefer to learn on their own, and they have the skills to acquire and use scattered resources such as might be found, for instance, in a general database. In addition, the cost of developing tutorial instruction is high. Finally, there are many things we don't understand about subject matter. Hence, we see three important research issues concerning tutoring systems:

- Description of the student populations for which tutorial instruction is most effective;
- Analysis of the costs and benefits of tutorial and other forms of computer instruction;
- Description of the subject matter domains for which tutorial instruction is most suitable.

USING INFORMATION TECHNOLOGIES TO IMPROVE OUR UNDERSTANDING OF THE WRITING PROCESS

New information technologies can assist the teaching of writing, the exploration of language and the act of writing. Each of these functions merits serious consideration from researchers, practitioners, and policy makers. But there is a fourth function, which may have an equally significant impact. That is, technologies can be used as a window into the writing process itself, thereby revealing the thinking and learning that occur in the act of writing.

Despite extensive research on writing in recent years (Frederiksen and Dominic, 1981; Graves, 1981; Hillocks, 1986; Whiteman, 1981), we still know too little about how writers generate ideas, how they revise, how they use what they have read in writing, or how their writing changes over time. One reason is that many such processes take place in the writer's head, and external manifestations, such as pauses, backtracking, use of resources, oral interactions with others and so on are difficult to record or quantify.

When writers produce and store text on the computer, writing processes can be examined in new ways. Some text editors already offer a "replay" facility which re-enacts an entire editing session allowing student and teacher to see the process of text creation. The *Writer's Workbench* described above, not only assists with writing, but also offers detailed analysis of any text, giving a rich picture of the writer's use of language. *Pain* (1985, Thesis Edinburgh University) not only corrects spelling errors, but also gives a profile of the types of error: phonetic, letter transposition, etc. It would be possible to design a program that detects linguistic features, such as word repetition, ambiguity, inversion or ellipsis, and produces an analysis that partially unveils the writer's thinking processes.

Research on the writing process with information technologies involves:

- Developing profiles of types of student writing;
- Developing methods for giving feedback to students during the writing process.

A REDEFINITION OF WRITING AND WRITING INSTRUCTION

Information technologies are rapidly becoming essential for writing outside of schools Many people now use text editors, formatters, and computer message systems. The advent of multi-media messaging, low-cost random-access mass storage devices, "idea processors", hypertext, and other such devices will change writing further. We need to ask, not only whether technologies are appropriate for teaching writing, but whether their very presence in the adult writer's world is a cause for rethinking the writing curriculum.

Ten years from today, will we say someone is accomplished in his writing skills if he cannot use a word processor? Will such a person be able to engage in writing in the workplace if he cannot read and write electronic mail? Will the boundaries between thinking, reading, writing, and even programming become fuzzy as more and more powerful computers are used for a greater variety of problem solving tasks (see Bruce, in press)? Such questions are difficult to answer today, but they deserve consideration. Research is needed to redefine what we will be forced to mean when we discuss literacy in the future.

New Forms of Text

Increasingly, computer-based writing is never published as words on a printed page. Electronic mail, on-line documentation, and "electronic encyclopaedias" are read directly from a video screen. The computer is a new communications medium, and we have only just begun to discover its possibilities. Computers are well-suited to creating "connectivity": webs of related information. An author can easily make explicit connections, or links, allowing readers to travel from one document to another (as one does with an encyclopaedia) or from one place within a document to another. The computer can help a reader to follow trails of cross-reference without losing the original context. Electronic document systems also facilitate co-authoring of text. A group of children, for example, can create a common electronic notebook, by creating their own contributions, viewing and editing one another's items, then linking the items together.

Ideally, authors and readers should be given the same set of integrated tools to create, browse and develop text. They would be able to move through material created by other people, add their own links and annotations, and merge the material with their own writings. In consequence, the boundaries between author and reader could largely disappear Research is needed to understand these changes and the consequences they have for writing instruction.

Chapter 4

IMPLICATIONS FOR INSTRUCTIONAL PRACTICE

We are still at the beginning of the two major educational changes mentioned in the Introduction, namely the revolution in the use of information technologies in education and the revolution in the teaching of writing. If present trends continue we will see dramatically different classrooms in the next generation (Bruce, in press). But detailing these changes is not an easy task.

Bad, as well as good, effects of the two revolutions are already evident. First, inequities in access and use of technologies are widespread (Michaels, Cazden and Bruce, 1985). Second, contradictions in the current trends have appeared: information technologies seem to foster simultaneously more controlled and more open instructional practices. The same program may be used in different settings to achieve diametrically opposed objectives. As if mixed outcomes and contradictory applications were not enough to confound the futurist, there is another source of uncertainty that must be considered: researchers, teachers, administrators, software developers, publishers, and policy makers are active agents in these changes. What we all do today will influence tremendously what happens (we hesitate to say "determine" because these changes are also affected by forces well outside the educational realm).

We consider here a few of the implications these changes have for instructional practice, focusing on those areas in which appropriate actions today can make a significant difference to future educational outcomes.

Tools for Composition

Information technologies facilitate almost every aspect of the writing process (see Chapters 2 and 3). Because they make writing easier, they can help in motivating students or in assisting the teacher to focus where help is needed most.

Using word processors, students produce text that can be read more easily. The printed format can provide confidence for students. It also means that the text can be read by a variety of readers and that handwriting does not influence the grading of content and structure. The text editing function allows corrections to be made easily without decreasing the readability of the text. Students with reading and writing disabilities can also produce texts more easily than before. The computer can check spelling and even wording.

These functions are already changing the way writing is done outside the school. They can also produce changes in both writing and writing instruction within the school.

The possibilities for exploiting information technologies as tools for composition depend to a large extent on the teaching strategy. If pupils write compositions only on assigned topics, and instruction is based on the teacher's corrections and notes, a word processing program is beneficial only with regard to surface features, such as grammatical correctness or spelling. If, on the other hand, teaching emphasizes the writing process and includes brainstorming, planning, searching for data, and revising the text, as well as feedback from the teacher and classmates, information technologies provide possibilities for quite different kinds of work.

Environments for Communication

New forms of writing, such as electronic mail and hypertext, are already entering the school context; preliminary findings are that these new forms of writing, such as electronic mail and hypertext, can facilitate learning to write (Bruce and Rubin, 1984a) and learning other subjects through writing (Cohen and Miyake, 1986). It is important today to look at how new communication environments, which are already entering the schools, affect school writing.

Language as a World to Explore

In various areas of science and mathematics, computer-based microworlds have been developed. These allow students to explore new domains, testing out hypotheses, constructing models, and discovering new phenomena. Technologies can also be used to create analogous microworlds for language. Investigations of such microworlds can be highly motivating for students, but just as important, they cause students to think seriously about concepts such as language patterns, conceptual relationships, and the structure of ideas. We are at only the beginning of this potentially powerful mode of using information technologies for language instruction.

Intelligent Tutoring Systems

Similarly, intelligent tutoring systems have until now been applied primarily in areas of science and mathematics. As computers become more powerful, as storage of large amounts of text becomes more feasible, and as we learn more about how to use technologies for teaching, we should see greater use of intelligent tutoring systems in writing. Systems that embody expert models of the writing process, for example, have been proposed. Also, we should soon see systems that integrate tutoring functions with computer tools and communication environments.

Understanding the Writing Process

Over the last twenty years, work on artificial intelligence, including the development of computer systems capable of common sense reasoning and the use of natural language, has had a major impact on studies of human thinking and learning. The shift in perspective brought about by artificial intelligence approaches has been more significant than the specific programs that have been produced. In the area of writing, for example, work in artificial intelligence and related cognitive science areas has led to a deeper understanding of the essential planning processes in composition.

Computer systems have thus served as models for the human activity of writing. They also serve as laboratory tools in the sense that they help make previously invisible processes visible. When a writer uses computer tools for writing, a trace can be generated that is henceforth available for inspection by the writer, a teacher, or a peer. The trace can reveal problems in writing or help to improve the writer's awareness and control of her own processes. The revelatory function of information technologies is just beginning to be understood and utilised. Together with the modelling function growing from artificial intelligence related work, it has the potential to improve greatly our understanding of the writing process.

New Conceptions of Writing and Writing Instruction

The use of computers should promote the attainment of the general goals of school education. Writing instruction is critical because it is often through writing that the student develops a world concept as he or she combines information obtained from different texts, from experience and from discussions.

In general, there is too little time in school for discussion, argumentation, and development of the students' thoughts and conceptions. In the current practice of the teaching of writing, attention is often focussed only on practising sub-skills of writing and not on the actual meanings that are conveyed in the writing. Similarly, in the teaching of other subjects, attention is frequently focussed only on the correctness of the students' answer. In order to avoid this, we need integration across the curriculum. Writing instruction, utilising information technologies, such as computer data bases, intercultural networks, hypertexts, and so on, could act as an integrative factor between subject areas. It would help to focus students' attention on the content and purpose of their writing by facilitating access to texts and communication with responsive audiences.

The use of new technologies affects not only teaching methods, but also content and objectives. The extensive adoption of word processing and other new technologies will change written communication, the writing process, and the handling of documents. Writing instruction should take these changes into account, including the question of how instruction can prepare students to cope effectively with the demands of the information society.

Applying New Information Technologies

Research in the area of gender differences in learning shows that, in general, girls excel at verbal tasks, and boys, at spatial problem-solving, and now, in using computers. There is some evidence that learning to write with a computer (Cameron, 1985; Linn, 1984; Michaels, Cazden and Bruce, 1985), might attenuate these traditional differences; that is, girls who use a word processing program become more motivated to write when they can use a computer to do so.

This is but one example of the way the use of information technologies may have an impact far beyond simple improvement of learning in a given subject area. Research has noted greater collaboration with other students and improved motivation, especially for the disaffected learner (Bruce, Michaels and Watson-Gegeo, 1985; Rubin and Bruce, 1986).

It is fair to say, though, that at this point we simply do not yet know the full effects of applying information technologies in the teaching of writing. We do know that attention must be paid to the context of application, e.g. to teacher training, follow-up, on-going support, maintenance of equipment, administrative policies, testing, integration with existing curricula, language differences, scheduling and many other factors that influence successful use (Loucks-Horsley and Hergert, 1985; Michaels, 1985a, 1985b, in press; Michaels Cazden and Bruce, 1985; Rubin and Bruce, 1986).

RECOMMENDATIONS

Many of the recommendations of the Working Group on Writing pertain to the use of new information technologies in education in general. These are covered in the general report (cf. Part One of the present volume). Here, we detail those recommendations that apply specifically to their use for writing instruction. Because we are still in the early stages of this work, several of our recommendations call for further research on their applications.

In the area of writing, the best documented, most effective current use of information technologies is as tools for composition, specifically, tools for getting ideas, organising thoughts, composing, editing and revising text, and obtaining feedback about one's writing. A second use, of growing importance, is the establishment through information technologies of new communication environments (e.g. electronic mail systems) Uses of information technologies to create microworlds for language exploration or intelligent tutoring systems for writing are just beginning to be developed, but hold great promise for the future

The pedagogically effective development of information technologies for the uses just outlined requires three types of research. The first is research on the writing process, with and without the aid of technologies. We must build upon what we know of the cognitive and social factors involved in composition. In this way, the design of technologies for writing instruction benefits from basic writing research. At the same time, they provide us with a window into the process by making writing events visible and analysable.

The second type of research needed is on the design of better technological systems for use in writing instruction. The level of technology available today for business, industrial, medical, scientific, and military applications far exceeds what is available to schools, even in the most advanced OECD countries. Some of this disparity results from short-term cost considerations alone, but much can be attributed to inadequate visions of whether and how to use information technologies for teaching. Research is needed on developing cost-effective information technologies applications suited to the educational setting. We need exemplary prototypes that can be studied and adapted for use in new settings, and tools for instructional designers to use in developing new programs.

Third, we need research that brings together studies of the acquisition of writing skills with research and development of information technologies for instruction in writing Specifically, we need a better understanding of how they can be introduced into classrooms or laboratory settings, how teachers should be trained, what sorts of support are needed to achieve success, how the social organisation of the classroom changes, how computer expertise in students develops, and what are the negative effects of introducing new technologies

In addition to research and development of improved methods of teaching writing based on technologies, we need better means of communicating what is being learned. There should be expanded use of electronic networks for exchange of research reports and computer programs, and for collective problem solving. Such networking should also be extended to student use, for the possibilities of enhancing writing through the use of such systems seem immense. There should also be demonstration and evaluation centers at which software and other technologies can be compared, where results from different countries can be evaluated, and where long-term development efforts can take place with the collaboration of researchers, software designers, and teachers from different countries. International centers of this sort would also facilitate exchange among countries with very different experiences and levels of development in the use of information technologies in writing instruction.

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III. SCIENTIFIC AND TECHNOLOGICAL CONCEPTS

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Introduction

To deal properly with the influence new information technologies could have on the learning of scientific and technological concepts, the Working Group had to consider not only the learning of concepts, but also the learning of: procedures (skills and processes) by which concepts are built; facts (empirical data) which the concepts help to organize; and values, according to which the concepts, procedures, and facts are evaluated. This report deals not only with learning about established theories and existing technology but also with learning the processes of theory-building and design.

ISSUES IN SCIENCE AND TECHNOLOGY EDUCATION

Science and technology have affected every aspect of our lives and have become critical components of a modern education in both developed and developing countries. We need well-educated citizens not only to continue scientific and technological activity, but to understand, evaluate, and direct that activity. Rapid development has created new educational issues and left old issues unresolved. Some of the issues that technology might help to resolve are described in this section.

Issues Concerning Students

Students face difficult choices in planning their secondary school programmes. Obtaining the best balance of courses in science, technology and other subjects is not always possible, given the separate requirements of vocational and academic programmes.

While some students are very successful at mastering the concepts, facts, and procedures taught in secondary school science, others experience frustration and lack of success. Motivation and interest vary widely among students. Not all are willing to make the sustained effort to understand scientific concepts and to develop skills in reasoning, problem-solving, and experimentation. In subtle ways, education often works better for boys than for girls. This is particularly the case in science and mathematics. Lower participation rates of girls in technological studies, science, and mathematics is of great concern.

Issues Concerning Teachers

Ongoing professional development is needed to help teachers deal with rapid changes in subject matter, instrumentation, and experimental technique, and to deal with changes in student attitudes and societal values. Furthermore, in some countries such as the USA, there are shortages of well-qualified teachers. In sparsely populated areas it is difficult to provide a full programme of courses offered by specialists in each field.

The careful development of concepts and processes is a great challenge for teachers. Teachers must not only explain concepts well, but must help students bridge the gap between their own theories about nature and the theories they are taught.

Teachers wishing to change the content of their courses or to increase the emphasis on concepts and processes sometimes meet with opposition from students who simply want to know the facts or from colleagues who will have to teach the students in the following year. For example, at the end of a year in which extensive use had been made of computers, a student asked his teacher, "Will we be allowed to think like this next year?"

Curriculum Issues

Because science and technology are progressing rapidly on many fronts, it is difficult for school courses to reflect current developments. It will not be enough to continue to revise curricula every five to ten years. More flexibility is needed in curriculum development and implementation. There is also a need to shift from teaching established results to teaching concepts, processes, and values.

Giving students the opportunity to articulate and test their own theories, to create their own designs, and to work individually or in small groups at their own pace is commonly accepted as an effective mode of learning in science and technology. Accommodating this form of individualization creates major problems in the organisation of instruction and facilities.

The separation of technology from science in education is ingrained in public schooling by the separation of academic and technical streams at the secondary level. Few students in the academic stream take technical courses either because there is no room in the programme of elective courses, or the students view the courses as intellectually and socially unattractive. The same separation exists in teacher education programmes.

Implementation Issues

It is desirable not only that students of science and technology work with ideas from both those fields but that they use the tools of science and technology in the same way professionals do. Upgrading facilities and equipment is a complex problem. Schools are expected to provide resources which are inexpensive, versatile, durable, safe, easy to use, motivating, and up to date. It is hoped that the large-scale introduction of the new information technologies will help meet these severe constraints.

THE POSSIBILITIES AFFORDED BY INFORMATION TECHNOLOGIES

We are now in the Information Age. A debate has been going on for a quarter of a century on how the tools of that age should be used to address the problems of education. Extensive use is made of computers for educational administration and for instruction in specialized areas such as business studies and computer science. The cost-effectiveness of computers for training in business and industry has been proven, but it is still far too early to assess the cost-effectiveness of computer instruction in the public schools.

The benefits of using information technologies appear to be non-economic. The computer offers possibilities for greater flexibility in the curriculum, for keeping courses up to date, for increased individualization, for improved motivation, for gaining a deeper understanding of the concepts and processes of science, and for developing the self-esteem of students.

There are now many examples of courseware at all levels of education for learning about science and technology. The following examples provide a quick tour, although there are other examples of high quality courseware in Canada, the United Kingdom and Japan, among other places:

- For young children, the series *Mademoiselle Merveille* (Canada) introduces the basic concepts of the world around them;
- For elementary schools, *The Voyage of the Mimi* (United States) develops similar concepts using a widely varied environment (microcomputer, film, book). A range of microworlds is available for explaining various simple concepts
- For secondary schools, a best-seller like *Rocky's Boots* (United States) is an effective method of teaching the somewhat complex concepts of logic circuits; other courseware exploits the possibilities of databases or certain educational games, such as *People Pyramid* and *Dirigible* in Australia and other interesting examples in the United Kingdom and France. The programming language LOGO is widely known and has been used as a learning environment in many elementary and a very few secondary schools, particularly in relation to mathematics and problem-solving and to introduce students to using the computer;
- In higher education, the very successful *Physics Courses* of the Open University (United Kingdom) and the Educational Technology Center at the University of California, Irvine (United States) use tutorials, exercises, problem-solving activities and a wide range of simulations. They are now becoming available on microcomputers;
- In the laboratory and workshop, *Microcomputer Based Instrumentation* (MBI) has extensive and cost-effective applications in fields ranging from gas chromatography to Computer-Assisted Design and Manufacture (CAD/CAM) using instruments which, although not highly accurate, demonstrate all the basic principles (e.g. some of the products of British manufacturers or the Conservatoire National des Arts et Métiers, France);
- In the information technology, chemical and biological industries in most industrialised countries, and particularly in Japan, Computer-Assisted Training is considered cost-effective in such areas as the operation and use of a microprocessor, chemical analysis by nuclear para-magnetic resonance, and genetic engineering A steelworks that switched over to special steels considers that the success of this operation was due to the use of Computer-Based Training (using videodiscs with a considerable saving compared with traditional methods of training);
- For pilots and astronauts, training involves the use of extremely sophisticated simulation of the complete working environment including instrumentation, view, and movement.

At all levels, there is a place for Intelligent Tutoring Systems (ITS), which provide individualised instruction based on recent developments in cognitive science brought about by the use of these very technologies (mainly in the US, although some development has been done in Japan and Europe, i.e. the United Kingdom, Germany, France and the Netherlands).

Educators will have to work out a new balance of roles for themselves and for the computer – teacher as instructor, teacher as guide and collaborator, computer as instructor, computer as tool. It is not clear what that new balance will be or how it will be worked out; it is inevitable that the balance will change.

We now have enough experience to assess the potential of new information technologies in science and technology education. Much research, development, and evaluation is needed in the immediate future. The aim of this report is to provide the background and direction for that activity.

Chapter 1

SCIENCE AND TECHNOLOGY EDUCATION

This chapter serves as background for the parts which follow and describes the nature of science and technology and the aims of education in science and technology of various countries, and comments on the current curriculum, teaching resources, and the problem of gender differences

THE NATURE OF SCIENCE AND TECHNOLOGY

Science and technology reflect the human capacities for rational thought and technical production. Through the capacity for rational thought, our curiosity has driven us to increase our knowledge of our environment and ourselves. Through the capacity for technical production, our desire to improve the quality of life has driven us to change our environment for our own benefit. Science and technology are intricately interwoven; both are concerned with human purpose and human benefit; both are concerned with solving problems through a combination of imagination, experiment and logical reasoning; both involve doing as well as knowing; both have led to changes in our physical environment, our social and economic life, our work, our leisure, and our beliefs; both shape our world view.

We are slowly beginning to realise that science and technology are themselves a part of nature:

> In our society, with its wide spectrum of cognitive techniques, science occupies a peculiar position, that of a poetical interrogation of nature, in the etymological sense that the poet is a "maker", active, manipulating and exploring. Moreover, science is now capable of respecting the nature it investigates. Out of the dialogue with nature initiated by classical science, with its view of nature as an automaton, has grown a quite different view in which the activity of questioning nature is part of its intrinsic activity. (Prigogine and Stengers, 1984, p.301).

We need new ecological values for judging science and technology. The application of science and technology in this century to agriculture, manufacturing, nuclear power and aid to third-world countries has had highly undesirable and unpredicted consequences: loss of soil nutrients, pollution of water tables, radiation from nuclear accidents, and increased dependency of those whom we wanted to help. These developments were based on means-ends analysis rather than on ecological considerations. Education is needed, not only to continue scientific and technological development, but to create and maintain a knowledgeable citizenry that can evaluate and direct its science and technology wisely.

The new science of the mind, cognitive science, and the computer are finding their way into education. In adapting them to education and in adapting education itself we need to respect the full essence of the mind and not merely those aspects of it which we can now model computationally. Nowhere do we see nature questioning itself more clearly than in the study of the mind. The answers it finds must support a pedagogy which respects the individual in trying to make sense of the world both individually and in collaboration with others.

Scientific Knowledge

It is important for science educators to distinguish the various forms of scientific knowledge: concepts, by which data are organised, and from which theories are built; processes, skills or procedures, including forms of argument: data, facts, or empirical knowledge; and values by which the correctness and appropriateness of the other forms of knowledge are judged.

a) Concepts

Scientists make use of a small number of basic concepts having wide applicability. The following examples are drawn primarily from the physical and natural sciences:

Systems:	Atom, Molecule, Organelle, Cell, Tissue, Organ, Organism, Population, Community, Ecosystem
Processes:	Exchange, Interaction-at-a-distance, Deformation, Transport, Optimisation, Adaptation, Evolution, Bifurcation
Relationships:	Conservation, Invariance, Linearity, Non-linearity, Constraint, Symmetry, Equilibrium, Randomness
Variables:	Position, Time, Momentum, Energy, Temperature, Pressure, Density, Concentration, Entropy, Information, Population, Spectrum, Phase, Mass, Charge

Similar lists, organised according to various schemes, appear in curriculum documents. For example: Life, Energy, Matter, Earth, Space.

b) Processes

If students are to understand science, they need to develop relevant processes, or general skills. In broad terms, the processes relevant to science and technology education are·

- Communicating;
- Formulating questions;
- Experimenting;
- Collecting data;
- Generating knowledge;
- Evaluating.

As part of an activity/thinking approach to the curriculum, the development of processes can not only enhance the acquisition of scientific concepts, it can lead to further refinement of the processes themselves. For example, the student who collects data about the number of people passing a certain point and then draws a graph to illustrate the data, is using his/her communication skills in a particular content area of the science and technology curriculum, say "movement of people in society". It is through such examples that processes are seen to be just as important as concepts as goals of science and technology education.

c) Values

Science has well-established values by which the validity and appropriateness of its concepts, procedures, and data are judged. Criteria of validity include reproducibility and refutability. Criteria of appropriateness include simplicity and correctness More subtle values have to do with what questions are interesting to pursue, for what research funding should be sought, and what concern should be given to the consequences of applying the knowledge obtained. Important ethical considerations are brought into play when scientists compete for scarce resources or the glory of being the first to make a discovery, or when the investigation entails extensive exploitation of natural or human resources, or the use of animal or human subjects.

Scientific Theories

Much science teaching reflects a view of science as a highly-organised body of established facts and procedures. There is plenty of evidence to support this view. Science textbooks are full of laws, mathematical equations, definitions, classifications and facts, reported in charts, graphs, and text. By contrast, in much scientific research science may be seen in less formal terms. In the constructivist view, the process of creating theories is a natural process by which all human beings make sense of the world and learn to function in it. Even new-born babies create theories: in the development of the concept of "object", for example, and later in the development of language. Science evolved from this natural process by making the theories explicit.

It seems reasonable, therefore, to help students become scientists by asking them, equipped perhaps with appropriate computer tools, to create and study hypothetical worlds: for example, a universe in which gravity is not quite an inverse square force or a world like in *Mr. Tomkin's Stories* (Gamow, 1950), in which quantum and relativistic phenomena are part of everyday experience. Through practice in exploring competing theories as scientists do, students can begin to express their own ideas and subject them to scientific scrutiny.

The Role of Intuition

Developing scientific theories is not only a matter of applying accepted forms of reasoning and judgement to systematically gathered data. Intuition and insight, which are not well understood, are of great importance. Intuition seems to be at work in selecting which of several hypotheses to investigate, in solving problems for which algorithms are not known, for working through unusually complex arguments, and for imagining the behaviour of a system under various conditions. The thought experiments which scientists often carry out to exercise and test their intuition can now be carried out through computer simulations, an exciting development for science education.

Links with Other Disciplines

Science has always had a strong link with mathematics. Much of mathematics has developed to meet the needs of science for expressing relationships, for building conceptual models, for predictive calculation, and for the analysis of data. Most developments, even in pure mathematics, have found their way eventually into science. Programmable calculators and computers have made it possible for scientists to perform complicated calculations without having to learn explicit techniques. This has also eliminated the need to base calculations on over-simplified mathematical expressions. The qualitative features of complex systems governed by non-linear relationships can thus be explored computationally by students who have access to appropriate software. This computational power should be a great boon to students who feel a lack of confidence in dealing with mathematics.

The concept of science is progressively being broadened to include a wide range of disciplines which use the same methods of reasoning and confirmation, the same techniques of modelling and calcula. ι or the same methods of processing information. Progress in disciplines such as geography, history, psychology, sociology or economics depends on the scientific abilities of their practitioners. For example, the use of mathematical models in economics has made skills in mathematics and the use of computers a normal part of university training in economics.

AIMS OF EDUCATION IN SCIENCE AND TECHNOLOGY

The air s of education in science and technology reflect concerns for a scientifically and technologically literate society, for social and economic development, and for the preparation of men and women who will use the science and technology of today wisely and who will shape it for the future. It is desirable that as many people as possible be educated to appreciate and evaluate the impact of science and technology and to understand and enjoy life more fully as a result of their education. The aims and objectives of science education have been listed frequently, in various forms. At a United Nations Conference on "Science and Technology for Development" held in 1979, the main implications envisaged for education, if science and technology w e to play their full role in national development, were given as: *i)* emphasizing the teaching of science as a traditional value; and *ii)* organising educational activities around problems where modern science and traditional values can be integrated, while encouraging a climate of opinion favourable for social and economic changes desired by individual countries.

The compelling reasons for scientific literacy have been stated by Chisman (1983) as:

- To function successfully and responsibly in a scientific and technologically-based society, and to be safe, healthy and comfortable in that society;
- To maintain a vigorous democratic state in which citizens of the late 20th century participate knowledgeably in deciding public issues.

A complete understanding of scientific practice requires that children be provided with opportunities to think creatively. Indeed it has been argued that technology is a better vehicle than science for fostering creativity, in that many technological problems have more than a single correct solution. In this area, project work, case studies and Compu.. r-Assisted Learning have been identified as good instigators of creativity. With the above in mind, the aims of science education have been summarised as follows:

- The acquisition of factual and theoretical knowledge;
- The acquisition of laboratory skills and techniques;
- The critical scrutiny of evidence and arguments for and against particular theories;
- Practice in using theories for explaining phenomena;
- Using theory for prediction;
- Testing predictions and other consequences of particular theories;
- Designing experiments to test hypotheses or to illustrate theories;

- Hypothesis generation;
- Testing hypotheses by logical criticism internal consistency and compatibility with other existing theories;
- Testing hypotheses by experiment;
- An appreciation of social, historical and economic issues concerning science and its applications.

A tendency to adopt a constructivist approach to science education gives special consideration to the role of the individual in the construction of personal knowledge. From this viewpoint, the aims of science education should include the following (UNESCO, 1981):

- To introduce students to examples of how scientists have defined concepts in ways useful to them, but which conflict with commonsense experience and usage;
- To make explicit the world views of natural phenomena that students hold and to relate these to world views held now and in the past by scientists;
- To enable students to recognise that scientists invent general concepts which idealise and over-simplify real substances and phenomena;
- To help students relate scientific concepts to a wide variety of examples;
- To help students take a natural phenomenon or piece of technology and identify several features with their corresponding scientific concepts;
- To help students recognise and use varieties of representation used by chemists and physicists to describe substances and physical conditions.

Consideration of the structure of science, scientific knowledge and scientific method – even though there was no universal agreement as to what constituted "scientific method" – formed the basis of many science education curricula of the 1960s and 1970s. It was subsequently considered that such a view presented a distorted image of scientists as "objective, open-minded, unbiased and possessing a critical and infallible method". The neglect of social and humanitarian considerations was not only detrimental to the production of future scientists but even more detrimental to the production of a scientifically literate citizenry. The image of science as impersonal and lacking in social responsibility has been identified as responsible for turning many students, especially girls, away from science. Consequently, it is felt that a programme of science education is incomplete if it neglects to include any of the following (Hodson, 1985):

'A concern for scientific knowledge (certain facts, principles and theories worth knowing), a concern for the processes and methods of science (reasoning and investigating), direct experience of scientific activity, appreciation of the complex relationship between science and society and the fostering of positive attitudes towards science.

THE CURRENT SITUATION

In many countries, the teaching of science begins in elementary school. At this level most teachers do not have specialised training in science education. In the upper grades of elementary school, some teachers teach science to their students, while others defer to more confident colleagues or to specially-trained consultants. The teaching of science as a separate subject begins halfway through secondary education. In the English-speaking countries and many others, the main aspects are taught under the heading of "General Science", with the separation between physics, chemistry and biology occurring only at the end of secondary education. Other countries offer separate courses in physics, chemistry and natural sciences (biology and geology) from the outset.

In the United States up until about the 1950s, secondary schools emphasized individual laboratory work, demonstrations, problem-solving and informal lecturing and discussion Since then, there has been a marked tendency towards a stricter description and methodological classification of phenomena.

In other countries, and particularly France, the move has been in the opposite direction Up until about 1980, schools emphasized memorisation of facts and principles, note-taking during lessons, little laboratory work and a logical and verbal treatment of an organised body of scientific facts. Since then the aim and the tendency has been to give students more contact with the practical aspects, shifting the emphasis from a purely descriptive approach to an understanding of facts and phenomena. In Ontario (Canada), teachers are encouraged to adopt a perspective which is a personally determined balance of emphasis on "scientific literacy", "science, technology and decisions", "scientific processes", and "the structure of science" (Ministry of Education, Ontario, 1978).

Curricula

Curricula in many countries emphasize both processes and content. For example, the science and technology curriculum for elementary schools in France is:

- First year. Learning basic methods: observing/classifying/ manipulating/observing materials (tools), living things (one's own body, plant growth, animal growth), common devices.
- Second and third years. More extensive and detailed treatment of the above subjects:

  Solids/liquids/gases, air and water, soils and rocks;
  Reproduction, nutrition, aggression/defence, movement, sensory organs;
  Plants' requirements of water and light, seeds, cuttings;
  Mechanics, electricity, simple technologies.

- Last two years. Problem construction, hypotheses experimentation, reasoning

  Rudiments of geology, astronomy, physics, energy;
  Electromechanics, electronics, logic, computers;
  Biological evolution, respiration, digestion, sexuality.

Students learn some of the processes of science by making observations, comparisons, and measurements, and organising them through simple records, sketches, diagrams, charts, and tables. They develop a sense of how simple technology is related to science through designing and constructing various devices, and using simple tools of measurement. Through the topics selected for study, students begin to see science and technology as part of their social and economic environment.

The Implicit or Hidden Curriculum in Technology

The technological curriculum in schools is taught both explicitly, in courses about technology, and implicitly, through the way technology is used in education. Students learn technological concepts and processes in large part through using technology. They acquire values from their own use of the technology and from observing:

- How access to technology is controlled (availability of equipment, allocation for various purposes, availability of information on how to use it, attitudes towards users),

- Whether educational institutions adapt the technology to education or simply adapt education to fit the technology;
- Whether or not the uses of technology in school are connected to uses outside school;
- Whether the social structure of the use of technology fosters competition and isolation or co-operation, collaboration, and a sense of self-esteem

The Utilisation of the Usual Teaching Material

a) Textbooks

Textbooks in the physical sciences first appeared in the 18th century following the industrial revolution Materials were more widely available and textbooks were reproduced more rapidly. As scientific bodies of knowledge came to be identified under separate subject headings and examinations began to determine the content of syllabi, the textbook became an essential part of the teaching and learning of science.

Textbooks serve well as sources of conceptual and factual information. Textbooks also serve as sources of information about scientific values and procedures, but acquiring these forms of knowledge requires that students engage in the processes of design, experimentation, analysis and discussion. Textbooks are also limited in helping students bridge the gap between their own theories and those presented in the text. Some texts are written in modular fashion, allowing students to work at topics in various orders. It is quite common for texts to have a core of initial chapters which are in a tight sequence followed by optional chapters which can be studied in any order. It is possible that the usefulness of textbooks could be extended by coupling them with computer-based materials to provide students with individual experience and attention.

b) Other Instructional Media

Excellent films, filmloops, filmstrips with audio cassettes, and, more recently, video cassettes have been prepared for educational purposes but have not found widespread use in science and technology classrooms. In order to guard against the computer becoming "just another medium" to collect dust, it is important to consider reasons for the underuse of instructional media, including cost-effectiveness, availability, flexibility, ease of use, and form of student interaction Most media are now quite easy to use and are quite reliable. The videodisk offers new flexibility, but the range of materials available is still too limited to generate widespread use. Educational games, which are often inexpensive, are sometimes used to provide a comfortable and motivating form of learning through social interaction. The computer, coupled in some cases with the videodisk, promises to be a far more flexible and interactive medium than any of the others mentioned. Serious attention must be given to ease of use and availability.

c) Equipment for Practical Work

It is important that students be involved in designing, preparing, adapting, and using apparatus of varying complexity. Much important learning can occur with the use of commonplace, inexpensive materials (boards, marbles, seeds, tadpoles, small electronic components). The use of household materials makes it easier to encourage students to continue their work at home. Excellent kits of materials, such as those on meal worms, batteries and bulbs, and mapmaking to accompany the Elementary Science Series, can be shared among classes and offer almost unlimited options for the teacher to adapt them to local conditions and student interest. When computers are more readily available, it will be possible to couple the use of these kits with computer-based simulations and data analysis.

In the science and technology labs of secondary schools, equipment is more specialised and standardized. Computers are scarce outside of computer science and business studies laboratories. Digital electronics devices are used in technical laboratories, but there is little computer use in science laboratories. There are rich opportunities for the use of computers in experimental measurement, data analysis, and simulation.

Gender, Science and the New Information Technologies

The ability, motivation, participation rates and achievement of girls in science subjects in schools relative to boys have been extensively studied in many countries, and a common pattern emerges. Girls have low participation rates in the physical sciences (physics, chemistry), but often high participation rates in the natural sciences. In an informed, scientifically literate world, there is an equal need for both men and women to be scientists and technologists. Social inequalities must be redressed. Extensive investigations of the cognitive abilities of boys and girls have found few and only small differences. It is doubtful whether these differences are innate, especially since social factors which affect them are strong and well documented. Even so, the differences are too small to account for the difference in participation rates in science subjects.

Many proposals have been put forward aimed at improving the participation and performance of girls in the physical sciences. For example:

- Science curricula should emphasize practical applications and the social implications of science, reflecting the interests and experiences of girls as well as boys;
- In the design of science curricula, the inter-relatedness of science with other disciplines needs to be emphasized wherever appropriate;
- Teachers should provide activities for girls which address the imbalance in relevant experience brought by boys and girls to the science classroom;
- Curriculum materials should be examined to identify sex-role stereotypes, gender bias and cultural bias, and appropriate classroom action taken;
- Wherever possible, courses should be developed which integrate the natural and physical sciences.

Chapter 2

LEARNING PROCESSES AND THE ROLE OF INFORMATION TECHNOLOGIES

This chapter discusses learning as seen through the eyes of the new science of thinking and learning – cognitive science. Cognitive scientists assume the existence of thought structures and processes and proceed to study their development. The following principles and features characterise cognitive science (Gardner, 1985):

- That activities of the mind can be understood in terms of mental representation;
- That computers and computer-based models are essential tools for understanding cognition;
- That many disciplines (philosophy, psychology, artificial intelligence, linguistics, anthropology and neuroscience) contribute to our understanding of cognition.

MODELLING OF STUDENTS' KNOWLEDGE AND PROCESSING

Research in cognitive science has made extensive use of new information technology in developing models of human mental activity (Anderson, 1985; Glaser, 1984). Such processes as solving a mathematics problem or searching one's memory to find a category into which to fit a given word have been represented as computer programs. Comparing the performance of the program with human performance suggests how well the theory that specifies the rules of the program fits actual human processes.

There remains a need for more specific models concerning particular domains for example, various scientific areas (White and Fisher, 1985) or specialised cognitive activities (for example, arithmetic operations, comprehension in reading, programming techniques, etc...) (Anderson, 1983). In addition, it is necessary to take individual differences into account and use models that can be specialised for each particular student.

Declarative and Procedural Knowledge

Cognitive science suggests that there are two different kinds of human knowledge: declarative knowledge and procedural knowledge. Declarative knowledge comprises the facts we know, procedural knowledge refers to the cognitive skills we know how to perform. Anderson (1985) describes the acquisition of cognitive procedures in three steps: a cognitive stage, in which a description of the procedure is learned; an associative stage, in which the method for performing the skill is practised; and an autonomous stage, in which the skill becomes rapid and automatic. Procedures can be taught to students, but they must then be practised to become attention free.

Production Systems

The relationship between knowledge and action can be described by means of production systems. Originally, production rules were condition-action pairs of the "if..., then..." form, with the "if..." part specifying some sort of general knowledge, and the "then..." part defining an action to be carried out. This schema was closely related with the stimulus-response schema used in behavioural psychology. However, the restriction that the second part of such a production must be an action in the real world was given up long ago. This part may be a cognitive process, adding new data elements to an individual's working memory. An example of a production rule is, "if Person *A* is the father of Person *B* and Person *B* is the father of Person *C*, *then* Person *A* is the grandfather of Person *C*".

Production systems are sets of productions (or production rules) used to perform various cognitive tasks. They are well-suited to representing procedural knowledge used in problem solving and in inductive and deductive reasoning (Newell and Simon, 1972; Anderson, 1983). Production systems are run on computers to model specific cognitive processes such as adding numbers or thinking about physical phenomena. For such tasks, production systems allow good prediction of errors.

Knowledge Structures

Declarative knowledge is often represented in the form of semantic or conceptual networks (Norman and Rumelhart, 1975; Brachman, 1979). Cognitive science emphasizes the role of prior knowledge in learning (Glaser, 1984). Strongly connected, hierarchically structured collections of human knowledge, often called cognitive schemata, prototypes, frames, scenarios, or macrostructures (Minsky, 1977; Schank, 1982) permit linkage of new knowledge to old. Concepts are a particular sub-class. Schemata are viewed as bundles of information, consisting of invariant cognitive components or relations, and values or sets of values. Schemata can be abstracted from out-of-school experience or through instructional learning. In science education, several studies have shown the differences between novices and experts in applying cognitive schemata in solving problems (Chi *et al.*, 1982).

Mental Models

Representation of parts of the world, e.g. natural science phenomena, and of various sorts of problems in the student's mind, can be assumed to have the form of "mental models". The teacher must have a model of this model in his/her own mind. Although the concept "mental model" is used variously by different authors (Gentner and Stevens, 1983; Johnson-Laird, 1983), the main idea is that a propositional or conceptual representation does not suffice for describing the student's knowledge and misconceptions. The concept of mental model seems to be especially useful in the context of representing the knowledge of novices and experts about phenomena of physical science and about technical devices. Mental imagery, about which little is known, must be taken into account.

Another important question is how particular knowledge is used in the solution of general and abstract problems. For example, Johnson-Laird (1983) provides evidence that most people, when asked to solve syllogisms containing the quantifiers "all" or "some", use very small sets of mental objects and make logic computations on them: if they are told that "some *C* are *B*", they form a representation of perhaps six *C* objects, of which four are *B* and two are non-*B*, and make their deductions on these sets. In a somewhat different version of the "mental model" notion, the role of analogy in the formation and use of concepts in physics has been well demonstrated.

Diagnosis of Individual Knowledge

The rule-driven character of errors and misconceptions has been confirmed (cf De Corte and Verschaffel, 1985). This result is in line with a general finding in cognitive psychology. The more one knows about the subjective problem space of a person – the rules and possible procedures he or she thinks of as applicable in solving a problem – the more one is able to detect systematic errors instead of erratic behaviour. This parallels a well-known trend towards qualitative assessment of knowledge, e.g. of arithmetic skills. The probabilistic quantitative models of the early seventies (Spada, 1976) predicting the number of correct answers, will be replaced by qualitative deterministic models, which are constructed to give a detailed account of various forms of systematic errors in the algorithms applied The results of such a diagnosis may be related to didactic and cognitive objectives. Diagnosis, information about the current state of knowledge of a particular student, is a sub-goal of the instructional goals. Diagnosis is particularly important when it provides evidence of misconceptions or disfunction in the student's reasoning.

New technologies will allow diagnosis to be partly automated. In particular, techniques are being developed to diagnose problem-solving processes in the student, going far ahead of conventional evaluation based on multiple-choice questions. This can be useful only if a careful classification of possible cognitive errors, misconceptions or disfunction in the student has been previously carried out by teachers, and if methods for overcoming these have been devised. In this case, new technologies can provide a powerful tool for application of such knowledge about the student. On-line recording of cognitive errors, their analysis and classification is realised in the *KAVIS-III* System (see Chapters 3 and 4).

Intelligent Tutoring Systems (ITS) use dialogue to build up models of the knowledge of the student (Sleeman and Brown, 1982). A tutorial dialogue is thus a dialogue between two learning systems – the student and the ITS. Through the dialogue, the ITS constructs a formal representation of the student's knowledge and skills. This representation is used to govern the performance of the ITS in presenting problems to the student, giving advice and asking questions. The techniques to assess the domain-specific knowledge of a student and his/her skills in information processing have to be improved, combining the structural approach of "bug" diagnosis (Brown and Burton, 1978) with a quantitative approach.

The diagnosis of individual knowledge and its change over time is of relevance not only in connection with Intelligent Tutoring Systems but with all types of learning and instruction. Powerful statistical methods exist to assess quantitative change (Mobus and Nagel, 1983; Fisher, 1976), but it is a common view today in cognitive psychology that differences in knowledge have to be understood as qualitative differences in its content, structure and applicability (Elshout, in press). The literature shows how difficult it is to assess qualitative differences. In general, the diagnostic procedures are based on (naive) reactions in a deterministic way. This assumption presupposes data free of measurement errors and a cognitive model that takes into account every relevant detail.

ACQUISITION OF KNOWLEDGE

Conditions for the Acquisition of Knowledge

Knowledge can be acquired through direct perception or through language (i e. perception of spoken or written discourse), pictures, etc. The relative influence of these sources varies according to the age of the student and the subject matter itself There is no reason to assume an a priori preference for one source to the other. Recent psychological work on semantic memory has shown the interaction of information coming from both sources. However, the role given to the language source cannot be viewed independently from the relationship that exists, at a given age and time, between the content of the student's semantic memory and his or her past perceptual experience. How efficient verbal teaching is closely depends on the representations the student activates when hearing or reading words, sentences or lectures. Insufficient previous knowledge or misconceptions are frequent causes of inefficiency in knowledge transmission. This question has to be solved by means of diagnoses oriented to these particular questions.

The role of attention and intention-to-learn in knowledge acquisition is of special importance. Most early acquisitions are unintentional. They depend mainly on the richness of the child's environment. Presumably, incidental learning gives rise to inter-individual cognitive differences, attributable to the social environment. In contrast to how children learn incidentally, conventional instruction is largely based on students' capacity to do intentional learning. Some modern methods of instruction systematically try to arouse spontaneous attentional states in students, to take advantage of both motivated and incidental learning. The new methods manipulate the student's environment in various ways which may be individualised. New technologies make it possible to create situations specially designed to arouse attention and motivation. At the same time, these situations, which are artificial but may be made very close to actual ones by simulation, can provide information to the student in a way most suited to cognitive processing in knowledge acquisition.

The role of the student's action in knowledge acquisition depends strongly on the type of knowledge that is to be acquired. Any acquisition involves active information processing in the student's mind: in this sense, no learning is passive. Declarative knowledge may be acquired through ordinary experience, by working with specially devised microworlds, or by observation and processing of information presented.

The role of previous knowledge for the process of learning and teaching was mentioned in discussing the relevance of a thorough diagnosis of individual knowledge. Current psychological research emphasizes a property of human long-term memory, according to which acquisition of knowledge is in no way cumulative or modular. Any new knowledge is collected, processed, and integrated into memory by using the schemata or frames of previous knowledge. Acquisition of new knowledge interacts with previous knowledge, causing positive effects of transfer or negative effects of interference. Further research is needed on the following questions: When does it help to provide new information in acquiring knowledge? When is such acquisition impaired? Does previously acquired knowledge deteriorate? In the same context, an important problem, concerning curricula, is the following: is it possible to determine an optimal order – and perhaps individual optimal orders – for information presentation to the students that would increase instructional efficiency?

Acquisition of Concepts by Abstraction

Concepts may be acquired by abstraction from sets of empirical examples, or through written or spoken text. The first form of acquisition is often identified with acquisition of prototypes. The role of typicality has been strongly emphasized in this process of acquisition (Rosch and Lloyd, 1978) and merits more investigation in connection with use of new technologies. Similarly, acquisition of concepts through language involves problems about meaning, knowledge representations, relationships between language and knowledge, role of verbal examples, etc... On examining the format of typical definitions, a rather small number of relationships seems to predominate: the class of concepts to which a concept belongs, the properties which tend to make the concept unique, and examples of the concept.

Naturally-acquired concepts may be misconceptions in the sense that they do not stand up to scientific scrutiny. Investigating misconceptions is of particular importance teaching scientific concepts implies not only detection of misconceptions, which is a problem of diagnosis, but also a better comprehension of environmental, educational, and psychological factors that have caused them. The problem of correcting erroneous concepts presents a great challenge for the use of new technologies.

Acquisition of Concepts through Instruction

The ideas of concept formation held by the psychology of thinking are now converging with the memory-based approach of knowledge representation just described Aebli (1981) has shown that most of the former investigations were concerned with the attainment of concepts in the case in which an individual develops a concept by abstraction on the basis of particular examples. This case, however, appears to be quite rare. Normally, the student is confronted with established concepts, which are taught through direct instruction with the help of textbooks. Thus, most of the concepts are introduced intentionally rather than extensionally. In the case of teaching concepts by direct instruction, the learning is still a constructive process. According to Aebli (1981), concepts are not attained but built. What happens, for instance, in reading a text or following a computer program is that, under the guidance of the author and on the basis of prior knowledge, concepts are continuously being built and existing concepts are being modified.

Acquisition of Misconceptions through Instructional Analogies

The heuristic of drawing analogies may impede the construction of concepts if the student draws incorrect inferences. White and Gunstone (1980) discovered such a case in their study of knowledge structures in the domain of electricity: a college science graduate who had been given the water flow analogy during his early instructional experience with electric current had extended the analogy by comparing a water pipe to the electrical insulation surrounding a wire. As a consequence, he believed that electrical leakage was akin to a hole in a water pipe and that it could result from a bare electrical conductor. He had deduced that much of the research effort in electrical engineering was devoted to the production of more efficient (i.e. less friction-generating) insulating covers for wires. Understanding the limits of analogies in teaching deserves more attention. The use of analogies in teaching concepts may be improved through assessment of the construction of new concepts and by using this information in subsequent instruction. This type of individualised teaching may be enhanced by new information technologies.

Acquisition of Strategies

The concept "strategy" is understood in different ways by different authors If we call "strategies" procedures that cannot be made entirely explicit for the student, or cannot be acquired by making the student aware of their structures, practice is the best method available for acquiring them. For example, reading and comprehension involve very complex strategies for eye movements. These strategies are perceptual, in so far as they control information grasping in reading. But they are also under control of higher cognitive processes that take place during comprehension. As a matter of fact, such strategies cannot be made fully explicit for every particular reader, and even if they could this would hardly help the reader to improve. However, as soon as maladapted str gies have been detected in a reader, for example, too many backtracks, special reading situations car be set up for him : her, in particular by use of reading tasks on a video screen with appropriate disposition of the text, so that more eff ent strategies of eye movements can be shaped in this student. Similarly, problem sol g in olves many implicit strategies (problem solving is discussed below). Many authors discuss the form of strategies called metacognitive procedures and their role in memory or problem solving (Fl .vell, 1976). The improvement of metacognitive abilities is an important goal of education in science and technology.

Teaching Cognitive Strategies

In the analysis of problem solving and knowledge acquisition, it has been recently emphasized (Brown, 1983) tnat metacognitive processes should receive more consideration in the development of teaching programs. If training measures are applied only at the operative level, then one cannot expect the student to develop metacognitive abilities, which are used to assess the task, to monitor work on the task, and to evaluate outcomes. Nor can one expect that cognitive operations which are not deliberately reflected upon and elaborated will be retained in long-term memory. According to Brown (1978), a teaching program should help explicitly to acquire mechar as to control and monitor the domain-specific knowledge and cognitive skills. Some of the mechanisms are strategies for planning, sequencing of cognitive operations, and monitoring procedures. Acquiring cognitive strategies is a central learning goal which can be addressed by using the new information techn gies to provide opportunities for individua ed, adaptive learning. Recent studies of training in the development of cognitive strategies demonstrate the success of cognitive and metacognitive training measures with students with learning disabilities, students with different levels of maturity, and students in different college semesters (Brown, 1983; Campione, 1983).

A promising way of learning science is to formulate hypotheses and to test them by means of experiments simulated on the computer. Such microworld learning environments might reflect the laws of classical mechanics, the laws of geometrical optics, or laws invented by the student. Students would acquire domain-specific knowledge and improve their skills in gathering and processing information. Students might learn how to design good and informative experiments, how to test and refine hypotheses, and how to use feedback. These are important cognitive procedi es in science, which might be in oved by the use of the new information technologies.

Problem Solving

Only twenty years ago, problem solving would not have been one of the main themes in a discussion of learning and instruction. To improve problem-solving capability, the teaching of general domain-independent heuristics was recommended. In artificial intelligence, the so-called power-based systems, which were de eloped as general problem-solving tools (Newell, Shaw and Simon, 1965), represented such an attempt Today, in artificial intelligence, research is conducted on various types of knowledge-based systems. In psychology, parallel studies were conducted on problem solving. Today there is no doubt that a thorough analysis of the domain-specific knowledge of a person is a necessary condition for understanding the person's problem-solving activities in each domain (Glaser, .984).

Application, and modification over time, is closely linked to the analysis of problem solving and investigations in the field of learning and instruction. Investigators who stress the active role of the learner and the constructive aspects of acquiring knowledge believe that acquiring knowledge and developing problem solving are complementary activities. A good knowledge base is needed for effective problem solving. Conversely, effective problem solving is an important way of acquiring flexibly organised knowledge.

Many theoretical and empirical investigations have been conducted in recent years. General views of human problem solving, mainly based on a means-end approach and the elaboration of artificial intelligence methods, either for automatic problem solving (e.g. theorem demonstration) or for assistance to humans (expert systems) have proved very helpful in understanding the acquisition of problem-solving abilities. It has been shown that students go beyond rational methods when they solve problems. Both novices and experts readily assign every particular problem they meet to a "problem class", of which they appear to have a representation in their minds. How the classes of problems are represented is related to problem-solving efficiency. In particular, it has been shown that novices take into consideration more surface features and fewer deep (relational) features of the problem than do experts. Consequently, teaching problem solving should include instruction about the relevant features of various problems and methods of assigning particular problems to appropriate categories. Exercises bearing on classes of problems should take these principles into account to allow appropriate generalisations by the students, rather than generalisations based on incidental features.

Guidance in problem analysis and classification can also be adapted to the analysis of problems that are not well-defined. It is important that students have experience with a multiplicity of points of view in analysing problems. Relevant studies on problem solving in physics have been conducted by Larkin (1981).

Teaching Problem Solving

The improvement of domain-specific knowledge and of general heuristics is seen to be of special importance in furthering the problem-solving capacity of a student. Elshout (in press) has suggested how to combine the teaching of domain-specific knowledge and general problem-solving heuristics. In studies by Mettes (in press), this approach is exemplified by a curriculum for the solution of science problems. In two courses on thermodynamics and electromagnetism, the regular subject matter is taught together with useful heuristics and methods. Declarative and procedural knowledge are taught in an integrated form. Both types of knowledge are acquired by the students in a highly supportive context. The general heuristics and methods are adapted to the specifics of the domain of application. The resulting curricula are fine examples of guided learning by doing and, as the results of empirical evaluations have shown, they have been successful.

Reif and Heller (1982) have formulated a model describing the types of knowledge and cognitive procedures that are conducive to effective problem solving in physics. Their model includes components for the following:

- Describing and analysing a problem to facilitate solution;
- Decomposing a problem into manageable sub-problems; and
- Assessing the correctness of the solution and determining whether it is optimal.

Reif and Heller (1982) emphasize that several quite common teaching practices may hinder the development of students' problem-solving skills. They provide several examples:

- In natural science, a desire for precision often impels instructors and authors of textbooks to overemphasize mathematical formalism at the expense of a more qualitative mode of description. As a result, students may even come to regard such qualitative descriptions as scientifically illegitimate. But seemingly vague verbal and pictorial descriptions help greatly in the search and planning of solutions, they are also commonly used by experts. Hence one needs to teach both qualitative and quantitative problem representations;

- The most common method of teaching scientific problem solving is to provide students with examples and practice. But most students' problem-solving skills are quite primitive and improve only slowly. Furthermore, many students find the problem solving required in college-level physics courses difficult or even unmanageable. Reif and Heller argue that cognitive mechanisms needed for effective scientific problem solving are so complex that they are not easily learned from examples and practice without special support and training.

In a subsequent study, Heller and Reif (1984) have shown that their model can be used to guide accurate problem representation in controlled learning situations, and to improve the problem-solving performance of students who have already taken a physics course.

In contrast to the carefully controlled conditions of Heller and Reif's (1984) study, Hewson and Hewson (1983) have implemented a conceptual change model that deals directly with students' misconceptions in a more realistic instructional context Hewson and Hewson's model describes instructional strategies for replacing or modifying the alternative conceptions that students have prior to formal instruction.

Motivational Factors

Assimilation of new information is possible only by using previous knowledge. The relationship between the newly-presented information and the previous knowledge is a source of positive or negative cognitive motivation for the student. It is commonly accepted that novelty of information plays an important role in this respect, and that there exists an optimal novelty, which may be different for every subject. If the novelty of the presented information to be learned or problem to be solved is close to this optimum, a positive state of motivation is created, and presumably is associated with this subject, or with instruction in general. If, on the contrary, the new information or problem is either too novel, thus creating unfruitful efforts, failure and frustration, or not novel enough, thus creating boredom, negative states of motivation may be aroused which impede work at the current task and may then be associated with the particular subject, or with instruction in general.

New technologies allow presentation of information or problems to a student at his/her own pace, permitting control of novelty and optimisation of the motivational states of the student. Continuous feedback is of high relevance for motivating the student to improve his/her solution processes and correct wrong ones. New technologies also allow very detailed feedback based on the knowledge state of the learner.

Recent trends in motivation and attribution theory show that feedback is neither information per se nor is it reinforcement or encouragement per se. The interpretation of a feedback event is subject to a switch between both components dependent upon the learner's success/failure. There may even be a time independent "filter" installed at the side of the learner reflecting his earlier learning history respective of his success/failure orientation. There are recent suggestions to prevent the learner from premature, aversive feedback interpretations by stressing "hits" rather than "misses" in the beginning, while error-collecting feedback should be administered only after some mastery has taken place. Feedback-based tutoring systems should take this into account as is the case with the *KAVIS-III* System.

Chapter 3

TEACHING AND LEARNING WITH INFORMATION TECHNOLOGIES

The new information technologies may be used to extend existing modes of teaching and learning, to help teachers adapt their work to meet individual needs, and to improve motivation. At the same time, introducing new technologies into the classroom places additional demands on the teacher to develop new competencies, to adapt established teaching routines, and to modify the teaching and learning environment.

TEACHING MODES, ADAPTIVE TEACHING AND MOTIVATION

Chapter 2 dealt with aspects of learning: types of knowledge (concepts, cognitive procedures, cognitive strategies, problem solving) and the acquisition of knowledge. This chapter deals with aspects of teaching: teaching modes (system-oriented or discovery-oriented), adapting teaching to the individual, and motivation.

Teaching Modes

a) System-oriented Teaching

A question teachers face is whether to present information to the learner directly or to provide for discovery learning. In system-oriented teaching, for example in expository learning, the learning material is presented as a complete system and the sequence of the learning steps ensues from the logical relations within the system. This procedure seems to be especially useful if the learner has to be introduced very quickly into a completely new field of knowledge or if he already possesses sufficient knowledge about the domain. Ausubel (1968), a proponent of this teaching method, assumes that the knowledge in every academic discipline has a specific structure which can be arranged hierarchically. Learning is viewed as a process of continuing differentiation of yet undifferentiated concepts. Ausubel assumes that meaningful material can be learned and retained only if the person has existing concepts which will retrieve and integrate the information to be learned. This information must be anchored within the existing cognitive structures of the pupil and must be protected against being forgetten. According to Ausubel and others, the learning and storing of meaningful material can be facilitated by advance organisers, progressive differentiation and sequential organisation.

b) Discovery-oriented Teaching

In system-oriented teaching, the aim is to present a complete knowledge structure. In discovery-oriented teaching, the learner must discover the path of knowledge acquisition. Proponents of this method claim that knowledge acquired this way is more flexible in use, can be better transferred to similar problems, and is not forgotten as quickly. Discovery-oriented teaching can be carried out very effectively using the new information technologies, especially using computerised forms of feedback-based learning, microworld learning environments and simulation programs. A central feature of successful discovery learning is a highly supportive context. New information technologies provide many possibilities to create such contexts.

In discovery-oriented teaching, the learner has to form conclusions inductively. He/she uses examples or individual facts and, via the inductive method, may find laws governing the relationships. Starting with an opaque problem situation, the learner is invited to think, to use his/her own discovery abilities and thus to gain increasing insight into the area. Since all the pertinent facts of a particular knowledge domain cannot be acquired through discovery within a reasonable time-frame, central problems have to be highlighted or presented as examples. The learner has to set up hypotheses which are either confirmed or rejected. If they are rejected, the learner has to construct new hypotheses.

c) Drill-and-Practice Programmes

In addition to system-oriented and discovery-oriented teaching methods, drill and practice is used to consolidate knowledge or cognitive skills. Some computerised instruction has proven to be very helpful in this context. Such drill-and-practice teaching programs usually consist of a sequence of exercise problems which are presented in the following manner: presentation of task, acceptance of the answer of the learner, assessment of answer, feedback to the learner, and change over to the next problem. In many programs, the feedback is simply provided in terms of the answer "true" or "false". Fast individual feedback is seen as a positive characteristic of such computerised teaching programs. The better drill-and-practice programs adjust the degree of difficulty and type of problem to the level and ability of the student.

Adaptive Teaching

Teaching is called adaptive if it adjusts either to differences between students or to an individual student's changes in knowledge, cognitive skills and motivation at different stages of learning.

a) Aptitude Treatment Interaction

Students might be differentiated according to characteristics such as cognitive learning prerequisites, motivation and performance. In order to achieve optimal success in learning, teaching methods should match these differences. This seems trivial but the problems facing the teacher in managing the development of effective instructional strategies are great. Interactions between learner characteristics and teaching methods, called "aptitude treatment interaction" (ATI), is the subject of extensive research (Gagné and Dick, 1983, p.282).

b) Tutorial Programs: Teaching the Individual Learner

Current computerised tutorial programs can be classified by how much student initiative they permit. Collins (1977) describes a *theory of Socratic tutoring* which he considers capable of teaching new knowledge and skills so that the knowledge can be transferred to new problems and situations more easily. The teaching dialogue of such a system consists of diagnostic and corrective strategies: the tutor analyses the student's knowledge and uses errors as clues to misconceptions. It is assumed that the learner not only acquires knowledge structures which are more completely interconnected but also that his/her ability to utilise querying strategies is improved. For this interactive tutoring, Collins developed several heuristic rules that generate questions for the dialogue. These ideas were applied to topics such as geography, biology, and medicine; Collins and Stevens (1982) see the following major advantages for this type of teaching strategy:

- Certain aspects of scientific thinking are imitated;
- The tutor has to respond in an individualistic manner to the individual student;
- The transfer of the learned material to new situations is facilitated.

Mention should be made here that this control notion was first seen and reflected by Mandl and Fischer (1985) and Fischer and Mandl (1987).

Recently, attempts have been made to realise discovery learning with *"microworld" tutorial systems* (Lesgold, in press) in which the learner monitors and directs his/her own learning. When learning with the computer, the learner is supposed to attain a deeper understanding of basic facts through research and discovery done in a specific domain, and to gain general skills in information search and problem solving. A microworld is a computer representation of a specific content area which enables the learner to acquire factual knowledge from some domain, e.g. from geometric optics (Spada and Reimann, in press). Microworld systems allow the learner to simulate "experiments" with defined conditions on the computer screen, e.g. the refraction of a beam of light in an optical medium. Based on this information, the learner can construct hypotheses about the laws governing the phenomena of the microworld. For example, he may set up hypotheses about the electro-magnetic force, current and resistance in an electric circuit and test them. The hypotheses are tested by the learner changing certain parameters and watching the effects on the screen produced via the computer simulation.

Simulation programs aim at imitating real systems, e.g. an ecological system (Opwis and Spada, 1985) or a technical system. The learner can vary all or some of the input variables of the system in order to get some insight into the modelled relations of the components by observing the system run on the computer. The outcome of the simulation is presented in graphical or tabular form. If needed, commentaries or feedback are given as interpretive assistance. Simulations are usually embedded in larger teaching units. They provide a relevant opportunity for discovery learning, especially of complex systems. Relevant research of this type has been done in Germany by Dörner *et al.* (1983).

In recent years, much effort has been devoted to developing *Intelligent Tutoring Systems* (ITS) (Sleeman and Brown, 1982). ITS, emerging from research in cognitive psychology, instructional science and artificial intelligence, receive increasing interest as instructional tools. ITS which use dialogue to build up a model of the knowledge of the student constitute a very interesting development. The techniques to assess the domain-specific knowledge of a student and his skills in obtaining and processing information have to be improved, however, combining the structural approach of "bug" diagnosis with a quantitative one. Intelligent systems perform the following tasks based on an analysis of the dialogue with the student: *a)* building up a representation of the student's knowledge in a domain of study; *b)* comparing this model with a criterion model, for example, an expert model of the domain, in order to evaluate the student's knowledge at various points of the learning process; and *c)* using didactic heuristics to decide what should be taught and how this should be done. These systems offer the learner flexible access to information and an adaptive dialogue based on the knowledge of the learner. They are labelled intelligent because they are highly flexible and adaptable in deciding when and how to intervene in the learning process.

In adapting instruction to individual students, it should also be kept in mind that students come to school with individual conceptual frameworks, including theories of nature, beliefs, and value orientations. Snively (in Driver and Erikson, 1983) has classified students' orientations along utilitarian, aesthetic, spiritual, scientific and recreational lines. He argues that it is important, in attaining instructional objectives, to make significant contact with students' preferred orientations and beliefs. For students to experience science, they must be given opportunities to explore both phenomena and new ideas, to listen to and appreciate alternative points of view without losing confidence in their own capabilities to comprehend and to act; to construct their own knowledge and perhaps by so doing, gain some appreciation of science as a pursuit of the human imagination. Individual conceptual frameworks are manifest in:

- Sensory experience (hence the importance of computers in simulating, replaying, and otherwise manipulating sensory experience);
- Language and available metaphor (hence the importance of the computational perspective: nature as computer, problem solving and theory building as programming);
- Analogy (which results in ideas that are likely to be more idiosyncratic and more fluid than those based on sensory experience and metaphor).

Students retain much of what is taught in the form of propositional knowledge, but make sense of their world through knowledge-in-action. How can the new information technology be used to help teachers identify and understand the conceptual frameworks of their students and help students reconcile their propositional knowledge with their knowledge-in-action? It seems particularly important to have software which allows students to manipulate systems by creating laws, imposing constraints, specifying states, and observing and responding to the consequences. The science classroom of the information age will have to integrate student-student and student-teacher dialogue with student-computer dialogue in a way that treats the students' own ideas not as errors or misconceptions but as emergent theories with bugs.

Motivational Aspects in the Construction of Computer-Based Learning

Motivation may be extrinsic or intrinsic. Extrinsic motivation is built into many "drill-and-practice" programs in the form of sound and graphics unrelated to the learning activity. Piaget and Bruner emphasized the importance of intrinsically motivated, playlike activities for many forms of learning. Some researchers (Lepper 1985; and Malone, 1980) have looked to computer games to provide intrinsic motivation. According to Malone, the learning situation has to have a challenging character in order to facilitate intrinsically motivated learning behaviour. Malone suggests that the learner's curiosity will be stimulated when he or she feels that his or her knowledge is incomplete or inconsistent with new information and experience. When the learner realises that the knowledge he/she has acquired enables him/her to execute meaningful activities, he/she will feel challenged to study the material.

Besides the motivating, instigating nature of challenging computerised learning, aversive contingencies and/or by-products of overt or covert feedback events in such systems should be reflected. Carefully planned feedback and/or diagnostic components in such systems are necessary.

Individualisation of Learning

The capacity of new information technology to accommodate individual differences is well-illustrated by a student-computer dialogue developed at the Educational Technology Center at the University of California, Irvine. *Batteries and Bulbs* is based on an earlier non-computer module developed in the Elementary Science Study series at the Massachusetts Institute of Technology (MIT). The average student takes about two hours to complete the dialogue, developing and testing a simple theory of how electrical circuits behave. In this first module, about fifteen minutes long, the task is to light a bulb, given a battery and wires. In testing with 12-year-old students, only one student out of seven could initially accomplish this task. At first, the student proceeds with the task, with little help except seeing if the bulb lights or not. The dialogue keeps an internal record of what connections were tried. If the student is making no progress, some aid is offered, based on what has been tried. In effect, the range of the intended discovery is narrowed down with this aid. Almost all students make the discovery, but at different levels. The discovery processs is individualised to meet the background and interest of each student.

Based on the rationale that feedback events (are they overt as explicit tutoring feedback or are they more or less covert as part of the diagnostic component?) are interpreted by the learner, the *KAVIS-III* System by Fischer and Mandl lays heavy emphasis on the role of metacognitive guidance and control. The learner is offered the capability at any time of his learning with the system to diagnose his current learning state and to localise his shortcomings. Since he is the agent of deliberate self-control by deciding whether and when he wants to be diagnosed and since he decides whether he is willing to follow the system's advice, learning in *KAVIS-III* is largely autonomous.

Many other examples, using a wide range of pedagogical strategies, could be given. Even in the narrow field of computer-based testing, several strategies of individualising tests have been employed. One aim is to allow shorter and more reliable testing. Several forms of systematic design have been used.

Artificial Intelligence Techniques

Artificial intelligence techniques can be used to facilitate the man/machine dialogue, for example through voice recognition or semantic analysis of a question or answer. These techniques are used in intelligent tutoring systems, although the approach is still at the experimental stage and requires sophisticated hardware; less ambitious methods could be introduced fairly quickly for the teaching of technology. The use of simulations and exploratory environments is an approach that would enable:

- A device to be presented in stages via a series of models of increasing complexity and realism;
- Interlinked devices to be studied separately by adjusting the "black box" operation of the computer on the basis of an experimentally established classification of the difficulties that arise;
- The student, by means of a kind of "construction game", to recreate some of the heuristics that have gone into the building of the device in question

It would seem that this form of learning, by making use of the flexibility of representation that is possible with a computer, encourages the transfer of knowledge between fields that are different but where the principles are similar. This approach can be an extremely fruitful one for instruction in new technologies.

There is still a great deal of discussion about whether artificial intelligence techniques can be used to simulate human intelligence and thus be of help in education. Some, like Hubert L. Dreyfus (1985), consider that computers cannot be used to simulate human intuition and that their use in education should therefore be restricted:

> Computers can and should be used only to provide the drill and practice by means of which human beings take the first step in their progress from analytic problem solving to intuitive action.

Lawler suggests that interacting with computers (especially when the student is in control) serves a transitional role as the child builds self-understanding and as we develop fuller theories of the mind (Lawler, 1985, p. 112):

> Although we may criticise a culture or subculture for leading people to think mechanistically about themselves, approximate, wrong theories can be a first step towards something better. Those children's theories of mind that will grow out of computer cultures are worthy of respect because they can serve as precursors to mature computational theories of mind which look toward sufficient complexity that they do not demean the person.

The adepts of artificial intelligence endeavour to simulate certain simple instances of intuition or flair by establishing an overall qualitative view of phenomena and by devising simple predictive rules based on "common sense" (see D G. Bobrow *et al.*, 1977). They consider that it is possible to develop courseware that calls for a higher order of thinking skills: assessment of a situation, problem-solving strategy, applying an algorithm.

There is no substantial evidence yet that Intelligent Computer-Assisted Instruction schemes are able to develop expert behaviour in novices, or that, if such improvements can be achieved in the Intelligent Computer-Assisted Instruction (ICAI) context, they will transfer into other contexts.

Interaction of the Student with the Environment

The importance of this interaction has been emphasized by S. Murray and L. Vogler (1984) in the context of the use of the microcomputer in the classroom. Olson and Brunner (1974), in their work on the cognitive aspects of learning, have developed a definition of the learning environment which seems to fit computer learning particularly well. They make reference to the external and internal environments of the learner, and to the development of models of the environment:

- The external environment ... consists of the information, concepts, skills, processes and attitudes which the teacher wishes the student to experience and learn, together with the physical environment; for example the classroom itself, the teacher, the other students, learning materials, technological resources, and even the football game visible through the window. Other elements which are not physical objects contribute to the learner's external environment; for example, the teaching strategies used in a lesson, the attitudes of the teacher and other students, or even the logic and thought processes of other people. Perhaps it would be even more accurate to say that it is the way in which these non-objective elements manifest themselves to the learner which forms part of his/her external environment.
- The internal environment consists of the student's own knowledge (facts, concepts, skills, attitudes) and perceptions of his/her own knowledge and thinking. The internal environment includes representations of itself and of the external environment.

A model of what a teacher does may be constructed using the notions of internal and external environments. The teacher shapes certain aspects of the external environment in order to influence students' internal environments. The teacher also monitors carefully the interaction of the student with his/her external environment Introducing computers into the classroom can bring major changes in students' external environment and the way they interact with it.

REQUISITE TEACHER COMPETENCIES

The specific competencies a teacher in the areas of science and technology must have to make effective use of new information technologies depend very much on the applications envisaged, the complexity of the technology to be used, and the access which the teacher has to the technology Because the demands and expectations placed upon teachers are likely to change rapidly in the next few years, the following list of competencies and dispositions is intended to apply to teachers who wish to make extensive use of information technologies:

- *Knowledge* of how to operate and maintain the systems used;
- *Understanding* of the uses of information technology by practising scientists and leading educators;
- *Vision* of appropriate pedagogical applications of information technology. In particular, a sense of how to use the technology to help students develop learning strategies, a strong sense of self-worth, and a spirit of collaboration and co-operation;
- *Sensitivity* to the messages conveyed in using the technology;
- *Awareness* of recent developments in science and technology;
- *Willingness* to invest time in re-examining old teaching methods, views on learning, and the organisation of the learning environment;
- *Perspective* on computation as a way of knowing and learning.

Competency in itself is not enough. Teachers must be given adequate support if they are to make effective use of the technology. In particular, they must have: the support and encouragement of their colleagues and superiors; time to learn how to use the new technology; sufficient access to resources; and good communication with colleagues doing similar work.

Chapter 4

EXAMPLES OF COURSEWARE

Courseware used for education in science and te、 nology varies greatly in purpose, form, complexity, and quality. The examples described in this chapter are organised according to purpose and form. The first two sections describe the most common software, used for drill and practice and for direct instruction (tutorial programs). The third section describes software to help students solve simple problems, to develop problem-solving strategies, and to develop complex arguments. The fourth and fifth sections describe courseware that allows students to manipulate data and explore relationships. The sixth section describes in detail types and examples of simulations. The seventh section deals briefly with software which uses animation to explain concepts and processes. The eigth section, on interactive educational games, includes examples of various purposes and forms, but having a g ne-like quality. The last section describes tutorial courseware of greater complexity, using notions from the field of artificial intelligence. There is no significance to the selection of courseware according to country, nor should the examples given be considered as a list of the best available in every category.

PROGRAMMED INSTRUCTION ON COMPUTERS

The first work in this area, for example that which was done by P. Suppes (1972), involved the transfer onto a computer of tutorials or drill-and-practice exercises prepared in accordance with the principles of programmed instruction, i.e. step-by-step progress, limited branching, emphasis on mastery, and simple responses. The programs employed a restricted form of dialogue, presenting only multiple choice or text completion questions, and made no use of graphics. The drill-and-practice exercises can be prepared at random and are usually displayed on a black and white screen with 20 or 24 lines of 40 or 80 characters; the student inputs his reply by means of a keyboard. Courseware packages based on these principles (although with improved readability) have been and continue to be produced in the thousands. A number of simple authoring systems enable the teacher to construct them himself without difficulty, using a set teaching strategy.

Many software catalogues list tutorial programs in the scientific field, e.g. the *CONDUIT Packages* (United States) on mechanics (movement, impacts, force, energy, etc.), on optics (lenses, diffraction, etc.), on electricity (resistances, capacities, circuits, etc.), on thermodynamics (heat, temperature, heat engines), on chemistry (elements and compounds, reaction equation, chemical equilibrium, chemical kinetics, etc.), on biology (cell division, Mendel's laws, etc.). All too often, however, the tutorial is no more than a series of electronically turned pages and the exercises merely a numerical comparison with no other comment than "Well done" or "Wrong, start again".

IMPROVEMENTS IN TUTORIAL AND DRILL-AND-PRACTICE COURSEWARE

Drill-and-practice courseware and tutorials have improved in part because of advances in hardware and in part due to better documentation, increased involvement of the student, and software design based on a careful analysis of teaching and learning. Improvements in video display technology including better colour, graphics and character forms have made it possible to display diagrams, graphs, tables, and text with more flexibility. The availability of other means of input, e.g. the graphics tablet, and of display, e.g. the videodisc, offer yet more flexibility to courseware designers. Better hardware does not automatically lead to better design or better teaching, but it does remove undesirable restrictions imposed upon earlier courseware.

Science tutorials of varying quality are now available in many subjects, including the following:

- General review for exams;
- Physics (mechanics, heat, light, gravity, diffusion, acoustics, strength of materials, energy consumption of the human body or of a house);
- Earth science (meteorology, geology, erosion, astronomy, comets);
- Technology (integrated circuits, plastics, materials);
- Chemistry (aromatics, atomic models, periodic table, formulae, equations, spectroscopy, chemistry concepts);
- Ecology (acid rain, land and water analyses, pollution);
- Biology (anatomy, digestion, reproduction, circulation, cells, plants, photosynthesis, zoology, dinosaurs);
- Health (physical and mental, nutrition, venereal diseases, the harmful effects of alcohol and tobacco).

In some cases the courseware package is accompanied by a printed document and a television programme One example is *The Voyage of the Mimi* (Bank Street College of Education, United States): 13 episodes and 13 fifteen-minute documentaries, a 160-page book, a teacher guide of 112 pages and four courseware modules with a teacher guide and a student guide. During the course of an exciting whaling expedition a whole series of concepts, operations and factual details are introduced: whales and their environment, measurement of the physical characteristics of sea water, reading a chart, methods of navigation, meteorology, solar energy, ecosystems on a desert island, repairing a ship, a visit to one of MIT's laboratories, etc.

The main improvements have come from an analysis of teaching and learning, with the commentary being adapted to the assumed student error. CONDUIT, for example, has encouraged science teachers to improve the quality of their courseware in this way (see H.J. Peters, in Bork, 1980). In order to remove the restriction of courseware dialogue to multiple choice questions, some development teams have designed and used tools that will analyse a sentence by key words, interpret a freely written formula, or convert a numerical result into different systems of units so as to maintain the dialogue (PLATO, United States; OPE, France) (see Le Corre, 1973).

A good example of effective dialogue is the series of physics tutorials used at the Educational Technology Center (ETC) in Irvine, United States. These are in the form of a set of quizzes which switch over to a tutorial mode as soon as the student encounters a difficulty (Bork, 1981 and 1985). The program *Heat* is a good illustration of this: the student is engaged in a number of thought experiments about familiar experiences with heat (reading thermometers, observing temperature changes, mixing hot and cold water, melting ice and boiling water). These exercises guide the student towards an understanding of the difference between the concepts of heat and temperature. The program has a conversational tone and unconstrained input. In France, a number of software developers use dialogues in a tutorial mode, where the student has to intervene frequently, e.g. on the principles of *numerically controlled machines* (Renault) and on the rudiments of *atomic physics* and *safety* (Electricité de France). More recently, techniques from artificial intelligence have been used to facilitate dialogue through voice recognition and through semantic analysis. The methods used for tutorials are the same as for other types of dialogues discussed in the following sections.

PROBLEM SOLVING

In problem-solving courseware, the student has to find an algorithm to solve each problem. Here we shall consider only those programs that do not use simulation. Often this merely involves carrying out a simple, straightforward operation (see Gauché, 1984), e.g. in chemistry: the calculation of the number of moles released in a reaction, the calculation of degrees of oxidisation, the possible extensions of a simple organic chemistry formula, working out pH values; in mechanics: calculating speeds and angles after an impact; in thermodynamics: applying isothermic or adiabatic laws of change. In many cases the calculation itself is done by the microcomputer once the student has clearly established his strategy for solving the problem.

Sometimes the problem that has to be solved is more elaborate and requires an analysis of errors in strategy. Examples of this are two diskettes produced by A. Bork *et al.* under the title *Problem solving in science* and a CNDP (Centre national de documentation pédagogique, France) courseware package called *Radac* which involves first learning how to write a reaction between an atomic nucleus and *alpha, beta, n* or *p* particles and then, with a number of conditional branches, predicting what types of particles are produced when all that is known are the nuclei or colliding particles.

In other cases, the object is to encourage logical reasoning. Some of the "best sellers" for children have a game-playing aspect: *Gertrude's secret* and *Gertrude's puzzles* (The Learning Company), *The Pond* (Sunburst Communications). The last of these is subtitled "Strategies in Problem Solving"; according to a description of it by Michael Shelly, the program applies "only two cognitive control strategies" amongst the 20 or so identified. A series of lily pads in the pond poses a problem for a frog. Only a portion of the pond is visible but the frog may explore the pond by jumping from lily pad to lily pad until a pattern is recognised. A successful pattern allows the frog to cross the pond. "It is doubtful that the skills developed in the search for patterns in a pond will transfer effectively to other types of problem."

One particular type of software consists of aids for problem solving, e.g. *Trouble Shooter* (Kepner-Tregoe). This software obliges the student to follow an analytical procedure: *i)* defining the problem; *ii)* developing possible causes; *iii)* testing possible causes. Each of these parts is then broken down further and further. Examples of problems are given in order to illustrate this procedure, which can be quite effective. Similar software has been prepared using techniques of artificial intelligence and therefore requiring specially adapted microcomputers. *Notecards* (Xerox) allows complex arguments to be assembled into a database. Relations between assertions of an argument structure can be indicated explicitly between pieces of text, graphics, and other information sources. When used to analyse the validity of arguments, it permits gaps in the supporting structure for the argument to be noticed more easily.

USE OF DATABASES

Some courseware incorporates small databases, such as a catalogue of chemical elements and compounds or the classification scheme of living organisms These databases act as reference documents for use during the program.

Other database courseware allows the student greater manipulation of the data. For example, *People Pyramids* (Education Department of South Australia), is a demography program which comprises three diskettes and constitutes a database and simulation of the populations of countries. It enables students to.

- View the population data for over one hundred countries as numbers or graphically;
- Enter new population data;
- Obtain projections of a population structure for any number of five-year periods;
- Print the numeric or graphical data on a printer.

It thus allows students to engage in the scientific processes of displaying data, adding to data, testing hypotheses, and communicating the results.

EXPLORATION AND DISCOVERY

In some courseware, students are given the opportunity to interpret phenomena through an imaginary experiment, the results of which are similar to a database display. Such programs are not simulations in the sense that they are not designed to permit the student to build or explore models of the phenomena. For example, *Chemistryland* (Martin Lamb, University of Toronto) provides students with an environment for the exploratory construction of atoms and molecules and the exploration of transitions of phase, using the first 18 elements of the periodic table. The program is in three parts:

- "Atom Factory" in which students combine nucleons to form nuclei;
- "Elemental Explorations" in which students control the temperature and observe the state;
- "Make a Molecule" in which students combine atoms to form binary molecules. Students can easily and quickly move from one part to another. The program indicates which combinations are stable, which substances are poisonous, and, when appropriate, state, colour, whether compounds are acidic or basic, and whether reactions are exothermic or endothermic.

The following example comes from Japan, where some 1 500 programs are available: *Relationship* is a role-playing game in biology which enables the student to investigate the factors and relationships which either inhibit or encourage the spread of disease (malaria). The program's objectives are to show the students how disease depends upon a multiplicity of biological factors, such as.

Factor	*Example*
germs	malaria
germ carriers	mosquitoes
environment	infected water
resistance	systems

and also on the control by humans:

water purification
medication
health education
financial resources, etc.

The program contains a database of records from villages, where medical teams have attempted to control the spread of disease The student adopts the role of medical officer for one village.

SIMULATION

The simulations discussed in this section are based upon an explicit model of the phenomenon to be studied. Simulations in which the student has to determine the model are called model-building simulations. Simulations in which the model is given for the student to work with are called behavioural simulations, which are of three types:

- Dynamic simulation: implications of the model (influence of the parameters);
- Methodological simulation: suitability of the model (range of validity);
- Operational simulation: behaviour of the model (simulated operation)

Simulation has to be distinguished from explanatory animation, which will be dealt with in a subsequent section.

Model-Building Simulation

The object of a model-building simulation is to construct or reconstruct a model from a series of data by devising a strategy of exploration that is close to the experimental procedure, identifying the significant variables, and determining their approximate relationships. In some cases, the area dealt with is governed by more or less imaginary laws that have to be rediscovered (microworlds). In the case of simple programs, the discovery process is guided in a constrained manner. In many cases the display is not very elaborate: there are some rather poor quality programs in use in French schools on Ohm's law, the Wheatstone bridge, resonant circuits, the movement of a projectile in a vacuum, Joule's law, etc.

A typical example, many versions of which can be found in a number of countries, is a simulation of Millikan's experiment, in which studying the equilibrium of an electrically charged droplet under the combined effect of gravity and a vertical electrical field is a traditional method of demonstrating the discontinuous nature of electrical charges. The ten or so programs on this subject that were examined treated this equilibrium rather like a game where the student has to adjust the numerical value of the electrical field in relation to the mass of the particle. Only one of these programs considered the case where the charge was a multiple of the elementary charge: not one made use of a simple dialogue to check whether the student had grasped the underlying concepts.

In some cases, the simulation is not closely guided and the student has to use his own initiative and imagination. There are many examples of this in mechanics (the movement of projectiles on land or in a gravitational field, the movement of charged particles in an electric and/or magnetic field, the refraction of light by a prism, acids and bases in solution) The following example is a program called *Flame Life* produced by John Olson, Elisabeth Churcher and Sandra Eaton:

> Students are given the opportunity to make repeated runs of a simulated experiment to determine the length of time candles will burn under an inverted beaker. Students may vary the size of the beaker, the number of candles, and the length of the candles (an extraneous variable) and organise the results in graphical and tabular form. Students learn to label axes, select scales, and plot coordinates. They gain experience in predicting, controlling variables, hypothesising, and interpreting data. The use of the program is

readily integrated with conducting the actual experiment. The simulation, based on actual data, allows students to focus on the organisation and interpretation of a greater volume of data than they would normally have time to gather in a science course

Here are two other examples from Bork *et al.* (1980):

- *Tribbles Families*. In this module, the student, behaving like a scientist, performs experiments, collecting evidence and building a simple Mendelian model of genetic inheritance. The extra-terrestrial creatures are studied to determine their attributes, how to predict whether they will mate with each other, and what rules govern the characteristics of their offspring.
- *Whirly Bird*. This program is designed to be used along with a piece of physical equipment, the *Whirly Bird* of the elementary school science curriculum The student is required to put together the devices, perform some experiments, and enter data into the computer. The program promotes a dialogue with students. encouraging them to develop skills of identifying and controlling variables, and to construct a model system to meet a given specification.

The LOGO programming language, which can be used for developing logic or geometry microworlds, can be used in other ways of relevance to science and technology education For example, sprites – graphical characters whose movement on the screen is governed by programmed rules – may be used to discover the rules of statistics, mechanics or the arrangement of gears CNDP, France: *Des ailes pour la tortue* (Wings for the Tortoise).

In some cases, the model building simulation is coupled with a practical manipulation exercise. Another example from Japan (Grade four, Takezonohigashi Elementary School) is a program dealing with the principle of balance. Students construct a balance of wood, string, aluminum plates, and nails. They explore, at their own pace and in their own sequence, the factors affecting the state of the balance: the length of the strings and arms, the shape and position of an unknown body made of modelling clay. They are frequently encouraged to record their results in their notebooks.

Students also make use of a computer simulation of the balance. Following the use of the computer, students are required to write a summary of their study. The teacher keeps an eye out for students who need to be helped. The computer itself may refer students to the teacher with the message, "raise your hand and consult the teacher". This gives more contact with pupils than in ordinary classroom lessons. Using the study unit creates a management problem: how does the teacher organise the learning activities when fast learners finish the course within five hours but slow learners cannot finish the course in nine hours?

Dynamic Simulation

Some dynamic simulations are designed to familiarise students with the significance of simple models that deviate from linear laws (energy dissipated by the Joule effect, Kepler's laws, the trajectory of a particle in a vacuum, collisions from a certain angle). Other dynamic simulations allow the student to vary the parameters on more complex models: generations of *Drosophilae*, the mechanism of *Embryogenesis* (Anxolabéhère *et al*, 1984); *Collision of Molecules* (pressure on a wall, diffusion rate of chemical reaction, etc.); the *Control of a machine* by coded instruction, the development of two or three *Competing populations* (CNDP. grass/rabbit/fox with epidemics and seasonal migrations). The program *Dynamic Modelling System* (Chelsea College, United Kingdom) allows students to insert mathematical models of physical and other systems. The student also chooses the variables and initial relationships and can observe how these variables are related to each other based upon the chosen models. For example: to study the population growth of rabbits, a young science student may introduce the model $R = R + B$, where the number of rabbits *R increases in each generation by the number of babies B* where *B* is a constant. *A* more realistic model of population growth would include a variation in the number of babies according to the food available. The student could then introduce an appropriate formula for *B*

Several programs are designed to provide an introduction to the physics of sound, for example:

Musicland. University of Toronto. Innovations Foundation (Martin Lamb). This program, operated using a graphics tablet, is a tool in four parts for creating and editing blocks of music (*Music Doodles*), orchestrating them with various timbres and articulations (*Timbre Painting*), assembling the blocks into a complete composition (*Tune Blocks*), and, of special interest for this report, designing the sounds themselves (*Sound Factory*). In *Sound Factory*, the following can be controlled:

- The amplitude of each of the first 16 harmonics;
- The amplitude of four points of the sound envelope;
- Frequency, amplitude and duration;
- Vibrato (by shifting the frequency of two otherwise identical components).

In addition the waveform itself can be edited graphically to produce very complex sounds

Here is an Australian example:

Lens is a computer simulation which traces a ray of light through a spherical lens. It is designed to assist year 10 and year 11 students to understand the basic properties of light. The manual explains the fundamental principles of optics and gives a brief outline of light and its properties. The program allows users to modify easily those parameters which will affect the path taken by light through a lens. Users are able to specify the type, position and size of lens, the refractive indices of the mediums through which the ray of light will pass and the position and angle of that ray. The trace of the ray produced on the screen can be saved for later use and traces can be superimposed over each other for comparison. *Lens* also offers the facility to create a *Slide show* which allows up to twenty screens to be saved and displayed.

Methodological Simulation

With methodological simulation, the aim is not to study the effects of one or more models by varying their parameters but to compare them with experience or common sense. Using methodological simulations can help students realise that a simulation is someone's theory of the phenomena being simulated, a theory which is wrong at its "edges". Students should never be allowed to confuse nature with simulations of nature. In fact, it is useful to ask students, whenever they are using a simulation, to find its domain of usefulness, outside of which it is either inaccurate or worse.

The CNDP's *Gal* (France), for example, requires students to compare the law of ideal gases with the results displayed, which are closer to those for a real gas (the hidden model is van der Vaals' equation). The students have to note that at high pressures the volume of gas is not nil (they have to reason in terms of the natural volume of molecules or the gas/liquid change of state). Taking the comparison further, they have to note that the pressure is not inversely proportional to the "free" volume but they need help if they are to understand that the qualifying term is due to the mutual attraction of molecules.

The following three examples are programs produced by Bork *et al* (1980):

- *Distance.* The module emphasizes the role of measurement in science;
- *Speed.* A rich environment is used to develop conceptual understanding of velocity;
- *Optics.* The task is to strike the target with a beam of light by bouncing it off a mirror. Data obtained from variants of this task are used either to support or to refute various models of reflection which are proposed.

In addition, there are a number of programs dealing with the non-validity of Aristotle's world (force considered to be proportional to speed whereas it is proportional to acceleration), e.g. a program produced by Leopold Klopfer (Learning Research and Development Center, Pittsburgh). At the IPN (Institute for Science Education) in Germany, programs were developed under the direction of H. Hartel in:

- *Electricity.* The electric circuit; voltage and surface charges; topology of circuits;
- *Hydrodynamics.* Current through a resistor; branching of a current;
- *Mechanics.* Force and acceleration; force, acceleration and friction; conservation of momentum; collision of two bars; contact forces and field forces.

The CUM-Project (*Computer als Unterrichtsmedium*) in Germany has developed:

- User software in connection with the construction of a computer interface for steering physical experiments and evaluating measured values;
- Simulation programs for informatics (searching, sorting, handling of linked lists and theoretical models as finite machines, Türing machines, etc.).

Operational Simulation

This involves simulating an experiment or a device and thereby learning the processes, the models and the systems, e.g. firing on a target or making chemical compounds react. For children, a "best seller" is *Rocky's Boots* (Learning Co., United States) where the object is to construct logic circuits on the screen (combination of the AND, OR, NOT functions). The humorous animation is tailored to a young public. The same subject is treated in a different way in *Black Box Technology* (Fiveways), which can be used as an aid to design. The following two programs are Australian: *Dirigible* enables a student to vary temperature, volume and wind speed to move a dirigible from *A* to *B* in a variety of wind conditions and altitudes; *Pisces* enables a student to control the growth of a fish population in a lake.

Two other examples are:

- *Circuit Design Program.* This is a program to help students learn the processes required to design fairly simple circuits which produce the required results;
- *Batteries and Bulbs.* (Bork *et al*). The student conducts an empirical investigation of electric circuits using batteries, bulbs and wires simulated on the computer. Concepts of current, circuit, resistance and parallel and series arrangements are developed in a qualitative fashion.

Simulation may be essential, as in the case of slow, rapid, dangerous, complex or expensive experiments, which are simulated by a number of different programs, e.g. *Chem Lab* (Simon and Schuster); in other cases, except on grounds of cost, it might seem unnecessary to simulate laboratory experiments at a school or university

The best method in many cases is to expose the students to simulation before taking them to the laboratory. At the OPE (University of Paris VII) it was noticed that students in an analytical chemistry laboratory worked far better and three times as fast after four hours of simulation. The program *Prelab studies for general, organic and biological chemistry* (John Wiley and Sons, nine disks) is designed for this purpose but uses a tutorial approach. The Huntington Computer Project (United Kingdom) provides complete support materials. Some of its 23 simulations in biology, physics and social sciences still are exemplary for this mode of computer use.

With operational simulation it is possible to adjust the parameters of a model. For example, for the game of *Tennis*, Durey (1984) studies the trajectories of balls and their effects in relation to the characteristics of the air, the racket and the surface. He analyses the movements of top-ranking players and examines how performance can be improved by using different rackets for different surfaces. One aspect of operational simulation is diagnosis, which is used in teaching how to detect faults in electrical circuits, electronic equipment (e.g *DAO*, CNDP, France), computers, cars, helicopters, etc. It is also used in spectroscopy. There are several examples of programs for teaching chemical analysis using *NMR*.

Biol (Salome *et al.*, INRP, France) presents batches of frogs that have metamorphic anomalies and requires the student to decide what medication or surgery they need. The student has to identify the nature of the anomaly (the role of the thyroid/pituitary in the hormonal control of the frog's metamorphosis).

Operational simulations sometimes require sophisticated hardware as in the case of *Guidon* (Clancey), which is based on a *Mycin* (medical diagnosis) expert system. The knowledge contained in the *Mycin* rules is screened by a set of pedagogical rules that make it possible to monitor and corroborate (or criticise) the logic of the expert system, which displays the probability of its conclusions.

Operational simulation is still the method of choice for simulating the behaviour of a complex system. Some types of simulator can be extremely expensive, e.g. the *Space Shuttle* (NASA), an *Aircraft* (Airbus Industrie et Aéroformation), and a *Nuclear power station* Electricité de France (EDF). Some highly simplified but very impressive operational simulations operate on microcomputers. *Aviator* is a well-known one and is used to test the compatibility of microcomputers. *Three Mile Island* from Muse Software and *Scram* from Atari's Program Exchange are impressive tools of exploring the design of nuclear reactors and serve as strong motivators for discussions; however, they are set up to make system failure likely, even unavoidable, in order to make the play of the "game" challenging. *Electrical Power Systems* (Imperial College, London, 1984) is the planning, design and operation of a power system to ensure minimum disruption of electricity supply. The package contains interactive programs for load flow, security enhancement and fault level calculations.

EXPLANATORY ANIMATION

The first examples of explanatory animation on a computer date back to the 1960s when Judah Schwartz displayed on a computer screen the wave functions in a potential well, the movement of different bodies and the relative distortion of a parallelepiped, and was thus able to produce instructional filmloops.

- In physics, animation can now be performed on microcomputers, e g. longitudinal and transversal *Waves*, the propagation of a pulse (see Borghi *et al*);
- In technology, animation will help to explain clearly the operation of a *Petrol engine*, a *Robot*, a *Microprocessor*, a *Turbine* (EDF).
- In biology, there is the IRL Press material on *Muscle contraction, pH titrations. Photosynthesis, Protein structure, Genetic code*

- In anatomy, *The Body in Focus* (CBS, Greenwich), explains and shows major body systems and allows students to peel away layers of the head, torso and arm to reveal underlying structures. A review feature tests student comprehension.
- In chemistry, *Molecules* are represented by wire, spheres and rods, or compact models, or models of molecular surfaces, for demonstrating the topology of molecules, the dynamics of molecular configurations, the designing of medicines, the correlation between structure and activity, the calculation and representation of individual mechanisms, etc. (see J. Weber, University of Geneva: Infographie).

For the latest applications powerful computers are necessary, but there are many educational programs for microcomputers. These can be used either by the student, particularly if he/she can control the various parameters, or by the teacher in front of the class.

INTERACTIVE EDUCATIONAL GAMES

Video games have found their way into most types of educational software. The game may have little to do with learning about science and technology or it may be designed on pedagogical principles. In some instances, a video game is offered simply as a reward to a student who has obtained a good score in a number of exercises. In other cases, the game has a weak connection to scientific ideas. In one program students may play *Pac-Man* in a labyrinth where a flask pursued by a beaker has to find the right chemical compound. Similarly, *Chemrain* is the equivalent in chemistry of *Space-invaders*. The educational value of these games is not proven; nevertheless, skills associated with data handling, discussion, research, planning, analysing, hypothesis generation and testing, forecasting, exploring, discovering, observing and organising can be developed through the use of games, particularly interactive computer games. The better educational games require that students interpret information displayed on a screen in a variety of ways, map out strategies, enter correctly spelled directions, and work with a partner, and encourage students to concentrate on a task which engages them for periods of 30 minutes to an hour. They combine learning with entertainment, and make it a pleasant experience.

For children who are not yet able to read, the *Mademoiselle Merveille* series (L'Espérance-Labelle, Guérin, Montreal) introduces them to a number of animals, forms of transport, stringed instruments, the difference between sweet and sour, tools and even some simple operations on a microcomputer such as entering into memory what they have drawn.

We referred earlier to the game-like nature of a number of programs: *Dirigible* can be played by as many as six teams. Two other examples are: *Mind Games Biology* (DEE, Lafayette): up to four students compete in an on-screen board game. Players advance by answering one of 140 biology questions correctly. Teachers can add their own questions. *Weather Command: A Science Game* (Educational Audio Visual, Inc.). The participant has the opportunity to provide ideal weather conditions for space visitors. If the student fully utilises the option to view and study "weather hints", it is possible to learn the effects of increasing air pressure, producing a cold or warm front, or how to generate a thunderstorm. This program requires considerable prior knowledge to succeed in changing weather patterns.

Electricity and Magnetism (DCH Educational Software) helps students to complete an electrical circuit. The game involves finding the missing elements in an island divided into 60 segments, but this involves a considerable waste of time and is of no great instructional value. *Sir Isaac Newton's Games* (Sunburst Communications Inc. USA) is a series of games which deals nicely with the transition from Aristotelian intuitions about motion to Newtonian ones.

Qualities such as co-operation and persistence at a task are evident where adventure games are used with children The range of adventure games is now sufficiently broad to allow the teacher to choose different games for students of different interests and abilities – from *Farenheit 451* to *Flowers of Crystal* Another adventure game which is under development has a more meaningful scenario A bowl of food has to reach its final destinations by discovering the complicated routes that lead there: mastication with the help of an input of saliva, the journey down to the stomach and the intestines with the action of gastric juice, bile, etc.

INTELLIGENT TUTORING SYSTEMS (ITS)

Intelligent tutoring systems have evolved from earlier tutorial software in the 1960s, which in turn was an improvement over exercises that involved filling in blanks, multiple-choice questions and electronic page-turning. A turning point was reached in 1972 when Carbonell developed the program *Scholar*. It employed three techniques which are characteristic of intelligent tutoring systems:

- Analysis of user responses to allow fairly unconstrained dialogue;
- Assessment on the basis of knowledge and inference rules;
- Use of tutoring strategies based on the progress of the student.

The techniques were developed in an attempt to allow the program to understand the student's comments, to determine what reasons the student was using and in what order, and to figure out why the student was using those particular reasons in that particular order. Examples of tutoring systems designed to address the same concerns using similar techniques are given in the remainder of this section.

Improvements in Tutorial Dialogues

Recent advances in computer technology make possible improved communication between the student and the computer.

Improvement of the Dialogue in Natural Language

It has been possible to achieve a virtually natural dialogue on limited subjects through a logical analysis of key-word skeletons (PLATO 1965, OPE 1967). Considerable progress has been made in the techniques of comprehending syntax and semantics. The advances that have been made by the Centre de Recherches en informatique de Nancy (CRIN) and the *Mosaïque* project at Grenoble are two examples of what can now be achieved on a microcomputer. *ACE* (Analyse Complex Explanation) is capable of analysing in detail an inconsistent and incomplete explanation on a narrow subject (nuclear paramagnetic resonance). The analysers are even expected to provide a response to an unforeseen move on the part of the student by taking the context into account.

Improvement of Graphics and Verbal Presentations

Improvements in graphics and verbal representation are used in a range of programs for teaching foreign languages, music, reading and writing; for speech therapy, teaching, and for simulation. Improvements will also be used in the *Sirène* program for persons with hearing defects. The *Steamer* program (1979), which demonstrates how a heat engine works, uses high-quality graphics to illustrate various operations.

Expert Systems on Microcomputers

User-friendly systems and interfaces can be created that will accept abbreviations, spelling mistakes and syntax errors in the dialogue with no loss of meaning. Expert systems using inference/deduction techniques for special applications can follow a line of reasoning involving incomplete inconsistent and garbled data. Some small scale systems can operate on microcomputers: *George* (Cabrol *et al*) is an aid for problem solving in chemistry and provides simple heuristics for solving a given elementary problem.

Expert Systems on Minicomputers

A tutorial program can be linked to a larger-scale expert system. For example, the operations simulated in the *Steamer* program have to be performed in a given sequence. An expert system detects and comments on errors of operation. The expert system manages about one hundred rules such as, "The circuit must be drained before opening this valve". The *Sphinx* system, expert in diagnosing jaundices, also serves as a teaching device by guiding and criticising the student, informing him/her of errors, premature diagnoses, and the pertinence of his/her remarks. The *Titus* system, expert in CAD (Computer-Assisted Design), can help the student by relieving him of routine calculations. The student, being guided at each stage, chooses the physical models, the mathematical equations, the mathematical procedures, the methods of problem solving, and the input into the machine (geometry, physical constants, limit conditions, visualisation of the results) These systems, unlike those we shall be examining later, are not designed to handle educational psychology data.

Use of Databanks

Artificial intelligence can be of assistance in retrieving information from a database. It is worth noting that most of the work being done in Japan on the educational applications of artificial intelligence concentrate on this aspect:

- Developing a generative database for each course;
- Collecting data from CMI (Computer-Managed Instruction) material;
- Determining strategy on the basis of a classification of errors.

Modelling the Student's Reasoning

By building rules of inference into the programs it is possible to improve on the analysis of the learner's behaviour without actually constructing an elaborate representation of the learning process. A good analysis of the student's comments is needed both to carry on a meaningful dialogue and to identify the rules of inference the student is employing even if the arguments are incomplete. The programs include heuristics to handle such ambiguity The system is designed to help the student learn by doing.

SOPHIE was the first major program to use artificial intelligence techniques for psychological applications. It was originally developed and worked on for about ten years by Burton and Brown and thereafter in conjunction with de Kleer. In 1973 the aim was to provide instruction on how to carry out electronic repairs on a regulated power supply used by the US Air Force. Initial work at the University of Irvine (California) was followed by two years' research at Bolt, Beranek and Newman (BBN) in Cambridge, United States.

- *SOPHIE I* (1975) was capable of evaluating the learner's hypotheses, criticising his measurements and accepting virtually any question raised on the subject.
- *SOPHIE II* (1976) was improved by the addition of new instructional elements and, in particular, because the expert revealed his strategy and tactics (becoming a "glass box" rather than a "black box").
- *SOPHIE III* (1978) incorporated improved educational strategies and improved techniques for modelling the reasoning and the learning process It then became clear that further improvements would seriously reduce response time on the equipment being used (PDP 10, 256 K).

The authors, who are currently with Xerox (Palo Alto), continue to draw lessons from *SOPHIE*: their opinion in 1982 was that they had "put the cart before the horse" because what they needed was a theory of human understanding Students would ask for qualitative explanations, whereas *SOPHIE III* would deliver only pre-compiled explanations for the rules of its specific circuit. The authors therefore turned their attention towards the theory of intellectual models on less complex subjects.

Detailed Analysis of the Learning Process

The following Intelligent Tutoring Systems have the same sophistication as the preceding examples, but in addition, are constructed using a model of the learner. They are of importance in research in the fields of cognitive psychology and artificial intelligence. The earliest examples, *Buggy* (Brown and Burton, 1978) and *LMS* (Sleeman and Smith, 19) concern arithmetic and algebra. The learner is modelled by a system applying right and wrong rules against a background of noise caused by spelling mistakes.

Listed below are several examples of programs produced by the Learning Research and Development Center (LRDC) at Pittsburgh, United States, and designed for a top-of-the-range computer system with window and mouse facilities (Xerox 1108).

- *Logic*. This program, designed by Marty Kent, requires the student to build an electronic circuit incorporating logic gates. It checks the coherence of the construction and displays the flows produced. The circuits can be memorised for subsequent use in more complex constructions. *Logic* can trace dynamically the history of the circuit layout either as designed by the student or as proposed by a tutorial package incorporated in the program.
- *Optics*. This tutor, which was developed by Peter Reimann, involves analysing the path of a ray refracted through a lens. It enables the student to construct an experimental situation, predict the refraction and compare his prediction with that worked out by the system. A refinement is planned whereby the student would be able to describe in pseudo-natural language the phenomena he has to predict
- *Ohm Tutor*. The system, designed by J. Bonar and J. Ivill, is designed to teach Ohm's and Kirchhoff's laws It incorporates a series of exercises in which circuits are presented to students who have means of measuring and varying voltage, resistance, and current.

The following programs were developed in Europe:

- *Electre* (Caillot *et al.*, 1984) deals with resistance systems incorporating a number of batteries. The learner is modelled by an expert system using metarules, rules and heuristics.
- An intelligent learning environment on the superposition of motion is being developed by Mandl *et al.*, Germany. The goal is an on-line diagnosis of knowledge at various stages of the learning process in which the actual knowledge of the learner (learner model) is compared to the knowledge of an expert in a corresponding learning or problem-solving situation (expert model).
- *KAVIS-III* (Fischer and Mandl. 1986) is an interactive audiovisual instruction system centrally based on on-line feedback. Feedback is administered either as a Prologue informing the learner about the logical status of his error, as audiovisual feedback correcting misconception, or as a combination of both. According to the nature of the learner's error, feedback is attuned differentially. Diagnostic protocols further inform the learner about his current state.

Chapter 5

HARDWARE AND SOFTWARE

Current developments in computer hardware bring new possibilities for enriching education in science and technology. It is becoming easier to connect laboratory equipment to computers. Inexpensive devices for display, measurement and control are coming onto the market. Flexible software for controlling all devices is being developed. While these advances are far from complete, we can now begin to put in the hands of students and teachers some of the new professional tools of engineers and scientists. Just as we can now give students new professional tools for writing, calculating and organising data, we can also give them tools for experimentation and design.

HARDWARE AND COURSEWARE SPECIFIC TO SCIENCE AND TECHNOLOGY

Current Situation

Educational decision-makers face difficult choices in acquiring computer hardware. At present there is a large and increasing gap between the sophistication of equipment used in science and industry and that commonly found in schools. At the same time, school systems are not yet in a position to provide students with full access even to the least expensive computers. Nevertheless, it is important to set criteria for hardware selection in order to ensure that whatever equipment is purchased will be useful for a reasonable length of time.

In order to provide for the applications discussed in this first part, it is important to have equipment with the following characteristics:

- Good characters, choice of fonts and sizes;
- Good graphics with high resolution (788 or 1 024 or better, TV aspect ratio);
- Possibility of animation;
- At least 16 colours active at one time, out of a much larger total palette;
- Standardized operating system to support portability of software;
- Standardized interfaces for measurements and for control and feedback experiments.

Decision-makers can choose, as many have done, to purchase existing hardware, or they can encourage the development of hardware specially adapted for educational use, as has been done in several countries. For example, in Canada, the Ontario Ministry of Education has created functional specifications and provides grants to school boards to cover a large portion of the cost of microcomputers meeting the specifications. The Ministry is currently establishing more advanced specifications which it expects will attract large international manufacturers.

Material Designed for Disabled Students

Some computers have been adapted for use by handicapped students. An Australian-designed computer has won the British Institution of Electrical Engineers prize for helping disabled people The computer called CEDRIC, features a cursor that responds to eye movements, and is designed as a communication and control aid for people with high level paralysis and loss of speech. The user may issue commands by focussing on w ds or commands on the screen and then blinking. The system is relatively expensive ($20 000).

The South Australian Education Department has designed a low-cost writing/games/communicator microcomputer (Educomm) for physically or mentally disabled children, with an estimated price of approximately $750. The Educomm device has been designed to accept any momentary action type switch to provide input, and to use a standard television as the output device

Courseware Concerned with Hardware

There are many educational packages concerned with the functioning of a computer and its interfaces. Many of them are written for a specific home computer. Some are more general. For example:

- *Understanding Computers* (Encyclopaedia Britannica Educational Corporation) is a single package for a wide-ranging survey course, designed to introduce junior high school students to compute The activities include multiple choice quizzes, simulations, demonstrations and programs for several computer applications. Another example is *Microprimer*, written as part of a United Kingdom program for primary school teachers;
- *The Information Connection* (Ski Soft Inc.) is designed to promote better understanding of computer telecommunications for use with people aged 10 years or older, regardless of their previous computer experience. It defines the basic concepts, explains the necessary peripherals for telecommunication and presents steps to be followed. The program predicts possible mistakes or errors and is designed to prevent them

There are many animated films describing the behaviour of memory units during the various operations performed by a microprocessor, for example:

- *Peeko-Compter* (Acorn-electron) simulates on the screen the simplified operation of a microcomputer with a view to familiarising learners with machine language. basic instructions, step-by-step or complete operation of the programs entered, representation of the content of memory and registers The Centre Mondial Informatique et Ressource Humaine has developed microworlds on the same subject: le *Microprocesseur*, l'*Interpréteur*, l'*Arbre*.

THE USE OF VIDEODISCS IN SCIENCE EDUCATION

The Videodisc System as a Self-Study Tool

Using the quick search function of the videodisc, a student can learn topics by himself In this case, a computer is not necessary. The menu of the contents may be printed on paper or recorded on special frames on the disc. This application could be used for science club activities, for students who have missed classes or for students who do not learn well through group instruction.

The Videodisc with a Computer as Interactive Video Tool

An interactive video learning environment may be realised by controlling the videodisc player with a microcomputer. Tutorials and simulations, which have often been used in science and technology courseware, will become more realistic and effective by using video images, even with small and inexpensive CAI systems. Very little computing power is needed to control a videodisc player effectively.

The Videodisc System as a Teaching Aid in the Classroom

The videodisc system is also useful for teaching in science. It may be used in three phases of classroom instruction:

- Introduction of new concepts. Video images may be used to arouse students' curiosity. For example, after showing an elephant supported by paper cups, a teacher could introduce the composition and decomposition of forces. Large-scale experiments, which are impossible to do in the classroom, may be experienced indirectly using a videodisc;
- Experimentation and observation. For explaining important points of an experiment and to make careful observations, the teacher can stop at any scene of a moving picture. Computer-generated display may be easily superimposed, for example, to show force vectors;
- Consolidation and review. Students may compare their predictions and explanations with those accompanying the video images. Since the videodisc has two voice channels, the teacher can first suppress the channel on which the explanation of the results is recorded and tell students to develop their own hypotheses. The teacher can then replay the same scene with the explanation audible. The same part of the videodisc can thus be used several times for different educational purposes.

Preparing Learning Materials on Videodisc

To permit the most flexible use of the videodisc in science education, individual scenes should be short (30 seconds to three minutes per topic) compared with the duration typical of a video tape recorder (VTR) materials (five to twenty minutes). It should be kept in mind that scenes will be used in much more detail on a videodisc than with a VTR because of easy random access to individual frames.

Examples of Using the Interactive Videodisc

In Japan, Victor JVC sells eight *Science Education Videodiscs* for lower secondary schools (Physics, Chemistry, Earth Science, Biology). A special project using videodiscs in 13 secondary schools is underway and tests show that the effectiveness in self-study is comparable to that of having a teacher carry out experiments. The Open University (United Kingdom) has developed programmes in scientific and technical education (CET-NIVE,

1985) dealing with such topics as *stress on various materials*, a case simulation made for a pharmaceutical company (*diagnosis and treatment of gastric ulcers*), and a programme on *anatomy* at the University of London

According to Laurillard (1984), videodisc use in the United States is of three types: tutorial dialogue (University of California, University of Utah), multiple choice (UCLA, Wicat) and database management (Washington, ISO, MIT). The tutorial dialogue is highly didactic, difficult to design and tends to make relatively little use of the random access feature of videodiscs as most of the individualised responses come from the dialogue itself The multiple choice method is pedagogically questionable. because it constrains the student's response, but makes good use of the videodisc The database management technique gives much greater freedom to the student to explore the source material on the disc but to use it well, the user needs much better forms of accessing and indexing than are currently available. Proper choice and design of forms of interaction are critical for the success of interactive video.

There is a videodisc made by the Educational Technology Center at Harvard called *Seeing the unseen*, that deals with the making and testing of hypotheses

In occupational training, examples of the use of videodiscs are:

- *Electronic maintenance/repair* manuals McDonnell-Douglas, *Motorcar maintenance*, *Aéroformation* (Airbus Industries);
- Skills training/upgrading: American Heart Association to teach *Cardiopulmonary Resuscitation (CPR)* The program employs a videodisc player, computer and a life-sized dummy, wired to respond to the student's efforts to get the heart pumping again;
- British *Steel* Gartcosh calculate that they have already saved four times the cost of producing a training programme through a dramatic improvement in operator performance;
- The EETPU (Electrical, Electronic Telecommunications and Plumbing Union) are using interactive video as a means of extending and enhancing training in *introductory solid state electronics*.

MICROCOMPUTER-BASED INSTRUMENTATION OR LABORATORY (MBI or MBL)

Most computers can be readily connected to a variety of devices for measurement, display, and control. They can be used for teaching in science and technology as follows.

- Measurement of any phenomenon: electrical, mechanical, chemical, optical, acoustical;
- Printing or plotting graphs;
- Processing of data with a view to modelling;
- Controlling all types of actuators.

Robert Tinker of Technical Education Research Center, Cambridge, MA and his group have devised a wide range of transducers for use as data collection front ends to microcomputers, including distance and velocity ranging, temperature measurement, light level and sound level detectors and now spectrometers. The Microelectronics For All (MFA) project developed by MEP (England) as a course for twelve to thirteen-year-old students, introduces the key elements of modern *digital electronics*.

Many companies sell interfaces adapted to a microcomputer, e.g. Griffin for the BBC:

- 4-bit *Switch input*. A simple application would be in biology; four pressure pads can be distributed around a small animal cage to detect the frequency of visits to key areas, such as water, food, sleep and exercise;
- 8-channel, 8-bit *Analogue Digital Converter (ADC)*. Many items of laboratory equipment such as pH meters, sensors and oxygen meters are fitted with separate outputs for connection to chart recorders. Use of the ADC can easily be enhanced by combining it with an output control feature. For example, an input from a pressure sensor can be monitored and the equipment switched off when a particular or dangerous pressure is achieved;
- ?-bit *TTL input and output ports* are often used together to allow the computer to talk to digital electronic units such as LEDs, electronic bleepers, and push-button switches. For example, traffic lights may be simulated using switches and LEDs;
- 4-bit *relay output*. The relays may be used to control small motors, lamps, solenoids or secondary relays to switch to even higher currents and voltages if required.

Many captors (input devices) are marketed at less than $100 for measuring temperature, pressure, magnetic fields, movement and light. There are also inexpensive (about $30) simple output devices such as stepping motors, gearboxes, and liquid pumps, as well as more complex devices such as robot turtles ($150), three-wheeled robots ($200), and robotic arms ($600).

The *Fischertechnik* series (Germany) is made up of robotics kits that are assembled like construction games and enable the learner to put together small plastic robots that can be connected to the computer.

VELA (Educational Electronics) is a VErsatile LAboratory instrument that can be used in place of conventional instruments such as scalers, frequency meters, storage oscilloscopes and data loggers. VELA has 17 programs in permanent memory which allow VELA to become many different instruments, ranging from transient analyser to waveform generator to radio-active pulse analyser.

In the LOGO/Lego project of MIT Professor Seymour Papert, school children are testing prototypes of materials (which should be available in late 1987) consisting of electric motors, lights, light sensors, and touch sensors, together with a computer interface and a version of LOGO which includes commands to control the input and output devices. In this way, children can automate and control a wide range of mechanical devices (e.g. vehicles and appliances), all built from Lego parts. Similar projects combining LOGO and Lego are underway in other countries.

As part of the French *EVARISTE* project *(Etude et Valorisation des Applications de la Recherche en Informatique sur les Systèmes Tutoriels d'Enseignement)*, software has been produced for modelling simulation (developing a model) and methodological simulation (confrontation of the model with actual experience) in the following subjects:

- Metabolism: oxygen probe for man, mouse or plants;
- Kinetics of chemical reactions: conductimeter, spectrophotometer, photometer;
- Characteristics of multipoles: test plate;
- Movement of trolley, disk or pendulum: elongation and time captors;
- Traffic light operating cycle: model of lights;
- Control of a crane: modified toy crane;
- Machine tool (lathe): tool holder fitted with strain gauges;
- Heat propagation: thermal captors.

A particularly interesting example is *Computer-Aided Design* (Five Ways). This program simulates a complete Computer-Aided Design/Manufacture system The operator can design a shape on the screen and then view a three-dimensional representation of it, altering it until it appears exactly as required. A small lathe, developed especially for use with the software, can be plugged into the microcomputer to actually make the shape designed. In this way, the program presents the complex CAD/CAM process as a series of easily understandable steps: designing, editing, machining. The ease with which the design can be altered before the finished shape is machined, and the accuracy of the machined shape, demonstrate simply but powerfully some major advantages of CAD/CAM systems in industry.

THE MICROCOMPUTER AS A TOOL FOR CALCULATION, DATA PROCESSING AND CONTROL

Programming Languages and Associated Courseware

Knowing how to program can free students from the mundane aspects of calculation and data manipulation. In technical and scientific training, the student has to be concerned with the significance of calculations (rather than with the method of calculation), the interpretation of data (rather than with how to collect it) and the effectiveness of control (rather than with its logic). There are many packages for teaching programming languages (BASIC, PASCAL, ADA, Prolog, LISP, etc.), for example:

- *Visible PASCAL* (John Wiley and Sons). The instructional strategies provided for the student offer guidance and student control, discipline and creative expression. This courseware does not contain all instructions normally available in other PASCAL systems (e.g. records and pointers);
- *MENO* by Soloway (1983) is an intelligent tutoring system for teaching PASCAL.

Applications of LOGO and Object-oriented Languages in the Acquisition of Concepts

A programming language may be used to construct, describe and model a situation. Building a simulation through programming is both a scientific and technological activity. It is scientific in that it entails developing and testing a formal description of a process. It is technological in that it involves the construction of a system. The single process of programming thus includes theory building (designing the program), construction of experimental apparatus (building the simulation with appropriate displays and interfaces) and experimentation (running the simulation under various circumstances to see whether the program is working as expected). Constructing a program is in some ways an alternative to conventional mathematical formalisation.

In mechanics, the behaviour of a system is often accounted for by specifying local conditions such as the state of motion and the forces. The global behaviour of the system is obtained by integrating the equations of motion starting with the local conditions. The integration is effected in programming by iteration. Using LOGO to learn mechanics and explore the behaviour of systems is the subject of at least two books and some interesting research [MIT: Abelson and diSessa (1980); CNDP: A. T[illegible]er]. Some of this work was done using a robot turtle or a simulated turtle on the computer screen. This approach could become more widespread as computers and controllable devices become more commonplace in schools.

One of the basic contributions of object-oriented languages is that they make it possible to study microworlds made up of several objects interacting within a system. Programming in object languages naturally leads on the one hand to consideration of local properties of the constituents and on the other hand to the results of the interactions, thus providing a method for the analysis of complex systems. The pioneering work on object-oriented languages done by Alan Kay and associates in developing Smalltalk (Goldberg, 1979) is now finding its applications on microcomputers such as the Apple Macintosh. This should allow non-programmers to use object-oriented languages easily. In one such example, parts of the system can be selected, positioned and interconnected by moving icons under the control of a pointing device called a mouse. The system thus constructed can be internal to the computer or it can be linked to various input and output devices such as sensors and motors

General Programs

In addition to general tools such as word processors, spreadsheets, and databases, there are tools tailored specially for use in science and technology:

- Siegel (1985) published a guide to 40 *statistics* programs for microcomputers;
- *SuperPlot* (Edusoft) is a function graphing program which is designed for students in grades eight and above. It graphs any polynomial, trigonometric, logarithmic, or exponential function. Since the program is designed to display a maximum of five functions at one time, the user can superimpose graphs and can compare the functions via scrolling, zooming and expanding. Although the program lacks some useful features (provision of intercepts, explanation of limits of its range, unambiguous notation, provision for hardcopy) it is still considered to be a good graphing program;
- A number of very elementary programs make it possible to draw histograms, calculate regression lines, exploit a series of experimental measurements, comparing them with a model and proposing other models For example, *LSF, The Least Squares Curve Fitter* (Prentice Hall) is of good quality. *CINE* (CNDP, France) makes it possible to compare measurements of chemical kinetics with reactions of different types.

AUTHORING LANGUAGES AND AUTHORING SYSTEMS

Authoring languages and authoring systems are designed to assist with the production of courseware through special commands and editors for the creation of text, graphics, and animated images, and for handling dialogue and analysing student responses. What role they will play in the development of courseware for education in science and technology is uncertain. According to one authority with extensive experience in science courseware development, other strategies are likely to be more fruitful (Bork, 1985):

> A large amount of effort has been thrown into development of CAI (Computer-Assisted Instruction) languages or interactive "CAI systems" whose purpose supposedly is to make it easy for one person to perform the entire process. Hundreds of millions of dollars have been spent in developing such systems. I do not believe that these strategies are successful. At best, they can work for limited small personal programs. The relatively small amount of material of any value developed with all CAI languages and systems is a clear empirical indication of the poverty of that approach. I do not believe it likely that

large amounts of excellent Computer-Based Learning material will be created using facilities such as *Pilot*, *Planet*, *Tutor*, *Coursewriter*, *Decal*, *Asset*, *DAL*, or any of the other explicit languages and authoring systems of this type For example, *Pilot* has existed for many years. It has been implemented on many different computers, and it has been heavily promoted for years in ads by major personal computer vendors But to the best of my knowledge, very little good Computer-Based Learning material is available in *Pilot*. The "Renaissance man" approach, with one person doing everything, is misguided. Most authoring languages and systems lead to trivial Computer-Based Learning material.

This point of view is widely held b it should be pointed out that recently certain authoring systems have been put to good use by teams producing courseware within organisations, by firms specialising in courseware development and by school publishers. The systems cost between $3 000 and $20 000 (while the price of *Color Pilot* is $80): *Tencore*, *Mentor*, *Ego*, *Duo*, *Diane*, *Authority*, *MicroPlato*, *Philvas*, *Wise*.

An intermediate point of view is that teams of teachers and advanced students will be able to create materials for their own use if they are given sufficiently powerful tools to permit flexible design with little or no programming. For example, *Menulay* (Martin Lamb, University of Toronto) is an interactive user interface management system which includes powerful editors for graphics, animation, and synchronised speech and sound.

Efforts are currently being made to link expert systems with authoring systems. However, an expert system as currently conceived in artificial intelligence is limited to providing a diagnosis or committing the user to execute certain actions. The technical competence of this user is assumed to be perfect, which is not the case in CAI, where the learner may experience all sorts of difficulties in following the instructions given to him. A good teacher recognises this situation and can cope with it by switching either to other examples or to a different approach while maintaining the learner's attention at a high level. In order to capture these two aspects of the teacher's expertise in a CAI package – maintaining interest through a high level of interaction and using adaptive strategies – the software tools required go far beyond a combination of rule-based expert systems and authoring languages of authoring systems.

Chapter 6

PROMISING AREAS OF RESEARCH AND PROTOTYPE DEVELOPMENT

This chapter contains a description of the areas of research and development which the Working Group believes should be pursued if new information technologies are to be used to further the aims of education in science and technology. It is important that these activities be carried on in concert. Basic research should be continued to help us understand the beliefs and values associated with the bringing together of science, technology, and education. We also need to continue investigation of the relationship between the computer and the human being, including those aspects of our thinking which can be modelled and fostered by the computer.

RESEARCH ON VALUES

Analysis of Values

Control is a central issue. We want to be in control of our resources, of our lives, of our learning, and sometimes of each other. Science and technology are sometimes viewed as vehicles for control and mastery. Will computers be used predominantly to control learning or to put the learner in control? How should the balance of control be worked out amongst teacher, student, and computer? How will the distribution and organisation of scientific knowledge be controlled in the future? Will the influx of new technologies control the way the teacher works? Are students and teachers going to develop an insatiable appetite for computer power?

Access is an issue related to control. Access to the technologies is influenced by the presence and availability of equipment, the knowledge of how to use it, self-confidence and interest in using it, and social acceptability. Once equipment is physically accessible, access is still influenced by the environment and by the student's attitudes. How will we ensure that all students have fair and equitable access?

An equally important issue has to do with the meaning of humanness. How have science and technology changed our views of what it is to be human? Are we becoming more like the machines we build or are they helping us to be more like what we ought to be? Is our scientific and technological activity improving the quality of life of some to the detriment of others and so degrading all of humanity?

These issues should be addressed through philosophical and historical analysis of the beliefs and values associated with science, technology, and education. Debate should be encouraged by students, teachers, researchers, teacher educators, legislators, educational administrators, and the general public. We need to sort out what values are associated with what forms of use of the technology and to reflect on what our values should be.

Views of Students and Teachers

There is a need for careful empirical and ethnographic study of the views students hold concerning science and technology, and concerning computers in particular, and of the conditions under which they hold those views. Is their perspective utilitarian, scientific, recreational, aesthetic, or spiritual? The work of each student in learning about science and technology and in using computers will be coloured by his/her particular world view. By understanding and respecting that view, the teacher is much more likely to help the student understand the concepts, processes, and values of science.

RESEARCH ON THE COMPUTER AND LEARNING

Computational Theories of Thinking and Learning

In the process of learning, the student works with knowledge of various types, which is changing, incomplete, and even contradictory. In building up new knowledge, guidance is needed. That guidance comes both internally through reflection upon the learning (metacognition) and externally from peers, teachers, and more recently from computers.

In making the computer a tool to guide learning, and in particular, to help students become aware of their own reasoning and develop strategies for improving it, two approaches show promise. The first is to give students tools for exploration and to let them work with their own knowledge–finding contradictions, reframing hypotheses, reorganising facts. The second approach is to provide more direct guidance through a tutorial program which draws students' attention to the reasoning they are using, and which points out contradictions, incomplete arguments, and misconceptions. This approach is based on models of the empirical knowledge of the domain under study, the rules of inference which might be applied within that domain, and possible lines of reasoning the student might take. In some cases the model is built up as learning proceeds. It is not clear whether the two approaches are alternate modes for the same learning or whether the knowledge developed in one approach is different from that developed in the other. For this reason, it is important to develop the two approaches side by side, somewhat in the way that an experienced teacher works out a balance between discovery-learning and direct instruction.

The Computer as a Medium for Learning

We need refinements in our understanding of the unique characteristics of the computer as a medium for learning. What symbol systems enhance or inhibit learning? What must a student learn about the operation of a computer in order to feel comfortable with it and confident in it, much as one would with a teacher? What distinguishes learning on a computer from other modes of learning such as listening and discussing, reading, viewing films, and working with experimental apparatus? How can the computer best be linked to other media for effective learning?

Learning Concepts and Processes with a Computer

We need to better understand how teaching modes and the various forms of computerised tutorials, simulations, and tools can be adapted to each other to produce powerful new modes of learning in which the computer is truly an extension of both the teacher and the learner. In particular, we should analyse the various modes in terms of the types of knowledge (concepts, procedures, facts, values) that are being acquired.

The Computer and Learning Through Social Interaction

It is commonly observed that using computers leads to many forms of social interaction. Many types of learning take place in this interaction, but these are only partially identified and understood. Of particular interest in science and technology education is the effect of discussion on metacognition. Studies should be conducted of various forms of project work mediated by the computer. In a shared task, how do students divide the work? If the computer must be shared, how is that done? What is the nature of interaction between two students using the same program running on two networked computers? (Studies are now in progress on the use of programs of this sort.) Careful attention should be given to the nature of leadership (fixed/rotating, hierarchical, heterarchical) and to the function of what students say (acknowledgement, conjecture, aha! reaction, example, counterexample, generalisation, etc.).

PROTOTYPE DEVELOPMENT

Tutorials and Simulations

We need to develop and test in various classroom settings intelligent tutoring systems which allow for multiple teaching strategies and which adapt to the rules and patterns of inference of the student. These programs would be based on discovering, diagnosing and correcting various types of misunderstanding. Such tutorials should also be adapted to students with special physical, intellectual, and emotional needs. They should also be extended to fields that have been insufficiently explored: scientific intuition, the understanding of orders of magnitude, metacognition. As much as possible, intelligent tutoring systems should be based on what effective teachers do. It remains to be demonstrated to what extent this is possible.

There is need for a wide range of simulations for teaching both scientific concepts (through discovering the model underlying the simulation) and processes (through operating a simulation for which the student knows the model). Some of these could be coupled with actual experiments, with material on videodisc, and with laboratory instrumentation for measurement or control.

Computer-based Instrumentation

There is a need for the development of inexpensive instrumentation, such as the examples mentioned in the report, together with software which can be readily coupled with the peripheral devices. Development of materials of this sort, when coupled with software for analysis, control, and modelling, could contribute far more than any specific courseware in giving students a sense of the nature of scientific investigation and technological design and production.

Software for Measurement, Analysis, Model-Building, and Control

There is great need for the development of a wide variety of tools for measurement, data analysis, simulation, and control. It is through using tools of this sort that students will come to grips not only with the usual notions of scientific data gathering and analysis and with some of the principles of using computerised instrumentation, but also with the nature of model-building and simulation as ways of making sense of the world.

Software and Hardware Standards

It is necessary to develop courseware that covers new scientific fields, that develops intuition, the physical senses, and the sense of orders of magnitude, and that favours access for all (isolated people, the handicapped, etc.) to the new technologies.

Further development of standards and guidelines is needed for the development of computer-based instrumentation so that schools can choose computers and peripherals independently from a wide range of vendors. Standards are also needed to facilitate telecommunications, including the transmission of programs and graphics. Educational authorities should be able to exert considerable influence in the setting of standards if they are able to demonstrate to industry that the educational market will increase dramatically in the coming years.

Courseware Evaluation

Criteria of courseware description and evaluation must be adapted, improved, and extended. It is customary to consider the user interface (screen layout, forms of control and feedback, nature of dialogue), the technical quality of the program, and its pedagogical structure and function (level, subject, objectives, methods, feedback). Of particular importance in science and technology education is to assess how the program deals with the four types of knowledge discussed in this report (concepts, processes, facts, and values). For example, in the simulation *Dirigible* (Western Australia Department of Education), students pilot a dirigible in a variety of wind conditions and altitudes. The simulation engages students in the processes of communicating, formulating questions and collecting data, and the sub-processes of quantifying (using standard units), locating (defining and using points in space), recognising and interpreting patterns in data (wind speed, altitude), exploring ("what if" questions), and making conjectures. The students learn concepts about matter and space and facts about navigation.

IMPLEMENTATION STUDIES AND PROJECTS

The projects should include extensive testing of prototype hardware and software, the development of curriculum support materials, the professional development of teachers, the redressing of gender differences and experiments on the reorganisation of the curriculum.

Several reasons may be offered to justify the close coupling of basic research and prototype development with studies and projects conducted in normal school settings:

- *Rapid change*. The new information technologies have permeated our culture. We can no longer think in terms of development times of 10 to 15 years from conception of an idea to extensive evaluation in school settings, as in the development of LOGO. We must think in terms of shorter periods of development (two years) and longer periods of evaluation and adaptation (five years);

- *The complexity of teaching.* Effective teaching cannot be broken into components, some of which can then be performed on the computer. If the computer is to be used effectively for educational purposes, its functions must be carefully integrated with those of the teacher;
- *The need for mutual adaptation.* The new information technologies and education must both be adapted to each other. That can only happen if teachers have an opportunity to experiment gradually over a period of years with new teaching routines and with prototypes which can then be adjusted according to contextual demands.

Development of Curriculum Materials

The courseware and other programs described in this report are themselves curriculum materials, but many of them are in a form where additional guidance is needed for the student and teacher to make effective use of them, particularly for open-ended software used for simulations and design. This additional support material may itself be computerised for convenient reference. The possibility exists for new hybrid forms of curriculum materials, including combinations of courseware with books, videodiscs, databases, study units, and lesson plans. These materials could include guidance in learning the concepts of theory-building and the principles of design through programming a computer, guidance in comparing real with simulated experiments, and topical guides on themes such as randomness in nature, fractal geometry, symmetry, recursion, and animal behaviour.

Professional Development

Forms of professional development have to be adapted to guide teachers through a period of rapid change in teaching routines, the nature of the subject and the emphasis on various types of knowledge. Of special concern for teachers of science and technology are the following: discovery-oriented teaching with the new information technologies, the usefulness and limits of models and analogies, the importance of studying the qualitative behaviour of systems, the teaching of heuristics for problem-solving and for learning, and the development of a language (which could have a computational base) for talking about the details of problem-solving and scientific reasoning.

School-based Projects

Projects in OECD countries should include the following characteristics.

- Close contact among projects in different countries;
- The use of entire schools rather than isolated classrooms;
- A commitment from the teachers to adapt their teaching in science and their use of new information technology to better prepare their students for living in the information age;
- Ready access for all students to computers and software during regular classes, during study hours, and beyond school hours;
- Close collaboration among students, teachers, consultants, educational administrators, software developers, teacher educators, and researchers;
- Opportunity for teachers and students to work out their own ways of teaching and learning with the new information technologies without imposed methods and curriculum;
- Thorough documentation and widespread dissemination of the results

Projects of this nature have been established in several countries. Two current examples in North American elementary schools are: *i)* Project "Headlight" of MIT (Professor Seymour Papert), which began in autumn 1985 at the Hennigan School in Boston; and *ii)* "Schools, Computers, and Learning", of Queen's University at Kingston, Ontario (co-directed by Professors Egnatoff, Higginson, Miller, Olson, and Upitis), which began in autumn 1986 in an existing school, and which will be expanded to include a newly-staffed school in autumn 1987. Close links have been established between the two projects.

With projects underway in many parts of the world, it would be possible to establish an international network of people working within the projects, and to compare many approaches to using computers. In one project, extensive use might be made of tutorials in many subjects and at many levels. Another project might focus on helping students build their own curricula and develop their own modes of learning. Some projects might provide highly-structured guidance for teachers, and others might support teachers in working out their own methods of adapting the technology. Some projects could be closely connected with hardware and software development projects and others could make use of readily-available resources. The projects could be linked through telecommunications, conferences, publications, visits, and exchanges of students and teachers.

Chapter 7

IMPLICATIONS FOR INSTRUCTIONAL PRACTICE

The introduction of new information technologies into the classroom on a large scale will be accompanied by changes in curriculum, forms of instruction, student motivation, and classroom organisation and management. This chapter suggests what some of those changes might be.

REORGANISATION OF THE CURRICULUM

Major revision of the science and technology curriculum is typically done only every five or ten years; however, changes in science and technology are so rapid that a new curriculum is out of date by the time it has been adopted. Textbooks have about the same lifespan and suffer the same fate. However some aspects of science evolve more slowly. Of the four types of knowledge discussed in this report (cf. Chapter 1), the concepts and processes of science form a core which changes slowly. The values for judging the truth of scientific facts and for judging the appropriateness of concepts and procedures are also fairly stable. The body of facts itself is changing rapidly. The values by which the appropriateness of scientific and technological activity is judged are now beginning to shift as we see some of the ill effects of large-scale developments which were intended for our benefit.

Because the parts of the curriculum change at different rates, it makes sense to provide for easy revision of the factual content of courses, while leaving the core of concepts, processes, and values unchanged. Some subjects can be dropped, reorganised or presented in more appealing forms. It should then be possible for students, with the help of the new information technologies, to develop a fuller appreciation of the overall scheme of nature and to engage more fully in theory-building and design. If students were given direct access to information and allowed to share their thoughts directly with students around the world, the curriculum could take on new meaning and relevance. Students could also create much of the factual content of their studies on their own, retaining it from year to ye in their own computer files. Students would be guided in their work by the concepts, processes, and values which teachers would help them learn.

There are several schemes for regrouping what is to be studied, all of which have been used to some extent. Units of the curriculum may be grouped according to themes which are common to many parts of science, for example energy or symmetry. Another approach is to offer students a smorgasboard of short study units on a wide variety of topics. Topics that were once considered advanced may be shifted to younger students as new means, e.g. courseware such as microworlds, are developed to make concepts more accessible Furthermore, the help with numeric or algebraic computation provided by microcomputers makes it unnecessary for students to learn certain mathematical routines and makes it possible to enter areas of physics where the algebra formerly required was too complex or calculations too difficult.

Regrouping topics by common themes and principles and integrating science with other subjects is much easier in the elementary schools, where the timetable is set by each individual teacher, although serious problems exist in coordinating programs from grade to grade. At the secondary school level, it is likely that the existing divisions of science and technology courses according to established subjects will remain for some years because of the organisation of the timetable and the inflexibility of the facilities. As new schools are constructed and old schools renovated, integrated science and technology labs could be created which include networks of computers for measurement, control, modelling, and design.

Scientists often wish that their students would develop a better sense of the overall scheme of nature An important unifying concept is that of order of magnitude by which one can order systems according to their age (ranging from the lifetime of unstable particles through the life expectation of man to the age of the universe), their size (from electron to man to the universe), their complexity (from an atom to a DNA molecule to an animal to a global society), or even their cost (a pencil, a computer, a school, a country's military defense programme). Computers offer many opportunities to grapple with ranges of numbers and levels of complexity.

The computer also offers new opportunities for practice in the construction of scientific theories. Programming involves problem clarification, design, development, coding, debugging, field testing, and revision, all of which have parallels in theory construction. Programming offers a medium for the construction of rules and the investigation of their consequences. Learning through programming can help students bridge the gap between their own theories and those that are taught.

The implicit curriculum based on how the new information technologies are used in education will change greatly as students are given access to new professional tools for learning New concepts, processes, and values will be associated with the implicit curriculum.

If the new information technologies are used extensively for communication in education, a global curriculum could emerge through students communicating regularly with students in other countries around the world. In this way, students would share facts about their daily lives and the impact of science and technology on their culture, and would come to know and appreciate each other's value systems. This idea is not new; for at least a century, there have been imaginative teachers who have had their students correspond with others around the world. There are several modern versions of this form of learning in the form of computer conferences. Extending these experiments on a large scale could contribute greatly to international understanding and to an ecological perspective.

INDIVIDUALISATION OF TEACHING AND LEARNING

Computers should be of direct and indirect assistance to teachers in providing for the individual learning needs of their students. Teachers will be helped directly by having tutorials and simulations which students can use at their own level and pace. Teachers will be helped indirectly through the insight they gain in observing students working at the computers and through the peer learning which is often enhanced by computer work. The development of software for constructing and operating simulations, and the availability of computer-based instrumentation in many forms, will allow students individually and in small groups to exercise their imagination and intuition without the teacher having to assume such a large responsibility in managing the details of what students are doing. Use of these tools should result in the more effective development of problem-solving skills.

Improvements in computer tutorials will provide both student and teacher with detail on the path of learning which is difficult to obtain any other way. Very good results have already been obtained with tutorials which are designed to help the student in some ways as a teacher would, without making use of any design pr s based on notions from the field of artificial intelligence. It is possible, although to o tell, that further advantages will accrue with tutorials based on computational n of the dialogue, the patterns of inference employed by the student, and the sequence of steps the student takes in learning.

Some prototype tutorial systems develop a model of what the learner is doing as the tutorial progresses and reveals to the student the line of reasoning being employed. This should be of some assistance in developing metacognition, particularly if students are working in small groups and are encouraged not only to describe the steps they take but to debate why.

Group differences, such as those between male and female students discussed in Chapter 1 of the report, may be more easily addressed with information tools. It is possible that by having a greater variety of modes of using the computer available to students, by making the computer a natural part of school life, and by removing any need to compete to obtain access to the computer, the differences in participation will disappear and the differences in preferred mode of working will be accommodated

MOTIVATION

It has been well-established that the computer can provide motivation to some students where all other methods had met with little success. Students who for various reasons would not or could not attend to any task for more than a few minutes without direct personal supervision, will sometimes spend an hour or more of concentrated effort programming a computer or using it in other modes. Activity at the computer can increase motivation to do related activities. It i ggested that conducting simulated experiments on the computer followed by actual exp . nts should increase interest and attention because the students will already have begun to develop important concepts and conjectures.

It is also expected that access to current information through various databases will be a strong motivator for some students who might be reluctant to search for information using a library. Finally, the social interaction stimulated by computer use can provide strong motivation as students take a more direct interest in each other's learning. Peer tutoring, which can be coupled very satisfactorily to computer use, is of benefit both to the tutor and the student being tutored.

CLASSROOM MANAGEMENT AND THE ROLE OF THE TEACHER

One of the most striking changes that the computer brings to the classroom is the need for new patterns of classroom organisation and management. Using computers extensively affects the structure of classroom communications, the form of assignments, the grouping of students, the nature of evaluation, and the scheduling of the various learning activities. Teachers need time and support in conducting experiments to establish new teaching routines.

The uses the teacher makes of the computer will depend ver· much on how much equipment is available With one computer in a classroom, it can b ed for demonstration by the teacher or as an activity centre. If there are several computers in the classroom, one or more machines may be dedicated during certain units of study to monitoring or data analysis while others could be used for writing, simulations, programming and other activities. As computers become fully accessible, the teacher will no longer have to adapt other activities to accommodate the availability of the computer.

In the coming decades, as we move through phases of implementation in which the amount of time available to students to use computers shifts from a few minutes per week, to one or two hours per week, to virtually unlimited access, the role of the teacher and the nature of science education will change. If students are granted extensive access to databases, the teacher and textbook will no longer be the main sources of empirical knowledge. More teachers will find that their role as guide becomes more important than it ever has been. The role of the teacher in ensuring that concepts have been thoroughly grasped and that sound judgement and appropriate values are being developed will always remain.

RECOMMENDATIONS

The following recommendations concern the main key issues drawn from the report, particularly from Chapter 6.

Values

Research should be encouraged on the following:

- The values underlying scientific and technological development including computer use in education, with special attention to the issues of control and access;
- The world views of teachers and students and how those views shape, and are shaped by, learning about science and technology;
- The nature of the computer as a psychological and social entity.

Learning

Research should continue on the following:

- A computational theory of thinking and learning; in particular, how learning can be enhanced by a pedagogy based on a computational model;
- The various symbol systems and languages used to interact with a computer, and the adaptation of those systems for learning;
- The forms of computational experience which help to make the concepts and processes of science a
- The nature of learning through social interaction associated with computer use.

Development

Development of the following should be continued.

- Tutorials and simulations, including those based on computational models of dialogue, patterns of reasoning, and learning;
- Inexpensive and versatile instrumentation for measurement, control, and display;
- Special programs for gathering and analysing textual and numerical data, for the construction and operation of simulations, for design, and for computer-based instrumentation;
- Standards for hardware, operating systems, software-development environments, software portability, telecommunications, and peripherals;
- Databases containing courseware descriptions, evaluations, and notes on classroom applications.

Implementation

All OECD Member countries should be encouraged to establish long-term, school-based implementation projects to link basic research and prototype development with classroom practice. The projects should include extensive testing of prototype hardware and software, the development of curriculum support materials, the professional development of teachers, the redressing of gender differences, and experiments in the reorganisation of the curriculum.

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IV. ARITHMETIC AND MATHEMATICAL CONCEPTS

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Introduction

PURPOSE OF REPORT

In the developed countries, the digital computer is gradually pervading every aspect of business, commerce and public service, bringing about significant changes in working practices through the automation of human manual and cognitive skills. The purpose of this report is to examine its effect on the learning and teaching of school mathematics (including arithmetic), and chart possible development during the remaining years of the century

During the last thirty years, many new technological devices have been introduced into our schools and classrooms, with accompanying promises of dramatic improvements in education. Radio, film projector, Roneo, TV, tape recorder, overhead projector, tape-slide machine, Polaroid camera, photocopier, electronic calculator and video recorder sit in offices, classrooms and, more often, in cupboards gathering dust. So much was expected, yet so little has been achieved. The return on investment has been small In the more pragmatic political mood of the 1980s this has not gone unobserved by governments, many of whom are reducing expenditure in education. The task that we face in this report is to attempt to show that the most recent computer-based technology is a radically different kind of educational technology. It is a dynamic educational aid, in line with the information revolution, and worthy of significant financial support by governments everywhere.

THE CURRENT SITUATION

There is widespread agreement that the mathematical attainments of some groups of school leavers fall short of expectations. Expectations take a variety of forms: one form of expectation is implicit in the standards adopted in national and international performance assessments; another form of expectation is employers' perceptions of school leavers' basic mathematical skills; another is concerned with mathematical competence and the ability to apply mathematics to novel problems; and yet another is an expression of popular opinion, generally derived from earlier experience, as in: "We were taught properly when I was at school. I know that point nought seven is seven tenths." Obviously, the specific form that any such expectation takes will differ from one country to another, and even between different groups in a country. But what most countries have in common is a desire to understand the problem, and take positive action. To this end, many investigatory committees have been commissioned.

In 1982, the Cockcroft Committee reported on the state of mathematics education in the UK. In evidence prepared for that Committee, Bell *et al.* (1982) argued that there was no evidence to suggest that standards of attainment had dropped in UK schools during the preceding decade, with about two-thirds of school leavers achieving a qualification in mathematics. Instead, they suggested that the problem was that current attainment did not match up to the nation's growing needs for more and better mathematical skills They reported that industrial and commercial practices frequently had to have their skill demands reduced to match the capacities of the workers involved. For example, since proportions are a difficult mathematical concept and generally not well understood, specific instructions about how to make up solutions to correct strengths by using marked pictures of a syringe are now provided to nursing staff. Finally, in comparing levels of achievements in mathematics among European and North American countries, they concluded that the general pattern of results is similar, that is, performance on routine calculations is fair, but performance on applications to fresh situations and on items containing some unusual aspect is much weaker.

This weakness in problem solving was also articulated in a recent report, published by the US Department of Education *School Mathematics: Options for the 1990s*. Of even greater concern to its authors is the fact that despite society's rapidly growing informational needs, only one third of its school leavers have studied mathematics at secondary level for three or more years. One consequence was a 72 per cent increase in enrolments in remedial mathematics courses at colleges between 1975 and 1980. Finally, the report draws attention to the markedly inferior position of minority groups in the United States, and to the generally disadvantaged position of women. The Cockcroft Committee also drew attention to the disparity in mathematics attainment between girls and boys in UK schools.

A BASIS FOR REFORM?

Whereas the Cockcroft Report gave no special place to the role of the computer in mathematics education, the US report suggests that the computer can serve as the basis for radical reform of the mathematics curriculum, by transforming both the content of the mathematics curriculum and the processes of mathematics education. But is this just another of the brave claims associated with the introduction of a new device into the classroom?

Those who doubt its validity will undoubtedly point out that for over thirty years there have been on-going attempts to reconstruct the mathematics curriculum. The most widespread attempt was the so-called new mathematics, which was based in part on the notion that by teaching pupils the underlying structures of mathematics, they would gain a better understanding of mathematical techniques and be better able to apply them to solve novel problems. By and large, the new mathematics must be judged to be a failure: we have already identified its inability to meet various expectations. However, we ought to be clear why it failed.

First, in many countries the reform was led by academic mathematicians, with little participation by grass roots teachers. Second, the content of the new mathematics curriculum was too different from the mathematics that teachers and parents were used to. It didn't relate to what they knew about; instead, it introduced abstract ideas, concepts and methods that appeared quite alien. Third, the new mathematics made too heavy demands on classroom teachers, requiring them to learn new content and new methods, and to develop new kinds of assessment techniques. Fourth, it ran foul of growing political conservatism in the late 70s and early 80s which advocated a "back to basics" approach in mathematics education. Fifth, it did not stay in step with the changes in society over the period. In particular it did not take account of the significant new techniques that computers were bringing to applied mathematics.

It is the last point which gives greatest hope that in time a computer-related reform of the mathematics curriculum will achieve the widespread acceptance that eluded the new mathematics. Today, in the developed countries, computer-based quantitative techniques are being applied to an ever-expanding range of problems in such areas as science, engineering, business, electronics, linguistics and sociology. Thirty years on, this is scarcely surprising, since computers were conceived as numerical engines, capable of fast calculation

In the early years, the needs of the physical scientist and the engineer dominated the use of computers. As a result, there is a vast, yet ever-expanding, collection of numerical program libraries. For example, MINNLIB, the Minnesota library, contains programs for operations on matrices, vectors and linear equations; the integration and solution of differential equations, polynomials and special functions, and YSMPLIB, the Yale sparse matrix library, contains routines for solving sparse symmetric and non-symmetric systems of equations.

This is only a small part of the story More significant is the fact that computers are providing new opportunities for observation and experimentation in mathematics. One example is the solution of the non-linear wave equation, the soliton, which was discovered by numerical experimentation before it became a mathematical object, and gave rise to a rigorous theory. Another is the investigation of non-linear models of chaotic behaviour, such as turbulence, by the iteration of real valued mathematical functions. the so-called "strange attractors". Yet another is the use of computer intensive methods in statistics, where standard unverifiable assumptions about the data, for example, that it is normally distributed, can be discarded.

The new statistical methods, the bootstrap, the jackknife, cross validation and balanced repeated replication are similar in spirit. Each generates very large fake data sets from the original data and assesses the actual variability of a statistic from its variability over all the sets of fake data. Not surprisingly, many previous estimates of the reliability of scientific inferences are being revised.

Next, there are many who would argue that the development of computer algebra systems is a second revolution in scientific computing. The capabilities of these systems are *symbolic* as well as numeric and include, for example, expanding polynomials and collecting like terms, symbolic differentiation and integration, arbitrary precision arithmetic, matrix algebra, symbolic solution of systems of algebraic and differential equations, and operations on abstract mathematical structures. These techniques have been applied in a variety of disciplines, including acoustics, algebraic geometry, economics, fluid mechanics, structural mechanisms and number theory, and in the design of propellors, ship hulls, helicopter blades, electron microscopes and large-scale integrated circuits.

Finally, perhaps the "best selling" program of all, the electronic spreadsheet, should feature in this list. Originally designed for financial analysis, it is capable of so much more It is a two-dimensional matrix of cells where the value of each cell can be made to depend on any other cell or group of cells. Quite surprisingly, much mathematical structure can be coaxed into this format; that is, the spreadsheet represents a quite general context for describing mathematical and logical relations and experimenting with them.

However, as we will see in due course, the proposed reform of mathematics education through computing does contain some seeds of failure. It is expensive: the hardware and software costs are still high in relation to schools' funding. While hardware costs will continue to drop, software costs are increasing as systems become more complex. The educational software market seems destined to rely on volume items, such as data bases and spreadsheets, for budgetary considerations. It is likely to be very demanding of teachers: they will be faced with the need to master new techniques, and to alter their classroom teaching practices. Finally, the widespread adoption of computer-based mathematical tools may appear as alien as the new mathematics was to many parents. These are only some of the challenges that the reformer must face. The going is likely to be slow, with new content and methods emerging naturally from the old. With the computer, traditional mathematics problems can be recast in more realistic and complex forms. Real world problems can be introduced and interdisciplinary projects can be tackled Hopefully, such approaches will find favour both with the advocates of basic mathematics and the progressively minded, to achieve a long sought consensus

Chapter 1

PEDAGOGICAL CONTEXT

GOALS OF MATHEMATICS EDUCATION

The Cockcroft Report (1982) opened with the question "Why teach mathematics?", remarking that although there was general agreement that mathematics should be taught in schools, there was a need for a detailed examination of its goals. We perceive that need as our point of departure in this chapter.

The answers given to the question appear to be of two main types. The first type of answer, sometimes referred to as a utilitarian answer, is that the goal of mathematics education is to satisfy the mathematical needs of living and working in the world today. For example, the *Institute of Mathematics and its Applications* (IMA, 1975) emphasized that at least a proportion of secondary school leavers should be equipped with the basic numerical skills needed by engineering and related technical occupations. This suggests that there should be some distinction between the secure and confident understanding of those number skills and concepts of wide application, and those that are needed at a high level of speed and accuracy only in certain occupations.

The Cockcroft Report (1982) was more specific. It defined a set of basic mathematical abilities, including "the ability to read numbers and to count, to tell the time, to pay for purchases and to give change, to weigh and to measure, to understand straightforward timetables and simple graphs and charts, and to carry out any necessary calculations associated with these". To this was added a feeling for numbers that permits sensible estimation and approximation, and enables straightforward mental calculation to be accomplished, and a need for sufficient self confidence to make effective use of whatever skill and understanding a person possesses. Broadly similar recommendations for the goals of elementary and middle school mathematics were made by the US Conference Board of the Mathematical Sciences (1983).

For many, the weakness of the utilitarian answer is that it is too content oriented; it does not equip people to cope with changes in the mathematical content of employment during the course of a lifetime. This is a particularly topical criticism, since the explosive expansion of advanced information technology in all developed countries has substantially increased their need for people skilled in newer mathematics, and has prompted even the most intransigent governments to launch emergency programmes, for example, the UK government's recent *Engineering and Technology* initiative.

This brings us to the second type of answer to our question. It rests on the notion that mathematics can be viewed as a means of gaining insights into aspects of the world around us, such as the form of the growth function for populations, changes in the rate of inflation or the concept of acceleration. It differs from a simplistic interpretation of the utilitarian view since its goal is to establish a structure of the ideas and skills strategies and aptitudes needed for the acquisition and use of new knowledge. We might replace the words "acquisition and use of new knowledge" by the words "problem solving".

As we noted earlier, there is evidence to suggest that all countries experience difficulty in teaching pupils to apply their knowledge to fresh and/or unusual problem variants. With this in mind, in the United States the National Council of Teachers of Mathematics strongly recommended in Agenda for Action (1980) that "problem solving must be the focus of school mathematics in the 1980s" (National Council of Teachers of Mathematics, 1980). Furthermore, to meet this recommendation they suggested that "the mathematics curriculum should be organised around problem solving", that "appropriate curriculum materials to teach problem solving should be developed at all grade levels", and so on. Currently, in Scotland and in Italy, new middle school mathematics curricula designed to promote problem solving are being introduced, and in Queensland, Australia, a draft mathematics syllabus for years 1 to 10 includes problem solving as one of its main objectives. Unfortunately, while we can all recognise problem-solving behaviour when we see it, we have a very inadequate understanding of problem solving structures and processes.

In addition to these goals, some suggest that one of the primary goals of mathematics education is to inculcate a positive attitude to mathematics so that the pupil will be willing to apply his or her knowledge as needed, rather than develop escapist strategies. However, it is difficult to see how this can be a primary goal. In general, mathematical confidence and a positive attitude to the use of mathematics arise out of success, whether in carrying through standard mathematical skills or in problem solving. Of course, cultures differ in their attitude to mathematics. In Japan, mathematical skill is highly valued by the culture, whereas in the United Kingdom, for example, parents are all too ready to confess incompetence in mathematics, thus creating a similar expectation on their children's part.

In summary, we recognise that each country's choice of goals will reflect its perceptions of its current needs and circumstances. However, it seems clear that in those countries that are building up their information engineering industries, there is a greater awareness than ever before of the need for mathematical competence.

LEARNING

The key question is how can mathematical competence be achieved? To get a perspective on this, we must begin by considering why mathematics is so hard to learn. From the time of the Greeks, the view that mathematics is the study of number and space has had a dominant influence on mathematics education. As Bell (1976) points out "it is not so long since mathematical education in England consisted, for the lower classes, of training to calculate accurately with large and complicated numbers, weights, measures and money, and for the upper classes, of the rote learning of Euclid's books". This object-centred view of the content of mathematics persisted until the beginning of this century, by which time the work of Boole, Russell and others had provided the basis for a very different kind of mathematics concerned not with particular objects but with the relationships between objects. From this emerged the concept of characterising mathematics in terms of the structures that stem from the notions of set and element, where the *relations* are sets of ordered pairs, functions are kinds of relation, algebraic structures are sets with laws of composition (also functions) and topologies are certain kinds of identified sets of subsets (Choquet, 1962).

The new mathematics was an attempt to blend together elements of the classical and modern approaches. As noted previously, it appeared alien to many who would have agreed with Russell that "mathematics may be defined as a subject in which we never know what we are talking about, nor whether what we are saying is true". Now, we can begin to understand why mathematics is so hard to learn: it presupposes that every human being has the mental capacity to represent knowledge about the world at a high enough level of abstraction, with an associated capacity for logico-deductive thinking.

We turn now to consider whether research into human learning can illuminate the problem. Broadly speaking, work on learning can be split into two strands, associationist and cognitive. The former relates most closely with developments in the United States where it is still a strong force today. Its key notion is that learning takes place through the association of an external condition (a stimulus) with a specific response given by the individual, establishing a mental connection or bond. Much of the research work, which began in the 1920s, has been concerned with elucidating the conditions for facilitating associations and strengthening the resulting bonds. The theory's implication for learning and teaching mathematics is clear: learning will take place when a response is accompanied by "a satisfying state of affairs", and teaching is concerned with identifying the bonds that make up the subject matter of interest, putting them in order of easiest first so that learning them will help towards learning the harder ones at a later time, and arranging for children to *practise* each of the kind of bonds.

By the 1950s, this drill-and-practice regimen had lost much of its favour. However, Gagné attempted to revitalise association by proposing that complex tasks are composed of identifiable simpler elements. Part of his cumulative learning theory involved the breaking down of skills into ordered sub-skills, or learning hierarchies. While the associationist approach has had a strong influence on mathematics education (largely since it is relatively easy to implement and manage in a classroom setting), it failed to take account of the diversity of children's learning behaviour. That is, it ducked the task of understanding the nature of the internal mental structures of the learner.

In contrast, in the cognitive learning strand, the Gestalt psychologists concerned themselves with these internal structures. Influenced by the European tradition of psychology that accepted individual reports as basic data and sources of hypotheses, they are distinguished from the associationists by their insistence that the human mind *interprets* all incoming sensations and experiences according to certain organising principles so that learning is more than merely taking in information. Although the Gestalt psychologists focussed on the immediate way in which problem structures are perceived, they said nothing about the recognition process that makes insight possible, nor how it changes with time. These issues were taken up by Piaget who tried to show that certain basic structures of thinking, which can be defined logically and mathematically, are developed through normal interaction with the environment. In particular, he focussed on the growth of logical classification systems and of the concepts of number, geometry, space, time, movement and speed.

Broadly, we can think of Piagetian structures as composed of elements and relationships, built up through mental or physical actions. The emergence of these structures is the basis for Piaget's stage theory, whereby the child proceeds from a pre-operational thinking stage which is dominated by perceived features of the environment, through a concrete operational stage which can support mental transformations of knowledge, to a formal operational stage which enables hypothetical reasoning and logical thinking. The problem with the stage theory is that the stages are usually thought of as discrete time periods in children's lives, as if they set bounds on the type of thinking that could be expected during each period. However, evidence suggests that a given child may exhibit pre-operational thinking behaviour in one task domain, and concrete operational thinking in another (Flavell, 1971). This implies that structure must be built up and applied in a *particular* domain of knowledge before operational thinking in that domain becomes possible. This discrepancy highlights one of the problems with Piaget's work: it is based on fragmentary evidence, snapshots of cognitive structures at various levels of functioning.

Case (1978) has argued that the problems of interpretation associated with Piaget's theory stem from the fact that it is structural rather than functional. It concentrates on the intellectual operations that children can carry out at various points in the development, but ignores the cognitive processes by which these operations are acquired and utilised. What we need are models of the processes underlying Piagetian structures which can account for the transitions they undergo during specific learning episodes. For him, the difficulties that children have with particular tasks is a function of: *i)* the mental structures available; *ii)* the number of structures that can be activated at any time; and *iii)* the strategy used in performing the task. All these factors interact, producing a rich variety of behaviour in any setting.

Where do we go from here? How can we refine and test the kind of model advocated by Case? Work in cognitive science concerned with the construction of information processing models in the form of computer programs that can be run and tested affords exciting new possibilities. In building these computer models, the cognitive scientist is making use of computational techniques developed within artificial intelligence for representing domain-specific knowledge, for expressing the processes involved in acquiring information about a given problem, and for organising the use of new and existing knowledge to solve the given problem. It is important to understand that such a model is not just a computer simulation of how a human being solves a problem, with each problem-solving step made explicit in the program. Rather, it is a system which is equipped with a set of structures and a set of processes, and it has to reason about how the structures and processes can be put to work to solve a given task. Typically, such a system will employ low level information gathering processes such as counting, measuring, calculating, organising, and comparing (pattern searching) to extract elements that can invoke prior knowledge. If the problem solver is an expert, that prior knowledge will include strategic knowledge about how to represent the problem and how to solve it, that is, knowledge about what additional information is needed and what low level processes could be used to elicit it, and knowledge about problem solving methods that may be applicable, including knowledge about how to choose between them. The latter involves higher level processes such as pattern matching and inference. The final step is verification of the outcome, involving such processes as comparing, approximating and estimating. For the problem solver who is not an expert, the task is to facilitate the building up of the knowledge structures that the expert brings to bear. Unfortunately, cognitive scientists and logicians have made relatively little progress with the modelling of induction. Clearly, building knowledge structures that represent concepts, relationships and methods also involves a range of processes, including comparing, contrasting, classifying, transforming, combining, making conjectures, and so on.

The message that emerges strongly from this review is the complexity of human learning, putting into better perspective the magnitude of the task that the mathematics teacher faces. Facts, processes, skills, conceptual structures, strategies: the list seems endless Yet all have a place in the child's mathematical armoury.

TEACHING

We turn now to consider research into teaching methods, and its relevance to mathematics education. From the previous section on learning, we can see that the class teacher is responsible for arranging sets of conditions and classroom activities through which a child will acquire mathematical facts and skills, conceptual structures, methods and general strategies: all these are involved in successful problem solving. The plural form "sets" is used advisedly to indicate that any one teaching regimen is unlikely to be satisfactory. We have already alluded to the drill-and-practice approach, favoured by the associationists As a theory of learning, it was inadequate since it could not account for the variability of children's behaviour in learning arithmetic (Brownell, 1928; Jones, 1975). However, that does not mean that drill-and-practice is not an effective teaching procedure. In general, the research shows that whereas drill is ineffective as a means of increasing arithmetic comprehension, it is very effective as a means of increasing the speed of recall of number facts and improving fluency in a skill Thus, it is reasonable to include the technique in the mathematics teachers' armoury, with the caveat that, as with any other technique, it should be used at the appropriate time.

We also briefly referred to Gagné's work on learning hierarchies in mathematics. The question now is whether they can help teach arithmetic skills. The obvious answer is to use the learning hierarchy as a map for a sequence of instructions. By associating diagnostic tests with each element in the hierarchy, children's work patterns can be individualised. The main criticism of the approach relates to the grain size: individuals vary widely in how quickly they learn, with some needing every step to be made explicit and others apparently skipping over steps, inducing the information in other ways. The implication is that the class teacher must also use this approach with discretion, avoiding rigid sequences of work and adapting choice of elements to his/her interpretation of the pupil's learning characteristics.

So much for computational skills, but what about the promotion of meaningful learning? In the last section, we outlined Piaget's developmental theory. Strangely, Piaget had little interest in education, either in terms of its significance for his theory or vice versa. Yet Piaget's ideas have important implications. We have already noted that learning mathematics is hard because it involves working at a level of abstraction that would require, in Piaget's terms, formal operational thought. Yet, there is evidence that some cultures never achieve fully developed operational thinking (Laboratory for Comparative Human Cognition, 1979). There is also evidence that even in those cultures that do achieve it there are many individuals who do not learn formal modes of thinking (Karplus and Peterson, 1970; Kuhn *et al*, 1977). The question therefore is what kind of teaching might be needed to develop this kind of thinking?

As yet, this is a research issue. One possible explanation is that children's thinking is bound by the concrete, intuitive models that they have conceived. For example, their model of space relates to the physical world. On the other hand, if they are going to build up geometrical knowledge, their thinking must become increasingly disembedded to cope with the fact that the geometrical knowledge will become progressively more abstract and detached from physical reality.

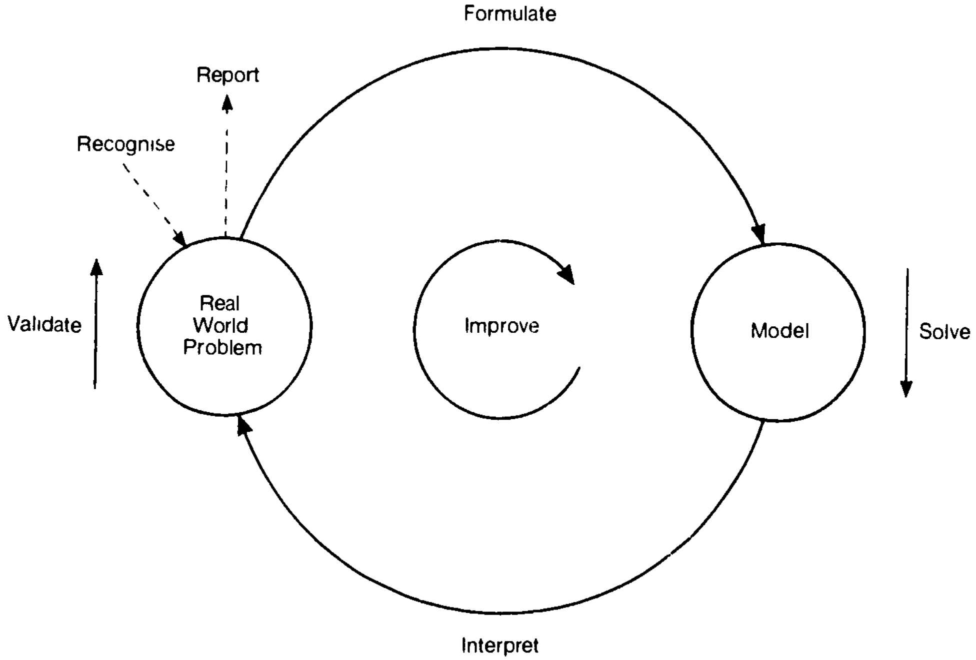
Greer (1984) suggests that many of the problems arising in mathematics classrooms can be traced to dislocation in a pupil's thinking between the symbolic expressions being manipulated and the original situations from which they represent an abstraction. This dislocation appears to be particularly common in the case of algebra (Küchemann, 1984; Booth, 1984), and if Hughes (1981) is right it also applies to pre-school and early school age children in the case of arithmetic. One possible teaching strategy is to try to embed the symbolism to a greater degree, as is done in "realistic mathematics" (Freudenthal, 1983; Whitney, 1985); another is to bring the learner face to face with the limitations of his or her thinking by provoking misconceptions, thus providing a reason to change it.

Our discussion so far relates to the concretising of the learning situation that Piaget advocated. In a sense, this is perhaps second order compared to the conditions that he proposed for understanding. For him, "to understand is to invent" through mental and physical activities proposed by the child rather than by the teacher. He recognised that this would lead to frequent errors, but regarded it as part and parcel of the business of building and making sense of concepts. Constructive learning, therefore, involves proposing ideas, trying them out and working out which are successful and which are not. In turn, this means that the teacher has to provide an environment in which the child will obtain "information feedback" in response to his actions.

In some sense, Piaget is not proposing a new approach: it is reminiscent of the "learning through doing" proposed by, for example, Dewey and Montessori. It has, however, provoked research into the relative merits of discovery learning versus reception learning (i.e. learning by being told), and of open discovery methods versus guided discovery methods. Taking the former first, the general conclusion is that discovery is often less effective than exposition for immediate learning, but is better for retention and transfer to novel situations. As for the latter, the evidence suggests that the nailbiting effect of failure to discover can be serious, thus favouring the guided discovery approach, with the caveat that the closer the guidance, the smaller the opportunity to develop personal strategies of enquiry. According to Bell (1980), the claimed advantages of guided discovery learning include:

- It ensures meaningful learning, since pre-requisite knowledge must be brought to bear as part of the discovery activity;
- Learning takes place in situations similar to those in which the learning will be applied subsequently;
- Besides conceptual structures, it promotes the learning of general investigatory strategies;
- Provided it is successful, it is highly motivating.

Figure 1



In our list of general goals we included problem solving. As we saw above, problem solving requires a variety of kinds of strategic thinking, concerning the selection of processes for extracting information from the problem statement, for formulating the problem, for invoking a method of solution, including tactical information about how to apply the method, and for verifying the outcome in the context of the problem solver's knowledge of the problem domain. Much of this strategic knowledge is thought to be heuristic (rule of thumb): perhaps the best known problem-solving heuristics were proposed by Polya (1957). In terms of classroom teaching, a technique that particularly promotes strategic thinking is model building. The model building cycle of activity is illustrated in Figure 1.

The model could be a set of equations, or graphs, or tables, or other mathematical relations whose variables correspond to observable quantities in the problem; it could also be a computer program which represents the variables and their relationships.

Model building is time consuming, simply due to the much wider range of tasks that the learner has to handle. The implication is that the problems tackled must be initially simpler, limiting the mathematical content that can be covered in a given time. However, if problem solving ability is valued highly, the approach will be cheap at the price, if it can be shown to be effective. In this regard, there is obviously much common ground between discovery learning and mathematical modelling. Just as discovery learning is often best organised with suitable constraints, so too is mathematical modelling, where in the initial stages the most effective way of introducing the pupil is to get him or her to experiment with, and adapt, standard models with which he or she is already familiar through more conventional teaching.

Chapter 2

CURRENT TECHNOLOGY

COMPUTER'S EDUCATIONAL ROLES

Our first step in this chapter of the report is to consider the ways in which the computer has been deployed in mathematics education. We will use the following classifications:

- *Application program.* A program that, given an appropriate input by the user, computes a result; for example, an integration program which uses Simpson's rule for finding the numerical integral of a function. The user's task, whether teacher or pupil, is to select a function and its limits, and the program supplies a number corresponding to the integral. Control of the interaction rests with the user because he or she initiates the computer's action;
- *Drill-and-practice program.* A program that rehearses basic facts; for example, the elementary arithmetic programs developed by the Computer Curriculum Corporation in the US. The pupil is asked to type in answers to questions. The program tells him about the correctness of his or her responses. Control of the situation rests with the computer in that it makes the decisions about the pupil's activity;
- *Tutorial program.* A program that teaches basic concepts or methods; for example, the program for teaching students the techniques of symbolic integration, developed by Kimball (1973; 1983). The student is asked to solve a problem, involving the transformation of an unknown integral into a combination of standard types. The system checks the correctness of each transformation selected; it queries inappropriate choices, and makes suggestions if the student asks for assistance. Control of the situation rests with the computer, which determines what problem the student should tackle;
- *Simulation program.* A program that represents an event, system or apparatus; for example, the Huntingdon II Project's simulation of the Hardy Weinberg Law of population genetics. Here the pupil may use pre-stored data from a simulated population, or his or her own data. The program prints out graphs, tables and comments incorporating the given data to represent the effect of the Law;
- *Computer modelling.* The activity of building programs as models of events, systems or apparatus; for example. Project Solo's learning environment in which children wrote BASIC programs to control devices like an organ, a spaceship and a flight simulator (Dwyer, 1974). The pupil does not receive tutorial help from the system, other than the standard error messages invoked by the program he or she writes. Control of the situation rests with the pupil who is free to write whatever program he or she likes;

- *Exploration program.* A program that facilitates the exploration of a domain of mathematics; for example, the *Excheck* program for verifying logical proof procedures (Smith and Blaine, 1976). For the pupil, the program is a tool for exploring and making mathematics. For the teacher, it is a useful teaching tool, somewhat akin to the application program.

The diversity of the computer's educational roles reflects its ability to do a wide variety of tasks. But more important, it reflects the different educational philosophies discussed in the previous section. Each program or activity can be located on a dimension anchored at one end by the view that pupils "learn by being told", and at the other end by the view that they "learn through doing and thinking about what they do". The teaching methods associated with the former view promote "instrumental" learning to satisfy the teaching objective of achieving a high level of performance in certain relatively limited functional skills. In contrast, those associated with the latter view promote "relational" learning to satisfy the teaching objectives of getting the learner to build relationships between new and old knowledge, making him or her better equipped to handle novel tasks.

As we saw earlier in this report, in many countries the modern mathematics syllabus has been designed to promote relational rather than instrumental objectives. But when teachers adopt an innovative syllabus without appreciating these objectives, nonsense can result. Teachers disposed to an instrumental approach, with its emphasis on exposition and practice, are drilling ideas that make sense only when taught in a quite different way. In a similar fashion, if teachers adopt (or have thrust upon them) interactive computer programs without understanding what their objectives are, the results of the innovation will be just as nonsensical. The fact that application programs and drill-and-practice programs are easy to implement on today's microcomputers, and easy to manage in the classroom, makes it likely that they will be used, and often misused. As we will see below, it is hard to build simulation programs and integrate them into existing curricula, and even harder to accommodate program building activity despite its enormous educational potential. As we have already seen, in many countries competence in problem solving has become the holy grail of mathematics education, leading to proposals for, and in some cases implementation of, significant curriculum reforms. Given that classroom practice has been the Achilles heel in the past, our main concern must be the computer's effect upon it.

APPLICATION PROGRAMS

An application program embodies an algorithm that solves a particular type of problem. In the mathematics classroom, the application program can be employed either as a teacher's aid or as a pupil's aid. The Electronic Blackboard and the Electronic Calculator are examples of application programs.

Electronic blackboard

Pictures in textbooks are static. Illustrations on the blackboard or overhead projector require artistic skill, take countless hours to prepare and are hard to manage effectively. Classic problems of illustration include:

- Drawing graphs of parabolas to show the effect of changing parameters;
- Demonstrating the deletion of certain terms from a function if one of its arguments increases to infinity or decreases to zero;

- Determining the area between a certain function and the ordinate;
- Illustrating the adding of functions, for example, to prove that the sum of two sines with the same period is another sine;
- Displaying and transforming three dimensional line representations.

Typical software packages available for these purposes include *Function Plotter* (US: Math Software), *Function Graph Plotter* (UK: Longman), *Graf* (Italy: IMA-CNR, National Research Council).

The teacher can also harness the machine's ability to carry out calculations quickly and accurately, as in factorising numbers, calculating factorials and generating data to demonstrate statistical laws. Useful software packages include *Stat* (Italy: IMA-CNR), *Imagiciels* (France: CREEM IREM, Research Institute for Mathematics Teaching).

Electronic calculator

In the context of the application program, today's microcomputer is tomorrow's pocket calculator. The latter has steadily increased in power, while remaining cheap. Today, a typical device is pre-programmed to carry out a range of basic arithmetical, trigonometric and statistical functions, delivering its results via an alphanumeric display which will soon be overtaken by a high-resolution liquid crystal display capable of graphing functions. As we will see below, the microcomputer's role as electronic calculator can be restricted to the manipulation of programs that make significant demands on processing power and/or memory.

Surprisingly, despite the pervasiveness of the pocket calculator within the developed countries – one estimate is that over 80 per cent of children in these countries already have access to these devices – many school curricula either ignore their existence totally (as in Japan), or restrict their use to certain age ranges and/or abilities of pupil. In particular, the debate is intense at primary level. Some teachers, and indeed some countries, do not want calculators in their classrooms; others allow calculator use to verify paper and pencil calculations, and others again allow pupils to use calculators in place of the paper and pencil methods, thus reducing the amount of time spent on this activity in favour of other tasks such as problem formulation, problem generalisation and extension of application of a method. Used in this latter way, the calculator promotes relational learning, albeit indirectly.

However, we can easily envisage a different scenario, with a teacher substituting an application program for paper and pencil activity to enable a primary pupil to solve more problems of a particular type in the time available. The greater the difficulty a pupil is having with the paper and pencil method, the greater is the temptation to use the program as an expedient. The fundamental argument in favour of persevering with the paper and pencil method for those having difficulty is that it is possible to relate the steps in the algorithm to the underlying meaning of the operation in a way that is just not possible with a calculator. In the latter case the child only needs to learn how to use the calculator's operating system to perform a successful calculation. Devices have been developed, however, which simulate the calculation process (Aigle, 1986) in order to illustrate how the calculator works. They make it possible to understand the operating logic of the calculator, and to present the significance of operations and manipulations when learning how to use it.

At secondary level, the situation is somewhat different. In many of the Western European and North American countries the electronic calculator has an accepted place in the mathematics classroom in the secondary school. At this level, the debate is about how the calculator can be used to facilitate mathematics education. By and large, this implies significant reform, since existing curricula, through a long process of historical evolution, contain only those mathematical topics, examples and problems that can be handled without excessive computation, either numerical or symbolic. The trend is to introduce new topics, as well as to broaden the range of examples and problems that can be tackled effectively through using the calculator, but that also relate to a particular country's goals for mathematics education. Some candidates for selection include functions and their inverses, term defined and recursive procedures for sequences, integration through partitioning and iteration, procedures for the use of Monte Carlo techniques and Markov processes, and matrix algebra. Many of these go beyond the capability of the pocket calculator, requiring access to moderately powerful (½-1 MIPS) microcomputers. Possibly the best example to date is Microsoft's MuMath package which contains a range of symbolic methods, derived from computer algebra, for tackling calculus, matrix algebra and some trigonometry problems.

At the end of the day, from a pedagogical viewpoint, the issue that always remains is: when should such an application program be used? Being able to run an application program whose result he does not understand is no more useful to a child than executing a paper and pencil algorithm whose results he does not understand.

DRILL-AND-PRACTICE PROGRAM

At the heart of the drill-and-practice program is a pattern matching routine that compares a pupil's response to a question to its correct answer (either stored or generated by an algorithm at run time). Its output is limited to informing the pupil whether or not the response is correct. Over the last decade, the visual appearance of the drill-and-practice program has been transformed. Initially, it was limited to lines of alphanumeric characters: now, in an effort to motivate the child, more often than not it is in the form of an arcade game, with full colour graphic illustrations.

By and large, the best of the drill-and-practice programs available today have been designed for use in primary level classrooms. They can be broken down into two categories: number and space. The former category includes: *Counters* (US: O'Brien), which reinforces counting skills; *Targets* (US: O'Brien), *Power Drill* (US: Schwartz), *Arithmagic* (US: QED), *Minus Mission* (US: DLM), *Maths Number* (Australia: Wesoft), *Building Estimation Skills* (US: Cuisenaire) and *Teasers by Tobbs* (US: O'Brien), which reinforce basic arithmetic skills, including estimation skills; *Darts* (US: Control Data) which reinforces fractions skills, and *Challenge Math* (US: Sweedler) and *Get to the Point* (US: Schwartz), which reinforce decimal arithmetic skills, including estimation of skills. The latter category includes *Odd One Out* (US: Stanger), *Code Quest* (US: Hermann) and *Funny House Maze* (US: Stanger) which reinforce discrimination, classification and pattern identification skills, and *Top 'n Flip* (US: Stan r) which drills mental shape transformation skills. Some examples of drill-and-practice programs for use in the middle school classroom include *Directed* (UK: Longman) which drills directed numbers, *Subgame* (UK: Longman) which practises construction of "lowest answer" subtraction sums, given randomly generated digits, and *Vector* (UK: Shell Centre) for drilling the difference between co-ordinates and vectors.

Just how effective is the drill-and-practice program? The short answer is that the evidence is equivocal. Some evaluation studies claim significant gains in mathematical performance and enhanced motivation; some suggest that gains are made by increasing the amount of drill-and-practice whether computer based or not; some fail to show any benefit accruing to pupils. Recently, Roblyer (1985) assessed the results of twelve previous reviews of evaluation studies published between 1972 and 1985. The author concluded that two categories of pupils benefit most from exposure to drill-and-practice programs. These are pupils in the early years of primary school and lower ability pupils.

TUTORIAL PROGRAM

As noted earlier, a teaching strategy based on reinforcement learning may be most appropriate for rote memorising of number facts, or for promoting skill fluency, on the assumption that the pupil already has a good grasp of relevant procedural knowledge. However, the shortcoming of the drill-and-practice approach becomes clear if we consider the situation where a child is asked a question whose answer involves using procedural knowledge that he does not have. For example, if a child makes an error, as distinct from a slip, in the course of doing a difficult subtraction sum, it is clearly not good pedagogical practice to tell him he is wrong without supplying any information about why he is wrong or about what he ought to do instead. What the best response is in such a situation is very much an open question, as Figure 2 illustrates.

Some evidence in favour of information feedback was provided in a study by Tait *et al.* (1973), which compared reinforcement feedback with information feedback. The latter took the form of six probing questions asked after a pupil made two errors. Suppose, for example, that he made a mistake in the second digit of the answer to 764 x 9. The computer would print out the following questions, each of which required an answer:

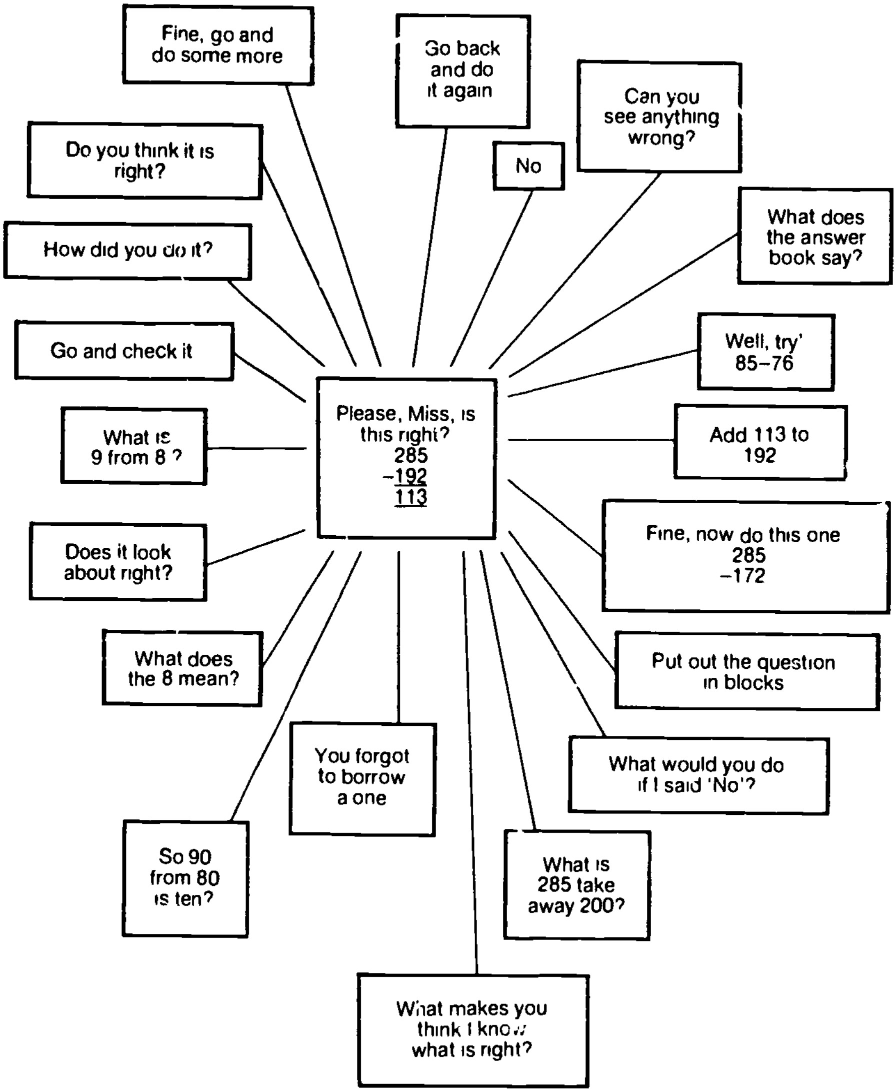
Question	*Information given if answer is incorrect*
What should you have carried?	No, it should have been 3
What number x 9 now?	No, it is 6
What is 6 x 9?	No, 6 x 9 = 54
Now, add on the carry	No, 54 + 3 = 57
What did you put down?	No, put down 7
What do you carry now?	No, carry 5.

The results of the study demonstrated clearly that the performances of children given *information feedback* were significantly better than those of pupils given *reinforcement feedback*.

Tait's program is an example of a tutorial program. The essential difference between the drill-and-practice program and the tutorial program is that the latter has a diagnostic capability. Instead of looking only for a unique match between a pupil's response and the answer, it is able to handle answers that differ in some degree. Just how different depends upon the way in which knowledge and knowledge handling processes are implemented within the program. Usually, a conventional tutorial program is equipped with a range of predicted responses for each activity, with associated information in the form of hints and suggestions about what should be done, whereas an intelligent tutor, such as Kimball's integration tutor, has an explicit representation of the knowledge that the student should acquire, an extensive catalogue of error types and their origin, with related hints and explanations, and a teaching model which decides when to interrupt, what kind of help to give, what type of problem to give next, and when to move on.

As an aside, we might note that one of the early issues surrounding construction of tutorial programs was that of designing a special programming language, called an author language, that would ease the task of building tutors by providing general data and control structures. Now, modern programming languages, such as structured BASIC and PASCAL, provide the necessary programming facilities, so interest in the author language is on the wane but may pick up again as improved systems become available. In particular, the author language Tencore is available on the IBM PC microcomputer and PC compatible equipment.

Figure 2



In the knowledge-based systems area we see an analagous situation, with a keen interest in the "expert systems shell program" that combines knowledge representation and inference-making techniques in a single system to simplify the task of building intelligent programs. But just as the early author languages' facilities were over restrictive, many of the engineers concerned with building intelligent systems are abandoning the shell program in favour of the more powerful and more flexible rapid prototyping systems for knowledge-based systems, such as *Loops* (Xerox), *Kee* (Intellicorp), *Art* (Inference Corp.) and *Knowledge Craft* (Carnegie Group). Whereas a typical shell combines a specific data structure and a specific control regime, a rapid prototyping system provides the user with a wide selection of these tools in a uniform setting, leaving him to choose the combination of tools which best suits the particular task.

As of now, intelligent mathematics tutors exist in prototype form only, and will be discussed in the next section. However, there has been a significant expansion in the availability of good, conventional tutorial programs for specific mathematics topics, at primary, middle and secondary school levels. Full advantage has been taken of high resolution graphics and colour, to enhance pupils' motivation. Also, many are now combining mathematical content with mathematical process and/or strategy. For example, at primary/middle school level, in *Bumble Games* (US: Learning Co.) a fantasy character named Bumble from the planet Furrin provides clues as pupils are introduced to number concepts, such as greater/less than, positive/negative numbers, columns/rows through guessing activities; in *Bumble Plot*, they use number pairs to set up roadblocks to trap a robber, read a sonar map to find treasure, and so on.

At middle school level, *Semcalc* (US: Schwartz) focusses pupils' attention on common/incompatible units in word problem solving; *Multiplying Fractions* (US: Microcomputer Workshops) teaches cancellation techniques for fractions; *Factoring Whole Numbers* (US: QED) deals with factor pairs, prime numbers, exponents, square roots, LCM and GCF; *Green Globs* (US: Conduit) draws graphs of pupils' equations in a target detecting game, and *Magic Grid* (US: Ideal School Supply) is concerned with solving equations using addition and/or substitution. Equation solving is also a popular topic at secondary level. *Equations* (US: Microcomputer Workshops) treats linear equations; *Solving Quadratic Equations* (US: Microcomputer Workshops) deals with quadratic equations by factoring; *Polynomial Practice Using Tiles* (US: Lund) is concerned with operations on binomials, monomials and trinomials, using pictures of tiles, and *Solving Equations and Inequalities* (US. Lund) builds skills in solving first degree equations and inequalities. The program *Enchanted Forest* (US: Sunburst) introduces sets and teaches concepts of conjunction, disjunction and negation.

Finally, some programs that combine content and strategy include *King's Rule* (US: O'Brien), which involves forming and testing numerical rules as hypotheses; *Number Quest* (US: Schwartz) which involves binary search strategies, and *Tobbs Learns Algebra* (US: O'Brien) which involves forming and testing algebraic formulae as hypotheses.

Today, there are still relatively few good tutorial programs available for school mathematics. Indeed, the use of the word "good" should be qualified as a subjective judgment since the educational effectiveness of these programs is still open to doubt. In general, their diagnostic capability is crude, leading to the criticism, as yet unrebutted, that they cannot teach as effectively as a human teacher.

SIMULATION PROGRAMS

The purpose of the simulation program is to represent a real-world situation in which specified factors can change, with consequent changes in that world. Since many relationships are complicated and their outcomes often unpredictable, the simulation program creates a problem solving situation where the user's aim is typically to "discover" the rules encoded within it through some kind of scientific investigation or to acquire a gut feeling for how the encoded principles control various situations. For example, in a program developed by Bork at Irvine that simulates planetary motion, the user sees a plan view of the path of a planet about a sun. He or she can shrink or enlarge the view, change the initial location and velocity of the planet, change the masses of the planet and sun and even change the exponent of the law of force. If the user makes good use of this program, he or she can "discover" the elliptical paths associated with an inverse square law of force, the concept of escape velocity and the unstable or non-periodic paths associated with some other laws of force.

As the example given so far might imply, the simulation program has been pioneered within the higher education area, in particular within the physical and biological sciences. So far, it has made little impact on school mathematics teaching despite the fact that it offers considerable scope for relating work in mathematics to real life problem solving situations However, there are a number of business simulation programs available, ranging from the simple to the complex. For example, the Sell series, comprising *Sell Apples*, *Sell Plants*, *Sell Lemonade* and *Sell Bicycles* (US: MECC), can be used to teach elementary ideas of business planning and business decision making. In response to the user's decisions about volume of sales, price per unit, advertising expenditure, and so on, the machine produces a financial report, displaying the company's performance in terms of units sold, cost per unit, net profit, and so on.

Big Business (US: Intentional Education) contains *Fast Freight*, a simulation of a road haulage business, which involves making decisions about whether to buy or lease lorries, or how much to bid for a job in the face of known competition, and so on. Finally, *Whatsit Corporation* (US: Sunburst) deals with the start up and running of a single product business. Start up decisions include the need for a market survey, the need for expert help, the extent of bank loans required and the type of franchise to buy, whereas operating decisions cover size of sales force, amount of inventory, repayment of loans, product price and advertising. The simulation is perturbed by unexpected problems like supply shortages and late shipments.

Other examples of simulations that promote the use of mathematics include: *Three Mile Island* (US: MUSE), where the objective is to control the nuclear plant and avoid meltdown; the Search Series of programs (US: Snyder) – *Geology Search*, *Geography Search*, *Community Search*, *Archeology Search* and *Energy Search* – that are part simulation, part adventure game and part arcade game, again constructed to involve pupils in problem solving that demands excellent data organisation and a high degree of group interaction; and *Dirigibles* (Australia: WESOFT) where students navigate their craft over swamps and seas, around buildings, hills and tall trees, in the course of which they interpret maps, plan movements in 3-D space, use compass points and bearings, read simulated instruments and encounter the idea of vector addition. *Fourmi* (France: Hanlez) is a program, based on an idea by Remy Chauvin, which, by simulating probabilistic models of the behaviour of ants, permits a visualisation of the different behaviours obtained from different probabilistic models. It enables the pupil to explore the limits of a model and suggest ways of refining it.

But notice that the simulation program, like the application program, is not a substitute for the class teacher. Merely providing the simulation and then leaving the pupil to make "discoveries" does not work. Evidence for this assertion was forthcoming from a study carried out by Bunderson (1971). He wanted to know what role the simulation should play in teaching new material. To investigate this, groups of students were given different amounts of guidance in the use of a simulation, ranging from step by step teaching to no teaching whatsoever. His simulation was of an imaginary science task, a Xenograde System. It consists of a nucleus containing small particles called alphons. One or more satellites may revolve around the nucleus, also containing alphons. Under certain conditions a satellite may collide with a nucleus, exchanging alphons and affecting satellite velocity. The learner's task was to calculate the state of the system in terms of alphon count, satellite distance, and so on, by entering the values of parameters and examining records in tabular form of the state of the system at discrete points in time.

Not unexpectedly, students in the unguided groups were extremely anxious, bewildered and frustrated. By dint of prying information out of the experimenters and from fellow students, and through perseverance, some of them did learn as well as any student in the more structured situations, but they took much longer, and some of them gave up the unequal struggle.

Besides learning the particular concepts and principles embodied in a simulation program, a pupil has to know how to interact with it. Whilst most students in the higher education sector will be capable of exploring a system in a systematic way, varying one parameter while holding the others constant to elucidate its effect, the average school pupil is unlikely to develop this isolation strategy on his or her own. An obvious solution is for the class teacher to construct a series of worksheets, each of which proposes an investigation and makes suggestions about the interpretation of the results.

Whereas the application program can save classroom time, the simulation program soaks up large amounts of time, even when used in a carefully organised fashion. This prejudices their widespread use unless mathematics syllabi are altered to make room for them. The problem is perhaps greatest in the case of the certified examination course, where there is considerable pressure on the teacher to cover it in full to meet the needs of the examination diet.

COMPUTER MODELLING

This is the most contentious way of using the computer in school mathematics. There are those who accept the value of computer modelling for teaching mathematics after secondary school level, but reject its use at an earlier stage; there are those who distinguish between modelling real situations using mathematics and the computer as tools and modelling mathematical processes, and argue that the latter is a perfectly feasible classroom activity for bringing insight into specific aspects of mathematics. Finally there are those who stress that computer modelling encourages children to develop their ability to formulate precise descriptions of how problems should be tackled – in other words, it brings problem formulating and problem solving skills together into a single context.

Designing a computer program involves knowing what the problem is and knowing a method of solving it. Building a program which is capable of producing interesting behaviour is usually a *reactive* process, since it is very likely that it will not work properly at the first attempt. We can distinguish errors which are due to the inexact or imprecise conceptualisation of a problem from errors which occur as a result of representing the problem in program form. In practice, a novice mathematics modeller will spend a great deal of time debugging his or her program, tracing through it in a step-wise fashion looking for clues about the nature of the errors. Only after repeated cycles of debugging and testing activity will the required behaviour be obtained.

In the early research into computer modelling in mathematics (Dwyer, 1974; 1975), pupils wrote programs in the BASIC programming language. The real power of program languages, the reason why so few commands can produce such complex programs, comes from their capacity to grow, with long programs built from a series of shorter programs. In BASIC, these shorter programs would be sub-routines within a main program. However, in BASIC the programmer's freedom to combine sub-routines is limited by the need to use the same variable names in the sub-routines and the main program, making it hard to combine sub-routines written for different purposes at different times. But this ability to develop programs incrementally is exactly what is needed when tackling complex programming tasks since the fine detail of the solution might not become obvious until much of the code has been written and tested. Fortunately, new programming languages like LOGO and Forth do not suffer from this restriction. Sub-routines can be incorporated into the language as new words or commands, as and when needed by the programmer, thus easing the program building part of the task.

Papert (1980) argues that the thinking and problem solving skills developed in the course of designing and debugging specific LOGO programs will be generalised, and will be transferred across subject domains. One of his key ideas is that "these skills should be acquired through discovery, in a spontaneous and natural way, analagous to how a child learns to speak". Feurzeig *et al.* (1981) have been rather more specific about the kinds of problem solving skills that children might learn through LOGO programming, and include: *i)* rigorous thinking and ability to express thoughts clearly and precisely; *ii)* understanding of and ability to apply general concepts like procedure, variable, function, recursion; *iii)* mastery of heuristic methods such as planning, problem decomposition; *iv)* debugging ability; *v)* awareness of alternative solution strategies. Unfortunately, whereas Papert's case appears to be based on a *rational* analysis of programming, and its component skills, *empirical* evidence does not support it. First, none of the published evaluation studies supports these claims (Hawkins *et al* , 1982; Homer and Maddux, 1985; Howe *et al.*, 1980, Watt, 1982). Second, studies in which logically identical problems were put into different contexts or given different surface structures have shown that isomorphic problems are rarely recognised, and concepts and methods used to tackle a task are rarely applied to the analagous task (Gick and Holyoak, 1982; Hayes and Simon, 1977; Simon and Hayes, 1976). Third, Glaser (1983) has produced evidence that problem solving ability in a domain is not just determined by general problem solving methods, but depends strongly on the learner's domain-specific knowledge.

More recently, Pea and Kurland (1984a, 1984b), after investigating the acquisition and transfer of planning skills by children with one year's LOGO programming experience, concluded that they were not more skilled planners than the non-programming control groups. Finally, Kurland and Pea (1985), investigating children's mental models of recursive LOGO programs after a year's exposure to the language, reported systematic conceptual bugs in the children's thinking. They also found bugs noticed by other investigators, such as assignment of intentionality and negotiability of meaning to lines of code, and application of natural language semantics to programming commands. In contrast to Papert's idealistic individual discovery learning, they suggest that self-guided discovery ought to be organised within a specific context

However, evidence is accumulating to support the claim that LOGO programming brings insight into specific aspects of mathematics. For example, working with trainee teachers weak in mathematics, du Boulay (1978) showed that writing LOGO programs to explore troublesome topics can promote understanding of the underlying mathematics. Other studies at Edinburgh with middle school children suggest that computer modelling can improve both the mathematics performance of some under-achievers, and their ability to talk sensibly about mathematics (Howe and O'Shea, 1978). More recent studies (Howe *et al* , 1984; Finlayson, 1985) at middle and at upper primary school levels, suggest that girls can benefit more than boys.

EXPLORATION PROGRAM

Du Boulay reported that the intrusiveness of the LOGO programming activity frequently distracted the teachers' attention from mathematical issues For example, they spent a great deal of time trying to write a program to construct a pie chart when they should have been thinking about the underlying mathematical issues. One solution to this problem is to provide programming "tool kits" containing the parts needed to build computer models for specific maths topics. Papert's *Turtle Geometry*, now a part of the LOGO language, is such a toolkit or microworld (to use Papert's terminology). The components in the Turtle Geometry toolkit enable a pupil to build a variety of two-dimensional shapes, ranging from simple patterns such as squares, triangles and hexagons, to complex patterns reminiscent of those made by Spirograph drawing wheels. One of the strengths of this kit of parts is that the concept of changing position and changing heading (of the drawing pen) are closely allied to a child's own understanding of his body motion, so he can use existing knowledge to help plan and debug his drawing programs. Recently, César (1986) has added primitives to the languages to create a new microworld in which the turtle can move in three dimensions.

As an aside, we should note the increasing availability of "tool kits" outside the LOGO environment. At present, there is no single name for these systems: they are variously referred to as "tool kits", "builders", "microworlds", and "problem solving environments". Their common features are that they are all closely linked to mathematical concepts, and they provide environments within which a child can explore mathematics, and even create his own mathematics. For example, in *Pinball Construction Set* (US: Electronic Arts), the pupil manipulates icons to create a simulated pinball machine. The machine is a game board with moveable bumpers and flippers, which can operate according to the rules of real pinball machines or according to rules modified by the user. Another example is *Rocky's Boots* (US: Learning Company) which contains elements such as wires, logic gates and sensors for building simulated electronic devices according to the internal rules of Rocky's world and the broader rules of combinatorial and sequential logic.

Now, we can see the distinction between simulation and modelling beginning to blur, since these builders contain constraints whose effects the user will experience, yet also allow the user to construct devices whose worth and sense he alone can judge. Further examples include *Gertrude's Puzzles* (US: Learning Company) for manipulating shapes, including shapes created by the pupil, to solve puzzles; *Delta Drawing* (US: Spinnaker Software) for introducing step-by-step programming as well as exploring geometric concepts that relate to drawing figures; *Geometric Supposer* (US: Schwartz) for experimenting with the construction of triangles, including circles, medi altitudes, parallel lines, perpendicular bisectors, and so on, and for conjecturing theorems, and *Ecluse* (France) for exploring the operation of a canal lock.

PATTERNS OF USE

In the previous section, we have described ways in which the computer may be used in the mathematics classroom. We turn now to look at evidence of how it is actually used, drawing first from the study carried out by Shavelson *et al* (1985) in 60 classrooms*(n)*, 49 schools and 25 districts in California. These investigators attempted to achieve an optimal mix among curriculum (mathematics and science), grade level (elementary and secondary), student characteristics (ability and socioeconomic level), and the extent and kind of support for classroom use. Altogether, 40 elementary and 20 secondary teachers took part, their teaching experience ranging from two to thirty-eight years, with an average of approximately sixteen years. All had a positive attitude to the use of the machine. Pupils were of roughly average ability overall, with individual classes ranging from low to high. The number of computers available varied from district to district, from ten to 98, with a mean of 59. Likewise, the number of machines available in schools varied from one to 55, with an average about twelve.

Altogether, teachers' use of the machine was characterised by 16 variables, such as mastering of basic skills, cognitive understanding, motivation and management. Applying cluster analysis to this data, four patterns of use were discerned, namely:

1. Orchestration ($n = 18$)	Computer-based activities are co-ordinated with other classroom activities, emphasizing both basic skills and conceptual goals. Modes of use include drill-and-practice tutorial, simulation (in approximately equal proportions), and computer modelling.
2. Enrichment ($n = 23$)	Computer-based activities are not co-ordinated with classroom activities, but are more concerned with computer appreciation/awareness. Modes of use include drill-and-practice, simulation, tutorial and computer modelling (in declining frequency of use).
3. Adjunct Instruction ($n = 14$)	Computer-based activities are linked selectively to certain lessons, with an emphasis on conceptual knowledge. Modes of use include drill-and-practice, simulation and tutorial.
4. Drill-and-Practice ($n = 5$)	Computer-based activities are linked to mastery and practice of basic skills.

Some interesting results include:

- At secondary level, the highly qualified mathematics teachers were more likely to favour orchestration and enrichment as patterns of use;
- Patterns of use varied systematically as a function of teachers' courseware knowledge, i.e. teachers in the orchestration group were more knowledgeable about courseware than teachers in the drill-and-practice group; they *were not* related to teachers' experience in using machines or their facility with computer languages;
- Patterns of use were related to classroom composition, with those of above average ability and a low percentage of racial minority pupils tending to be "orchestrated". As ability level decreased and percentage of racial minority increased, computer based use tended towards enrichment and adjunct instruction. Finally, the five classrooms with a high percentage of low ability minority pupils only used the computer for drill-and-practice of basic skills taught in class.

Results of studies of a similar kind are not available in the UK at secondary level. However, similar results have been culled from a study carried out in primary schools in Hertfordshire, UK (J[illegible] *et al* 1986). Over two-thirds of these schools had one microcomputer; 25 per cent h[illegible] d only 7 per cent had three or more machines. The maximum number in any one [illegible] as eight, and the average number per school was 1.5. Three-quarters of the schools [illegible] d machines from class to class. Surprisingly, less than half the machines were equipped with disc drives.

In terms of staff reaction, very few were negatively disposed towards the machine. Indeed, more than half the staff in the schools actually used it in the classroom.

More than half the head teachers and staff rated reinforcement of school work as the principal aim. By contrast, the development of logical thinking and problem solving were at the bottom of the list (c 15 per cent). The frequency of use of different kinds of software elicited similar responses. Over ha[illegible] e teachers used drill-and-practice materials; about 30 per cent used LOGO (turtle ge[illegible] etry) and about 30 per cent used some other type of problem solving software. As to subject area, the most popular was mathematics (75 per cent of teachers).

For the whole sample, 36 per cent only had access to a machine once a fortnight or less; 42 per cent once a week and 22 per cent twice a week or more. Given this restriction, 30 per cent of the teachers reported that each child/group spent less than ten minutes working with the machine during a session; 52 per cent between ten and thirty minutes, and 18 per cent more than thirty minutes.

The advantages and disadvantages reported include the following:

Advantages	*% Staff*
1. Improved motivation	47
2. Familiarity with the machine	43
3. Reinforcement of work	42
4. Improvement in learning	33
5. Learning to interact in groups	21
Disadvantages	
1. Insufficient access	35
2. Poor quality software	27
3. Computer as distraction	12

As in the Shavelson study, they found that frequency of use and attendance at training courses are associated with increased use of more sophisticated software. This suggests that to draw teachers away from drill-and-practice towards more child centred programs, more attention must be paid to providing appropriate software and support for teachers in its use.

Until studies have been carried out in other countries, we have to be content with these few results. If nothing else, they do afford a glimpse of the way in which the use of technology in the classroom is constrained by educational and social factors.

Chapter 3

RESEARCH AND PROTOTYPE DEVELOPMENT

TECHNOLOGICAL CONTEXT

As Shavelson's study showed, teachers' decisions about mode of use are governed by educational factors, not technological considerations. However, we cannot totally ignore the technological context within which courseware development takes place, since it imposes strong constraints upon courseware implementation.

Less than a decade ago, the interactive computing facilities needed to support educational computing were provided typically via typewriters or visual character displays, connected to a remote time sharing machine, either mainframe or minicomputer. The late 70s was a time of transition from the shared machine to the single user, local microcomputer, typically comprising an 8-bit microprocessor, 32-64 K bytes of memory and a casette type backing store. By the early 80s, their functionality had increased, particularly through the development of floppy disc technology for backing store, and the introduction of dynamic line graphics capability, including multi-colour displays based upon TV technology.

Through experience in the development and use of courseware, new educational tasks have been identified for the machine, extending beyond the computational power of the existing microcomputer. Now, the mid-1980s is a time of transition from 8-bit to 16-bit processors, from 128 K to 512 K memory sizes, and from low to high capacity discs. At the same time, cheap peripheral devices, such as mouse, touch screen, speech synthesiser, videodisc, are becoming readily available, of particular use for specific tasks, such as musical composition, or specific groups, such as the handicapped.

By the early 1990s, we can expect to have begun to make the transition from the 16-bit machine to the 32-bit machine, similar, for example, to today's Sun Microsystems SUN3 workstation, which has been designed to support advanced research in AI. With such a machine. the user can define areas of varying sizes and shapes (i.e. "windows") on the surface of its display screen, and can arrange to display simultaneously different kinds of information within these window areas. Thus, for example, one window might contain the text of an equation and the solution steps to date; another window might display the decision tree, representing the solution methods used so far, to make choices explicit, and yet another might plot the graph of the equation to help distinguish between actions on equations and actions on expressions, and so on. Only time will tell if this additional power can be put to good use in the classroom. However, as we will see below it does provide a technological context for the development of new modelling languages and knowledge based tutors. Before we tackle these advanced systems, we will briefly consider some courseware that is likely to become available in the classroom in the short run, through current transition from 8-bit to 16-bit machines.

TOOLKITS

It seems likely that the design and development of new computer based toolkits for exploring the process aspects of school mathematics will come to dominate research during the rest of the decade. Some possible lines of work include:

Spreadsheets

The electronic worksheet program, such as Visicalc, Lotus 1-2-3 or Multiplan, is heavily used by business and commerce for financial analysis for which it was developed. However, it has an equally important role in the mathematics classroom as a basic toolkit since a great deal of mathematical structure can be coaxed into its format, namely, a two-dimensional matrix of cells where the value of each cell can be made to depend upon any other cell or group of cells.

For example, to generate a Fibonacci series, the normal approach is to define and implement an algorithm, that is, a sequence of explicit instructions to be executed one after another. Using a spreadsheet, the approach is quite different. Each cell in the spreadsheet is specified by its coordinates in a grid, columns by letters and rows by numbers, starting at upper left. First, cells A1 and A2 are each assigned the value of 1, and cell A3 is assigned a formula such that its value is set equal to the sum of the value in the cell immediately above it and the value in the cell above that one. Next, the formula in cell A3 is copied into many other cells, for example A4 through A10. While the formulae are identical, the values are not, so the numbers generated from top to bottom are 1, 1, 2, 3, 5, 8, 13, 21, 34 and 55.

Another example is matrix multiplication. Instead of writing a sequence of instructions to multiply each element in the first column of the first matrix by each element in the first row of the second matrix, and so on, one simply defines the product matrix, setting each cell equal to a formula that represents the appropriate combination of rows and columns.

In the classroom, the spreadsheet program could be used either as a "black box" or as a "glass box" With the former approach, perhaps in the primary classroom, the teacher would prepare the formulae in advance, and the pupil would enter data and get results, much as if using an application program. With the latter approach, more appropriate at secondary level, the pupil would provide both formulae and data. It might also be possible to have an intermediate stage, where the pupil was shown the formulae and invited to change them systematically and try to make sense of the results. What we can conclude is the usefulness of the spreadsheet program, and the need to investigate methods of applying it at both primary and secondary levels.

Graphical Aids

The first example of a graphical aid is a logical development of the electronic blackboard discussed earlier. But whereas most of the existing software for plotting functions displays a single graph, or perhaps a set of superposed graphs, Schwartz has proposed a variant whereby two graphs appear on the screen, side by side. Now, any operation performed on the left hand side of a linear equation will change the left hand graph, and any on the right hand side will alter the right hand graph. Conversely, any change made to one or both of the geometric representations will result in a modified equation.

As indicated earlier, many children have difficulty in translating concepts between different representations. The Educational Technology Centre at Harvard is also developing a series of dynamically linked representations for intensive quantities. Four types of graphical representation will be available:

- Iconic representations, e.g. a window tesselated with rectangular boxes, each containing some kind of icon;
- A numerical, tabular representation, e.g. a window containing columns of related numbers;
- A coordinate graphical representation;
- A "quantity calculator" to enable a pupil to manipulate quantities (numbers with referents), with the referents appropriately tracked during calculations.

At any time, any three can be displayed on the screen, with simultaneous changes of their contents in response to a pupil's operations.

Exploration Program

An example of an exploration program is the *Algebraland* system under development at Xerox Palo Alto Research Center. The basic idea is that of keeping a record of the algebraic transformations applied during equation solving, in such a form that they can be displayed, edited, annotated, or even replayed, thereby providing a kind of animation of the solution path. This record is also represented graphically as a problem solving decision tree, showing a pupil's solution path, any backtracking points and retries. Brown (1985) suggests that this structure can become an object of study in its own right – that is, it becomes a meta object which a pupil can browse through in an effort to understand the features of an equation that point to the optimal transformations to apply to its solution. For Brown, their identification is the first step to discovering strategic knowledge.

Although we are far from understanding exactly how to integrate these tools into the mathematics curriculum, the basic notion underlying all of them is that a pupil will gain a deeper understanding by experimenting with them, by forming and testing hypotheses concerning the effect of operations on sets of data. As discussed earlier, it seems likely that a novice will need close guidance in the use of such a system, perhaps via a written scheme of work, perhaps via a games structure or perhaps via a knowledge based tutorial structure. The latter would enable the system to provide information feedback to help focus on a particular pupil's problems. Recently, Feurzeig (1986) has described a LOGO-based introductory algebra course for middle school pupils that is currently under development. It has three major components: LOGO programming projects, a graphics microworld (the marble bags microworld) for providing concrete iconic representations of formal objects and operations, and an algebra workbench which can either behave as a slave, carrying out algebraic operations to order, or can act as a tutor, providing advice and criticism.

Modelling Languages

The LOGO language's role in model building has already been discussed. But LOGO is not the only language designed to facilitate model building. Workers at the Xerox Palo Alto Research Center have developed a language called Smalltalk (Goldberg *et al*, 1982). Smalltalk is an "object oriented" language: that is to say, a user describes what he wants to model as a collection of objects which communicate with one another by sending and receiving messages. Each object represents either an object class *concept* or an *instance* of an object class. A class concept contains descriptions of messages and actions whereas the class instances actually do the work, e.g. draw on the screen, print text, and so on. To take a simple example, to program an aeroplane simulated in Smalltalk, one would define an object class called "instrument" and instances of that class to draw particular instruments on the display screen. Each instrument would have its own position on the screen, its own label and its own displayed value. Altering one of the aeroplane's controls would cause messages to be exchanged via the object class concept, which would locate the instances to obtain any values needed or to make alterations to these values.

A more complex example is the use of Smalltalk to build a visual programming environment (Gould and Finzer, 1984). The approach is known as Programming by Rehearsal: the design and programming process consists of moving "performers" around on "stages" and teaching them how to interact by sending "cues" to one another. The creation of a *Rehearsal World* production involves:

- *Auditioning.* The process by which a designer can discover the capabilities of a performer by looking at its category menu and its cue sheets to discover what kinds of things it can do, e.g. picture performer, text performer;
- *Copying.* The process of making an exact copy of a performer and placing it on the screen;
- *Blocking.* The process by means of which the designer specifies the sizes and positions of the performers on a stage;
- *Rehearsing* Trying out a production by showing each performer what actions it should take in response to a user input or to cues sent by other performers.

At present, *Rehearsal World* contains 18 primitive performers, each of which responds to a standard set of 53 cues and an average of 15 cues particular to that performer. In complexity, this would correspond to a BASIC with 1 000 reserved words. This complexity is made tolerable through the hierarchal organisation of the class instance structure, and the system's browser facility. Should the designer need a new performer, not available in the existing repertoire, he can drop through a trap door to gain access to the Performer Workshop which has tools for creating new primitive performers and defining new cues.

Another example is the use of Smalltalk to build a "laboratory" for modelling such things as geometric objects. In the laboratory, called *Thinglab* (Borning, 1981), an object is modelled by describing constraints between its parts; that is, relationships that must exist, and continue to exist. Thinglab makes sure that when one part of a system is changed, other parts are updated to re-satisfy the constraints. For example, the geometry theorem "given any arbitrary quadrilateral, if one bisects each of its sides and draws lines between the adjacent midpoints, the new lines will form a parallelogram" can be tested by setting a constraint at each mid point to ensure that it stays halfway between its endpoints. If the user moves one corner of the quadrilateral, the system keeps these constraints satisfied. Thus, he or she is free to observe the behaviour of the parallelogram as the quadrilateral alters its shape.

The designers of Smalltalk argue that object-oriented programming is more natural than procedural programming since it avoids the distinction between procedures for manipulating information, and the input of specific information to call these procedures. A somewhat similar argument is made in favour of programming in logic. The n[illegible] here is that statements in declarative logic can be interpreted as procedural instructions to the computer

(Kowalski, 1979). This provided the basis for the language Prolog, first implemented by Colmerauer at Marseilles in 1972. A version of the language, Micro-Prolog, is available for microcomputers (Clark *et al.*, 1981). In Prolog, the user can state facts, such as:

Elizabeth is-the-mother-of Charles
Philip is-the-father-of Charles.

and rules of inference, for example:

x is-a-parent-of *y* if *x* is-the-mother-of *y*
x is-a-parent-of *y* if *x* is-the-father-of *y*

Then, the user can ask simple questions, such as:

Is Elizabeth the mother of Charles?

In Prolog, this is written:

Does (Elizabeth is-the-mother-of Charles)

which produces the answer yes.

The question "Who are Charles' parents?" would be written as:

Which (*x* *x*-is-a-parent-of Charles)
Answer is Elizabeth
Answer is Philip
No (more) answers

The rule of inference has two roles. first, in this case it defines parenthood, and second, it acts as an instruction about answering questions about parenthood. Prolog is a particularly suitable formalism for building up databases of facts and rules which can be queried by pupils. Ennals (1983) argues that the real value of logic as a computer language is its contribution to the teaching of logical thinking in all areas of the school curriculum. He sees it as a replacement for traditional school subjects, such as Latin or Euclidean Geometry, previously valued for their encouragement of rigorous thinking. At this time, evidence supporting Ennals' view is still awaited.

In 1984, the European Economic Community (EEC) agreed to fund a project, the MicroProlog project, to test the educational advantages offered by a logic based language. The approach is to analyse and compare experiences in a number of classrooms in different European countries (Belgium, France, Greece and Italy), with a view to gathering evidence of the effectiveness of the MicroProlog language as a vehicle for developing students' ability in logico-deductive reasoning.

Regardless of which notation is favoured for model building, there is a crucial issue, as yet unresolved, namely the choice of teaching strategy. Papert (1980) favours open-ended discovery by a pupil, with a miminal amount of intervention by a third party, whereas Howe (1983) argues for a more structured approach, using ordered worksheets. They contain information; exercises which require a learner to type in, run experiments with and make modifications to pre-written programs; and "seeds", suggestions for open-ended program building and/or experimentation using the ideas and techniques exemplified by the pre-written programs. A somewhat similar approach was used by Goldberg (Goldberg and Kay, 1977; Goldberg, 1977; and Goldberg, 1979) when investigating the applicability of Smalltalk in the classroom. Pupils were presented with model object definitions, and were encouraged to explore, modify and extend them. For example, an illustrated booklet, *The Box Book*, provided a class definition of box, and helped the pupil learn Smalltalk by making boxes "play leap frog", "dance together" and make designs. Ennals (1983) also uses an ordered series of examples in his research into the value of Prolog for schools.

In some sense, building a knowledge-based tutor for a specific domain, such as elementary arithmetic, is akin to modelling a teacher's knowledge and skills, both of the domain itself and of teaching that material successfully to children of widely differing ability. During the last decade, artificial intelligence has made significant progress in developing "expert systems" which encapsulate an experienced person's knowledge and problem solving skills. However, an intelligent tutor is much more than an expert system. For example, the assumptions that it can make about the user's prior knowledge and skill are much more restricted so it needs a richer model of the domain to enable it to explain its behaviour meaningfully to a novice. A rich model is also needed to support the diagnosis of a pupil's errors, which may be due to carelessness, to lack of knowledge or to misconceptions. In turn, this forces the system builder to adopt some theory of how a child learns in a particular problem domain. If, for example, he follows Gagné and believes in cumulative learning, he is likely to adopt an overlay model: in other words, the objective is to get the pupil to build his own mental representation of the system's knowledge base and problem solving processes.

Such a system's teaching strategy would be concerned with the gradual transfer of knowledge from system to pupil, including the detection of any gaps in a pupil's knowledge and skills resulting from some breakdown in the transfer process. If, however, the system builder identifies himself with a constructive learning theory, he will expect a pupil to generate a wider set of errors, not only reflecting gaps in his knowledge but also reflecting misconceptions derived by the operation of higher order internal inferential processes on an incomplete knowledge representation. The implication of this theory is that the diagnosis of an error is a much more complex activity. Whereas an overlay model can be implemented in a system by adding markers to the database to designate elements as "known", in the latter case the system has to change its knowledge representation to bring it into line with what it believes a pupil knows, so that it can produce equivalent behaviour to explain his errors.

Much of the recent research into intelligent tutors has adopted either the latter strategy or some combination of both In reviewing it, three approaches can be discerned.

Detecting gaps in knowledge

The first approach is appropriate for domains in which there is no single algorithm (strategy) for solving all the problems and no way of gathering supplementary information from the pupil. Thus a system is limited to working from the pupil's actions only.

The strategy followed is to identify the important aspects of the domain, the skills which can be taught, and to decide on the basis of the pupil's actions which ones he or she lacks. This is the overlay model referred to previously. A major problem is identifying the existence of a skill which a pupil might possess but might not be invoked by any of the problem sets. The solution is to have an expert reproduce a pupil's actions and identify the sub-skills involved. Any apparent lack of a skill would only be significant if the expert employed it in given circumstances and the pupil did not.

This approach was explored by Burton and Brown (1976, 1982) in a re-implementation of the board game "How the West was Won". The pupil's task is to reach a goal in a minimum number of moves along a path 70 squares long. Depending on the position reached, there can be bonus or penalty moves. A basic move is defined by combining three small randomly generated integers into a simple arithmetic expression (using at most one each of the symbols +, -, x, / or parenthesis). The expression is evaluated to determine the number of squares. Although the environment is rich, untutored children tend to adopt a simple strategy and miss much of the game's potential.

The tutor, called *WEST*, constructs a model of the pupil by comparing the pupil's moves with the best possible moves. It uses the model to identify weak or missing skills. These include arithmetical skills (can he or she construct a certain number from the three integers?), game dependent skills (when and how to take advantage of the bonus squares) and general game playing strategies (watching your opponent). For each skill, there is a recogniser and an evaluator. Together they build up a pupil model containing information about the skills used and their relative strengths. This model supplies the basis for intervention by the system which provides the pupil with tactful advice.

Detecting errors

The second approach, namely, identifying a pupil's conceptual or procedural errors directly from answers, without any information about intermediate steps in the working of the problem, is appropriate for domains in which only one algorithm (i.e one strategy) is used when solving a problem correctly.

For example, the *Buggy* system (Brown and Burton, 1978) encodes its knowledge of simple arithmetic in a procedural network representation, where the methods attached to a network node may include incorrect variants of the correct method. Its purpose is to help teachers learn to recognise the pupils' systematic errors: "bugs". The system acts as pupil, invoking a buggy procedure within its network, and generates an example problem whose solution is incorrect. The teacher's task is to identify the bug by giving test problems to the system. When confident that he or she has found the bug, the system sets five problems to be solved using the hypothesised buggy algorithm.

Debuggy (Burton, 1982) attempts to diagnose a pupil's errors, taking as its data, problems that he or she has answered. It begins by identifying a fixed hypothesis set of 110 simple bugs and the 20 most common compound (i.e. multiple) bugs. The results of all 130 bugs are compared with the pupil's answers to determine an initial subset. Then the bugs in this initial set are combined to generate additional hypotheses particular to that pupil. Next, the initial set is reduced by finding and removing primitive bugs. Finally, pairs of bugs are found and the resulting compound hypotheses are compared with the pupil's answers. If a compound hypothesis explains more of his or her behaviour than either of its constituent hypotheses, it is retained, and so on. Eventually, the diagnosis made is the best fit according to a fairly elaborate measure.

Idebuggy is an interactive version of *Debuggy* which uses the pupil's answers as a basis for generating and evaluating a current hypothesis set of possible bugs. It is organised as a series of tasks, together with a heuristic strategy for deciding what task to do next, such as generate a new problem, reconsider a suspended hypothesis or produce a diagnosis. For example, two hypotheses can be discriminated by running them on selected examples until one is found on which they give different answers.

Repair Theory (Brown and VanLehn, 1980, 1982) is a generalisation of the approach adopted in *Buggy*. The basic notion is that when a pupil's grasp of a procedural skill is incomplete, he or she will use a general repair strategy (e.g. skip, quit, back up, analogy) in an attempt to overcome the impasse. The combination of incomplete procedures and permissible repairs generates a class of bugs to explain observed bugs, including compound bugs. The theory is able to explain bug migration, where a bug changes from one session to the next or even within a session, and bug frequency. In its most recent form, the theory has generated 180 bugs, two thirds of which are either impossible or unrecorded in studies of pupils.

The Leeds Modelling System (LMS), developed by Sleeman (1982), was built to investigate the inference of pupil models in arithmetic [solve 4x(2+4x5+6)] and algebra (solve 2x+4x+4=16). Whereas Brown *et al.* favoured procedural networks to represent the domain knowledge, Sleeman uses production rules which link consequences (actions/conclusions) with the satisfaction of pre-conditions. Bugs are modelled by introducing incorrect versions of some of the rules (i.e. mal rules). In addition, Sleeman supplies the system with a sequence of "ideal" pupil models, movement from one model to another being governed by the acquisition of one or more new rules. These models are used to define a pupil's competence level. Associated with each is a set of problems of appropriate difficulty. Depending upon the answers given, the system generates candidate pupil models by adding new rules to the existing pupil model. These models are executed by a standard production rule interpreter and those models agreeing with the pupil's answers are noted.

LMS was tested out with populations of 14 and 15 year-old algebra pupils (Sleeman, 1984a; 1985). While it diagnosed successfully the majority of errors made by 15 year-olds, it was unable to handle the majority of the errors made by the younger pupils who appeared to regress under cognitive load, i.e. they could only use a rule correctly when tackling a single task. Sleeman (1984b) believes that this is due to mis-generalisation, the invocation of mal rules previously inferred by the pupil from partial domain knowledge, but not subsequently erased. This stands in contrast to the explanation proposed by *Repair Theory* that the pupil will use a related family of mal rules, in the absence of any rules at all.

Detecting misconceptions

The third approach is appropriate for domains in which there is no single algorithm for solving all problems, but where the availability of intermediate steps in the problem solution provides a basis for reasoning about the strategy or plan that the pupil is following while solving the problem.

Perhaps the most relevant example is the *Advisor* system, developed by Genesereth (1982) to assist users of the *Macsyma* computer algebra system. A typical *Macsyma* user is likely to be a skilled mathematician who is using the system to manipulate complex algebraic expressions. But the typical user is unlikely to have expert knowledge about the *Macsyma* system. Thus, at some point, he or she may discover that it has produced the wrong answer. Clearly, he or she would like to know what has gone wrong. At this point, he or she is able to invoke the *Advisor* system, assigning it the task of detecting the location and nature of the error or misconception.

Invoking the *Advisor* involves telling it explicitly the goal that the user was trying to achieve. The *Advisor* already has a record of the user's previous sequence of *Macsyma* commands, together with a model of a novice *Macsyma* user (*Muser*). In *Muser*, valid plans are graphs explaining how actions achieve goals in terms of beliefs. Each goal is related to its subgoals and the actions used to achieve it by a planning method. Each method satisfies a particular goal and has preconditions and post-conditions that must be satisfied by the data. There is also a library of plan fragments and error fragments.

To recognise an error, *Advisor* uses a mixture of backward and forward reasoning. First, it builds a correct plan by reasoning backwards from the user's goal, then it uses forward reasoning in an attempt to convert the sequence of user's actions into a plan by recognising plan and error fragments from its library, and fitting them to the *Muser* model An error or misconception is detected at the point where a given action does not fit the model. The system has a standard explanation for each command, and presents this to the user. It might also suggest the use of an alternative command. It does not offer the user an alternative command, being restricted to patching the user's own plan.

Since 1986, the use of planning techniques for tutoring systems is gaining in popularity. Recent examples include the *PROUST* system for tutoring PASCAL programming (Johnson and Soloway, 1985a, b) and the *LISP* tutor (Anderson *et al*, 1985).

In conclusion, the research into intelligent tutors is maturing rapidly. It is also generating practical spin-off, in the form of simplified versions of some programs, like *Idebuggy*, which are becoming available on today's powerful microcomputers. But besides providing practical advice, perhaps the most significant thing about the current research is the forcing effect that it is having on our understanding of complex cognitive processes of learning and teaching.

Chapter 4

IMPLICATIONS FOR MATHS EDUCATION

TECHNOLOGY AND THE MATHEMATICS CURRICULUM

Primary School Level

- Calculators should be available for all pupils. They should be taught to distinguish situations in which calculators are appropriate aids from situations where paper-and-pencil methods are more appropriate;
- An adequate number of microcomputers should be installed in each upper primary school classroom;
- No *a priori* assumptions should be made about the appropriateness of any given mathematical topic for the primary school mathematics curriculum. For example, since decimals and negative numbers appear naturally when using calculators, they might be taught in place of fractions;
- Through simple LOGO programming, geometric and statistical concepts could be introduced, as could the algebraic concepts of variable and function, through individual and/or group access to a microcomputer.

Middle School Level

- Widespread use of calculators should be encouraged;
- An adequate number of microcomputers should be installed in each middle school classroom;
- No *a priori* assumptions should be made about the appropriateness of any given mathematical topic for the middle school mathematics curriculum. For example, some discrete mathematics topics, including counting, graph theory, probability and logic could be introduced;
- Pupils could be exposed to the solving of realistic problems using computer-based iterative procedures before formal methods are introduced;
- Pupils could be introduced to statistics by using computer-based procedures to manipulate and examine realistic data sets;
- The curriculum could take advantage of computers' graphical display capabilities for teaching geometry objectives;

- More emphasis could be given to non-traditional problem solving methods, such as organised lists, guess and check, and successive approximations, made feasible by calculators and computers;
- Concepts of variable and function could be introduced through LOGO programming and spreadsheets, as a basis for the study of algebra;
- Prolog programming could be used to explore properties of relations and to deepen understanding of arithmetic operations.

Senior School Level

- Senior school pupils should have unrestricted access to powerful interactive computing systems;
- Through the use of application programs emphasis on realistic problem solving by students of limited ability or restricted interest in mathematics could be increased, in particular on such skills as collecting, organising and interpreting mathematical information, estimating and approximating, strategic thinking, and evaluation of results;
- No *a priori* assumptions should be made about the appropriateness of any given mathematical topic for the senior school mathematics curriculum. For example, additional topics from discrete mathematics could be introduced;
- Ordering and timing of introduction of topics in geometry should be reassessed, since computer graphics give increased access to the geometry of 3-D space, co-ordinates, trigonometry and transformations:
- With increasing availability of computer albegra systems, skill objectives of algebra should be re-assessed, with the objective of increased emphasis on the learning of strategic (problem solving) procedures;
- Owing to increased access to computer-based modelling techniques, emphasis on personal mathematical discovery could be increased.

TECHNOLOGY AND MATHEMATICS TEACHING

- Teachers' understanding of and facility with specific computer-based mathematics tools and techniques should be substantially increased both to enhance self confidence and to enable them to cope with new computational techniques as and when they arise;
- Teachers' understanding of different learning models and their implications for the introduction of technological artefacts into classroom practice should be enhanced;
- Teachers should be encouraged to move from a teacher-centred approach to mathematics towards a pupil-centred approach, where the child is encouraged to become skilled at using computer-based materials, mathematical software tools, and symbolic model building skills to assist him or her to acquire significant conceptual knowledge and problem-solving processes;
- Teachers should be trained to manage a pupil-centred approach, including provision and use of structured materials as a basis for open-ended learning;
- Teachers' ability to assess pupils' work should be improved, including the interpretation of both procedural and strategic errors identified through using *Buggy*-type programs, model building through LOGO programming, and so on.

TECHNOLOGY AND TRAINING TEACHERS OF MATHEMATICS

- Every teacher should be given at least minimal training in the use of computers for teaching and learning mathematics;
- Pre-service and in-service computer courses for mathematics education should include the following components:
  - *i)* Awareness component, with emphasis on applications that enhance teachers' understanding of the technology's potential for improving mathematics education;
  - *ii)* Applications component, with emphasis on selection of programs as tools in learning mathematics and their integration into classroom teaching;
  - *iii)* Model building component, with emphasis on concept acquisition.
- The mathematical content of the course components for both pre-service and in-service training should be tailored to suit the needs of primary, middle school or secondary school levels;
- The choice of mathematics topics at a given level should be determined by the content of the mathematics curriculum, as revised to take account of technological influences;
- Teachers must be introduced to new forms of classroom organisation and new teaching methods that enable the integration of open-ended and exploratory ways of doing mathematics by computer. For this, a deeper understanding of what is taught and the way pupils learn will be essential;
- Educational authorities must provide sufficient resources to enable teachers to participate in adequate in- and pre-service programmes in computer-based mathematics education;
- Positive discrimination structures to increase the numbers of able mathematics teachers ought to be considered;
- Receptivity to research and innovation should be fostered.

TECHNOLOGY AND RESEARCH AND DEVELOPMENT IN MATHS EDUCATION

- Applied research in education must be distinguished from fundamental research, since the former must also take account of a wide variety of constraints imposed by the teacher, the classroom setting, and so on. In particular, software development is a major component of applied research;
- There is a dearth of good software. This situation should be ameliorated quickly, otherwise the computer might become discredited amongst mathematics teachers who are required to use it;
- In particular, emphasis should be placed on the development of application programs, new exploration programs and new microworlds for the LOGO, Prolog and Smalltalk languages;
- There should be recognition of the fact that the development of high quality software for mathematics education is a significant task, requiring a high degree of computational and mathematical skill. In other words, it is a highly professional activity, requiring significant funds;

- Fundamental research into the use of advanced computational techniques from artificial intelligence and cognitive science, for modelling mental structures and processes which provide the basis for both formal and intuitive thinking, shows signs of promise and should be stimulated by identifying and funding "centres of expertise", together with linked studies in other countries to test and refine ideas;
- Fundamental research into the design and construction of intelligent tutorial programs should be encouraged, in the expectation of new insights into issues such as modelling a pupil's knowledge and intentions, modelling different kinds of teaching strategies, and control of teaching strategies by updated information about an individual pupil's competencies.

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GENERAL CONCLUSIONS

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GENERAL CONCLUSIONS AND RECOMMENDATIONS OF WORKING GROUPS

The Working Groups made a number of recommendations. Some of these recommendations represent advice to all levels of government and society, while others are specifically proposed to OECD countries for national actions or to the OECD Secretariat for specific actions in its programme of work. The general character of these recommendations is consistent with a pattern that decision-makers have seen for a number of years. Each time new resources become available for education, some good occurs, but many actions are taken without clear enough understanding and consequently have minimal positive impact. The availability of the new information technologies, powerful as they are, has led to the same pattern.

Computers do not teach, they do not manufacture knowledge, they do not explain, they do not (in any enduring way) motivate. They are simply an artifact that humans can use to achieve a variety of effects great and small, positive and negative. As tools, they are potentially able to multiply human capability as dramatically as the book, the steam engine, the television, and electrical generator – for good or evil. School leaders throughout the OECD countries manifest disappointment over the minimal extent of the good that has thus far been achieved. However, we feel that the computer will be a powerful, positive force in education.

Exciting outcomes are discussed in the Working Group reports. The recommendations below build upon these initial successes. We also note that the computer makes such radical changes in our society that unusual strategies must be employed to optimise its contribution. Ordinarily, marginal investments in education lead to marginal improvements. In using computers, marginal investment often leads to frustration and rejection. Planning, purpose, targeted research, and significant teacher training will be needed to realise the information technologies' full potential.

The specific character of these recommendations is important, for they specify research and implementation actions that we believe are needed in order for the potential of the new information technologies to be realised for education. Particular problems of economically and efficiently using the technologies, of training teachers to take advantage of them, of shaping curriculum to take advantage of them, of developing and delivering tools based on them economically have been addressed, and those problems have driven the efforts of the Working Groups. Action on these recommendations is a critical step in using the only opportunity on the horizon for multiplying the productivity of our educational system to achieve the goal of basic education for all citizens that is adequate preparation for life and work in an economic world where the rapid changes in productive technology that we can expect will require continual learning and relearning, training and retraining.

EFFECTIVE EDUCATIONAL SOFTWARE

Because of a shortage of well-trained teachers, which is greatest in mathematics and science education, effort should be invested in systems that can supplement the limited supply of teachers. Research and development are needed to bring about the tools that instructional designers can use to create effective educational software. Currently, too much specialised computer-related skill is required, displacing attention from the content and quality of the curriculum. Efforts should also be made to involve teachers and students in curriculum design and to produce tools that teachers can adapt to their needs, not rigid systems that coerce students and teachers into unfamiliar modes of classroom activity. Work is needed particularly on the following:

- Tools for building intelligent tutoring systems and coached exploratory environments;
- Utilities to facilitate coding, modification, and translation (to different computer languages and for use in different human language communities);
- Data banks of misconception specifications, diagnostic tests, video images, and student information resources;
- Tools for building graphics and student-computer interfaces, tasks that consume much of the development time for computer-based instruction and on which much of its success or failure depends;
- Tools for rapidly encoding enough information about the structure and content of electronic text databases so that students' informational retrieval tools can readily use them;
- Methods for evaluating computer-presented lessons.

Exemplary prototypes for which annotated source programs and well-crafted design notes are in the public domain are needed to facilitate training of instructional designers. Among the prototypes that would be of great value are:

- Intelligent tutoring systems;
- Programs especially sensitive to differences in cognitive capabilities, i.e., examples of software which tailors instruction to individual students' capabilities;
- Guided exploratory environments;
- Tools for written composition, editing, and revision;
- Instructional systems that exemplify contributions of cognitive science;
- Advanced applications that can be delivered on common microcomputers (such as those with MS-DOS, Unix, or Macintosh Plus operating systems).

Demonstration and evaluation centers are needed in each OECD country (smaller countries might participate in the development and use of such centers, of course) at which the following activities can occur:

- The approaches in different countries and different cultural groupings can be compared;
- Prototype information products for education can be compared and evaluated;
- Long-term software and instructional development efforts can take place (the field suffers from too much fragmentation and insufficient follow-up of preliminary demonstrations).

Demonstration and courseware development projects with the following characteristics are needed in each OECD country:

- Close interaction among related efforts in different countries,
- Involvement of entire schools rather than isolated classrooms;
- A commitment of teachers in the demonstration projects to adapt their teaching and their use of new information technologies to better prepare students for living in the information age;
- Ready access for all students to computers and software during regular school classes, study hours, and after school;
- Close collaboration among students, teachers, teacher educators, software developers, and researchers;
- Opportunities for teachers and students to work out their own ways of teaching and learning with the new information technology without having to make regimented use of methods and curriculum imposed from outside;
- Thorough documentation and dissemination of results and evaluation data.

Real schools are not as ideal as the protected environments of demonstration projects. Sometimes teachers are reassigned at the last moment to teach subjects they know little about. Sometimes no one has the authority to call someone to fix a classroom computer when it breaks, or even to buy more paper for the printer. Sometimes the students who need the most help are removed from class for remedial work and thus miss the lessons on how to use the computer or have insufficient time to finish significant computer-based work. A recurring complaint is that software is poorly documented. These recurrent problems, found in classrooms throughout the world, highlight the need for educational, organisational, social, and economic research and policy analysis on how technology can become incorporated effectively into real classrooms. Appropriate topics for such research include:

- Use of new information technologies by students in economically disadvantaged areas (with attendant potential problems of poor equipment, little parental support, negative attitudes on the part of teachers and/or administrators, etc.);
- Use of new information technologies by non-native speakers, and the common special problem of multilingual classroom populations;
- Teacher training in new technology-using instructional methods and new curriculum content;
- Computer tools are not always used as expected, nor do they always achieve the goals their makers set for them. Sometimes positive changes occur that were unanticipated (e.g. a teacher who told one Working Group member that the main thing her students had learned from using a certain software package was not how to write better, but how to work together) Sometimes apparently powerful tools are ineffective, and we need to study how the potential of new information technologies is blunted when new computer tools are adapted to conform with prior classroom norms and values instead of being used to facilitate new learning.

Recommendation 1: *Each OECD country needs a national center where educational software prototypes can be developed, pilot-tested, evaluated, and demonstrated Many problems need to be solved before such tools can be used effectively outside such centers. Consequently, an important part of demonstration efforts must be the development and testing of teacher training and a clarification of the institutional and classroom contexts in which potentially valuable products can work effectively. An important additional outcome of demonstration efforts can be a set of tools for more efficient educational software development, but this will not happen unless it is specifically mandated and supported At* *the international level, it would be useful to monitor such demonstration efforts and disseminate information about them to Member countries. Further, Member countries may need assistance in establishing such demonstration centers, perhaps from visiting teams during the planning phase. Providing these international survey and assistance functions would be a worthwhile task for OECD to undertake.*

CURRICULUM AND CLASSROOM PRACTICE

The existence of new information technologies calls into question the content of the basic curriculum. More important, technology affords an opportunity and a challenge – a reconceptualisation of learning and an integration of subject matters is made more feasible (and more necessary) by information processing tools. Students can use graphing tools to analyse data, word processors to facilitate science report writing, intelligent tutoring systems to help them learn to read more effectively, text and graphic databases to gather data for social studies projects, etc.

Whether radical or incremental curriculum changes occur, teachers need to be trained in the content and rationale of technology-sensitive curricula and in the technology-enhanced means for teaching these curricula. Development of such new curriculum should be done by teams that include teachers, subject matter specialists, cognitive instructional specialists, and technology experts, and the programs developed must provide for the training of teachers in the new content and new knowledge delivery modes. Particular attention should be given to helping teachers understand their own partly pre-information-age world views, conceptual frameworks, and thinking strategies and how these differ from those of their students who have been raised in a technology-rich world.

Recommendation 2: *In each Member country, there should be a re-examination of the curriculum for basic skills education in light of the changes wrought by the new information technologies. Particular attention should be given to the knowledge that children raised in a technological world bring with them to the classroom, and to whether the separation of curricula for the different basic skills is still productive. These efforts will proceed more efficiently if there are ongoing international surveys and analyses of basic skills curriculum projects in Member countries and a means for facilitating cooperation and information sharing among these projects. Here again, OECD could make an important contribution.*

MATTERS OF INTERNATIONAL COMMERCE IN TECHNOLOGY

Which Informational Technologies Can Educational Systems Afford?

As each new level of computer tool has appeared, new educational possibilities have become evident. Researchers have wanted to develop prototype instructional systems that exploit the new power. As the information and computation revolution matures, it is becoming necessary to supplement analyses of what is possible with forecasting of what will be affordable. To the extent that instructional development focuses on equipment that will become inexpensive, it will have far greater impact. Today, certain capability that has not yet entered the classroom can safely be predicted to become as cheap as the cheapest microcomputers now in use. Other equipment, solely because of marketing technicalities, will reach a floor price that is still beyond the means of the average classroom. OECD countries are urged to be sensitive to the need for the industrial marketing expertise that can assist in determining how close to applicability various research and development projects really are.

Issues for International Cooperation

The economic questions posed above can also be addressed from the viewpoint of national policies for development and intellectual property protection of information products. Before the full educational potential of information products can be achieved, certain issues must be addressed by the international community. These include the setting of standards for educational software, the facilitation of easy exchange of software concepts and development techniques, and the development of means for promoting the storage of information in forms that permit it to be used for educational purposes.

Software quality. Thousands of educational software programs exist, and they have improved steadily over the years. But quality is still a problem. For instance, in the United States less than 30 percent of commercial educational software meets minimal standards of technological acceptability; many that do may fail to be pedagogically acceptable. Hence, educational software must be selected cautiously. Although significant advances in industry have occurred in the development of software tools and methods, the fruits of these development tools have yet to be felt in the educational marketplace. Still, new technology for quality software development can be used to educational advantage. More resources should be devoted to producing high-quality transportable software and developing shared methods of software testing and evaluation.

Hardware and software exchange. Technology is unevenly developed throughout the world. One cannot help notice the insularity of nations developing new technologies. While many new software techniques have great commercial value and cannot be distributed freely, the market for educational software needs to be stimulated by demonstrations of what is possible. Technologically advanced countries should establish economically feasible methods of sharing effective educational software concepts with other countries, through demonstrations, international interest groups, and joint ventures that transfer technology to other cultures. Exemplary hardware and software should be adapted for international use.

Hardware and software standards. Regulation and coordination of new technologies are major international concerns. Internationalisation of an operating system, for instance, demands that it be adapted to differences in local customs (dates, abbreviations, decimal delimiters, numerical codes for alphabetic characters and diacritical marks, etc.). In addition, student-computer interfaces must display text and allow responses in the user's own language. Finally, software documentation must be translated. Because of these problems, international standards are necessary. Without standardization, gains by one educational group are unavailable to others. Support should be given to open system architectures, in which information can flow, without hardware or software incompatibilities, across different computer systems. With such sharing, educational advances in one part of the globe can be transmitted instantaneously around the world. Most important for the future of international hardware and software, is the creation of products with modular components that can be easily changed to adapt to the character representations and languages of different countries. International groups can work together to build such architectures.

***Recommendation 3:** It is critical that the potential of the new information technologies for education not be thwarted by accidents of the marketplace. Achieving affordable and effective basic skills education is a matter of the highest importance to each Member country. Member countries, in developing standards for hardware and software and in making policy for protection of intellectual property rights, should give special attention to the impact of such policies on education. In planning future technology uses, they should attend both to what is possible with various technologies and also to which technologies will, because of forces outside the education sector, be particularly affordable or particularly expensive. The OECD Secretariat can play a useful role in collecting and disseminating such information.*

COGNITIVE AND INSTRUCTIONAL SCIENCES

Research in the cognitive and instructional sciences, especially research using formal and computational techniques from artificial intelligence, is essential if the full potential of new information technologies for education is to be realised. Current applications efforts represent only the beginnings of what can be achieved if we better understand human thinking skills and their acquisition. A number of research areas of especial importance are identified in the Working Group reports (Part Two) and the General Report (Part One). These include:

- Improved principles and methods for analysing and describing the student's current competence, for diagnosing student knowledge, for analysing student errors in cognitive performances, and for mapping performance onto the student model;
- Environmental, instructional, and personal psychological influences on acquisition of concepts and procedures;
- Methods for stimulating the learning of concepts and mental procedures;
- Nonverbal mental models and their acquisition;
- Metacognitive skills (skills for learning, self-management, and attacking problems that go beyond the textbook);
- How the social organisation of the classroom environment affects each of the above.

***Recommendation 4:** The OECD Member countries should give high priority to the cognitive and instructional sciences in setting national priorities for educational research. OECD itself might play a useful role by surveying and reporting the activities of Member countries in carrying out the needed research (e.g. level of expenditure, graduate student support, number of active investigators, topics of projects, etc.) and by facilitating international co-operation in these efforts. Electronic communications networks for this purpose have become available, and an electronically accessible directory of researchers involved in this area would be very helpful in stimulating a higher level of international co-operation in adapting education to the new technologies.*

Quality in education is a central preoccupation in all OECD countries. This study, carried out in an international context, seeks to define the role and the future of information technologies in improving the acquisition of basic knowledge and skills. It stresses the necessity for political will and international co-operation in order to exploit fully the potential of these technologies.

GLOSSARY

Many of the terms used throughout this book are somewhat technical. The nature of this field of inst ctional technology is interdisciplinary, depending upon people who may know one but not another of the disciplines on which it must rest. For that reason, Professor Alan M. Lesgold has prepared the following glossary of technical terms used throughout Part One; in general, the glossary represents their particular usage in this specific context. Variations of meaning are given by the authors of the various chapters of Part Two.

Activate Some theories of memory and recall refer to activated memory, viz., that part of memory which is currently conscious or available. In such theories, various perceptions and patterns of thinking activate additional memories if the appropriate memory associations have been formed.

Adaptive teaching Teaching that is varied according to the characteristics of the person taught In the United States, adaptive teaching has been used in classrooms principally as a means of instructing students with perceptual or learning disabilities.

Advance organisers Means, such as brief summary statements of the main ideas to follow, of preparing a learner to process a text deeply and efficiently. Experiments with a text whose subject was not obvious have shown that subjects given an explanatory title or picture before hearing the text were able to recall many and significant features of what they heard, while subjects given the same title immediately after hearing the text or given no title could recall only few and superficial features.

AI See *Artifi , intelligence.*

Algorithm The specification of the steps for accomplishing a procedure, as in a computer program.

Artificial intelligence Intelligent activity by machines, including learning, perception and thinking. Also research and development of algorithms and devices that are intelligent.

Authoring language A computer programming language especially designed for the development of educational software.

Black box A system or con ment of a system whose workings are not available to investigation or examination. Generally known only by its input and output. See *Glass box*. 'Opacity' and 'transparency' describe degrees of examinability.

Browse To inspect a structure of files or objects without exhaustive search. Often, to examine a graphical display that summarises such a structure.

Bug A defect in a computer program or system. By analogy, a defect in conception or procedure that causes a systematic pattern of error. For example, "A common bug in children's rational-number arithmetic is the notion that, if two fractions have the same numerator, the one with the larger denominator is greater."

Cloze A task in which one is asked to supply words that have been deleted from a text.

Cognitive science The study of thinking and learning mechanisms in humans and machines. Based upon work in psychology, computer science, philosophy, neurophysiology, linguistics, and anthropology.

Compact disc or **CD-ROM** An optical means of storing any information that can be converted into digital form, whether text, images, or sound. Currently a standard compact disc can store information equivalent to 550 million characters of text (see note 7).

Constructivist The view that knowledge is actively constructed, rather than being passively received, by the learner. That is, the student does not simply store or memorise facts he is told but rather constructs his own knowledge structures in response to prior knowledge, perceptions, and goals

Courseware Computer programs (software) and devices (hardware) intended for educational purposes.

Database An organised (structured) body of information; originally applied to data stored in a computer system, now extended to any collection of related knowledge.

Declarative information Knowledge stored in declarative memory. Facts Knowledge of what, as distinguished from procedural memory, which is knowledge of *how*

Digitised Stored in symbolic form rather than in analog form, that is as a direct transformation of the original event. For example, a phonograph record contains grooves that correspond to the frequency and loudness of the original music. The width and depth of those grooves, if specified as a set of numbers, would constitute a digital representation.

Discovery-oriented teaching Teaching that aims to present material from which the student can discover principles, on the theory that broad and permanent learning is most likely to result from the student's active construction of knowledge.

Domain-specific knowledge The knowledge of a particular field, including facts, concepts, and strategies appropriate to that field.

Drill and practice The repeated, rote exercise of a skill, usually with corrective feedback

Expert system A computer program that simulates the knowledge of a human expert in a field The expert system has facts, rules, and strategies (heuristics, or rules of thumb) to enable it to proceed under conditions of uncertainty.

Feedback Originally, and literally, a signal received by a device resulting from the device's output; by extension, information about the effect of one's own action, such as a verbal comment or a display of the result of the action.

Floppy disk A portable, flexible (hence the term *floppy*) magnetic information storage medium. Floppy disks hold from 160 000 to a little more than 1 million characters of information each. Microcomputers usually use floppy disks for information storage, though many also have a small hard disk, which can contain five million to 500 million characters of information. Generally, floppy disks can be removed from the device that accesses them, while hard disks cannot.

Frame A collection of facts and procedures (declarative and procedural knowledge) that are relevant for a particular class of situations. For example, one might have a frame of restaurant knowledge that includes what goes on in restaurants and how to behave in them. The declarative knowledge in a frame is organised into pieces that fill *slots*. Slots can have default values. For example, when one enters a US fast food restaurant, it is assumed, unless otherwise stated, that one pays as soon as one receives the food. In the terminology of cognitive science, "pay at once" is the default value for the "how-to-pay" slot.

Functional reading The ability to read well enough for some specified set of everyday demands.

Generative grammar For a language, a formal description that would specify rules needed to generate all and exclusively the sentences that a native speaker would produce.

Glass box A system or component whose internal processes are observable. See *Black box*

Graphics tablet A computer input device for entering graphical information A digital representation of what is drawn on the tablet is generated and input to the computer

Hard disk See *Floppy disk*.

Hardware The physical components of a computer system.

Heuristics Rules of thumb. Procedures with a good chance, but no certainty, of achieving a particular goal.

High-level language A programming language whose terms refer to fundamental components of the specific types of problems the programmer is trying to solve rather than to aspects of the computer's physical construction. *Low-level languages*, in contrast, consist of terms that refer either to the physical devices themselves or to some abstraction of the universal computational capability a computer has.

Host A computer that is accessible from a network.

Hypertext Text or graphic displays containing symbols or icons that can be expanded into more elaborated text or graphics.

ICAI, or intelligent computer-assisted instruction Computer systems for education that take advantage of artificial intelligence programming techniques. There is no sharp demarcation between CAI (Computer-Assisted Instruction) and ICAI, but ICAI characteristically uses artificial-intelligence techniques to permit less-constrained response from the student or to permit complex adaptation of the instruction to the student. Cf *ITS*

Informatics The study of information processing and its implications. Roughly equivalent in Europe to the combination of *computer science* and *information science* in the United States.

Information technology Techniques, particularly new ones, for communicating, storing, acquiring, modifying, manipulating and generating information of all kinds. Examples: word processing systems, computerised telephone systems, etc.

Instantiate To create a particular instance of a general class. In some computer languages, called *object-oriented computer languages*, instantiation takes place by specifying particular values for variables that represent class properties.

Interface The boundary between two systems. Often used to refer to the appearance of the computer to the person using it.

ITS or intelligent tutoring system A computer program, incorporating techniques of artificial intelligence, for teaching a subject area. The "intelligence" may take the form of: *a)* techniques for accepting relatively unconstrained responses from the student; *b)* an expert system that can diagnose the student's learning progress from his/her responses; or *c)* capability for coaching the student as he/she attempts to solve problems that stretch his/her capability.

Kludgey Patched or cobbled, rather than systematic. Colloquial, pejorative term used to refer to poorly-structured software. "Kludges" are likely to work in a specific situation, but present problems if efforts are made to generalise or extend the software if a generalisation or extension is attempted.

Knowledge-based system A system which gains processing effectiveness by using facts and rules specific to its field to define problems precisely (but perhaps narrowly) and to provide powerful, domain-specific problem-solving heuristics.

Knowledge structure An organised body of facts, procedures, and the rules and strategies for using them, possessed by an intelligent human or machine.

Language experience approach Methods for teaching reading and writing that emphasize building from the child's everyday language experience.

Laptop A computer small enough to hold on one's lap; the entire computer is usually the size of a large notebook and weighs about 5 kg.

Logic circuit The lowest level of structure in a computer system, consisting of logic elements that were originally discrete but are now combined by the thousands into integrated circuits. Each logic element receives input(s) that can have one of two values (*true* or *false*, *1* or *0*, *high* or *low*) and sends an output based on a logical function of the input(s).

Long-term memory The enduring store of knowledge a person has available for activation. The faculty of long-term memory is virtually unlimited in capacity, although long-term memories are not immediately available for processing. In contrast, short-term memory has a small capacity (5 to 9 pieces of information), and a short life, but is automatically available for processing. The term working memory refers to all memory currently available for processing, i.e., short-term memory plus the currently active parts of long-term memory.

Macrostructure The gist or higher-level structure of a text, including a computer program

Mainframe A large computer, usually serving many users, and possessing a variety of peripheral devices for storage, input, and output of information.

Means-end analysis One of a number of problem-solving strategies identified by Newell and Simon (1973). "If there is a method to reach a goal directly, then that method is applied. If there is none, then a subgoal is generated that reduces the difference between the present state and the goal. If there is a method to reach the subgoal directly, then this method is applied; otherwise a subgoal is generated, etc...."

Menu A computer screen display offering a list of program choices or actions from which its user can choose.

Metacognition Awareness, monitoring, or control of one's own cognitive processes.

Metarules Rules (procedures) for monitoring or controlling the course of intelligent activity.

Micro Colloquial term for *Microcomputer*.

Microcomputer A small (desk-top size) computer integrating input device (usually keyboard and perhaps mouse (defined below), processing unit, and output device (usually screen). Designed as a personal work station.

Microprocessor A single integrated circuit package (chip) that contains a complete computer processing unit. Generally the basis for a microcomputer.

Microworld A computer representation of a situation or environment that enables the learner to acquire factual knowledge of a specific content area by exploration of the representation.

Minicomputer A small mainframe or a large microcomputer.

Model A representation, usually simplified, of a device, system, or process. Models may be physical, linguistic, graphic, or mental. May be used to refer to an extremely complex computer simulation, as of an economic system.

Mouse A pointing device that can freely and rapidly transmit two-dimensional information. Moving the mouse causes an indicator, the cursor, to move on the computer screen The mouse can be used to indicate choices from menus, as a "paint brush", and as a means of selecting regions of the screen (e.g. part of a text to be deleted by a word processor). Named from its appearance: it is a less-than-palm-sized box connected to the computer by a wire "tail".

Natural language Ordinary language, in contrast to a programming language. Frequently used in discussing unconstrained input to a program by a user

Offload To transfer a file from a computer to another device, such as a disc or a tape.

Online Available for immediate processing. In contrast, a device not yet connected to the computer or not in electronic contact with the computer would be called *off-line*.

Open system architecture A style of computer system design and manufacture that facilitates the development of memory and peripheral devices by parties other than the original manufacturer of the system. Not to be confused with another term, *open systems interconnect* (OSI), which is an emerging standard for information networks.

Overlay model In an intelligent tutoring system, a representation of a student's current knowledge as a subset of ideal (expert) performance. Such models do not capture "bugs" (misconceptions).

Parser A facility for interpreting utterances or texts of a particular language

Personal theory See *Theory, personal*

Portability Ease of transfer to another system.

Primitive A basic operation or element from which more complex operations or structures can be constructed.

Problem space For any well-defined problem, the problem space is defined by all the possible moves and sequences of moves that can be made Usually represented as a graph in which the links are successive moves and the nodes are partial solution states A particular sequence of moves is called a solution path.

Procedural knowledge Knowledge of how to perform a mental process In John Anderson's view of learning and cognition, knowledge when it is first acquired is stored as declarative knowledge and then converted to procedural knowledge, which can be retrieved quickly, effortlessly, and without conscious attention

Production or **production rule** (a program composed of productions is called a *production system*) A rule stating an action and the circumstances under which that action can be taken Any computer program can be rewritten as a set of productions Because productions capture the essence of human associative memory, they are often used in simulating human cognitive processes

Prototyping system Some combination of computer language, hardware, and operating system support that facilitates quick development of new applications.

Representation A knowledge structure that stands for an external reality One's mental representation of a problem is thought to be critical to problem solving. See *Model*

Schema See *Frame*

Script See *Frame*

Semantic network A graphical representation of the mental relationships between concepts, where each concept is a node and relations between them are links.

Shell The interface for a computer system The same system may have multiple shells, for different categories of users.

Simulation A runnable model, usually in the form of a computer program. The results of running a simulation can be inspected and tested in order to learn something about the predictive power of the model or about the simulated system Such testing may take the form of comparing the end result with a known or an intuitive result: for example, a simple model of population growth could be checked against empirical knowledge. Or the testing may compare computer run time and processing resource use to known human performance statistics in order to validate a simulation of human cognition

Socratic tutoring Instruction by means of questioning the learner. Socratic tutoring attempts to provoke conceptual change by confronting the learner's misconceptions and extending existing knowledge

Spreadsheet A business calculations program based upon the paper forms used for calculations involving columns of numbers.

Sprites Small graphical figures on a display screen whose movement obeys instructions in a program

String A sequence of alphanumeric characters, usually processed by literal matching, rather than by symbolic interpretation.

Theory, personal The explanation by which a person makes a set of phenomena coherent and meaningful to himself For example, a child's personal theory might suggest that Daddy is older than Grandpa because people get bigger as they get older; then he might modify that theory to suggest that after a while people "grow down".

Thought experiment (also *Gedankenexperiment*) Procedure of performing an imaginary experiment, carrying through calculations based on hypothetical expectation, especially where an actual experiment would be impossible, as in weighing celestial bodies

Tool Adaptable code for a useful facility, such as accessing a file, drawing a circle on the screen, etc A toolkit is a related collection of such software tools

Tutorial An interactive teaching program, often used to introduce a computer user to features of the computer system.

Videodisk(-disc) A disk on which are recorded television images and sound, it can be played on a videodisk player to be seen on a standard television screen The images need not be run through sequentially, as on a tape, but can be called up by index (random access) The same technology can also be used to store digitised information.

Videotex A system for conveying graphic information very efficiently from a remote source Often used to provide "electronic bulletin boards" or "electronic tour guides" in public places Also used as low-cost interfaces for data base systems

Window A rectangular area on a screen display that is under the control of a relatively independent software routine. For example, a microcomputer may display parts of two different text files in separate windows, or a program to be edited, a graphical display, and a directory

Workstation A microcomputer for personal use Connotes a relatively powerful microcomputer

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