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on
Computer Education
1970

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Edited by Dr B. Scheepmaker and Dr K. L. Zinn

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(Nederlands Rekenmachine Genootschap);

the Netherlands Automatic Information Processing Research Centre
(Stichting Het Nederlands Studiecentrum voor Informatica);

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Preface

This Conference is the first of its kind ever to have been held. The proposal to arrange it arose first at the 1967 IFIP General Assembly in Jerusalem, when it was thought that 1969 would be a suitable time. It is now particularly appropriate that it should take place in 1970 and included in the programme of the UNESCO International Year on Education. The association with the OECD Centre for Educational Research and Innovation and the Intergovernmental Bureau for Informatics (IBI-ICC) is also very welcome.

It was considered that such a world-wide Conference should not be arranged without some preliminary meetings more regional in character. In consequence three symposia were held during 1969: the Western European Symposium in U.K. (March 1969), the Eastern European Symposium in Hungary (September 1969) and the Middle East-Mediterranean Symposium in Israel (December 1969). The OECD-CERI (Centre for Educational Research and Innovation) organised a Seminar on Computer Sciences in Secondary Education in Sèvres (March 1970). Recommendations of the meetings in London and Sèvres will be included in the documentation of this Conference.

The Conference itself provides a most valuable and timely opportunity for many people from many countries to meet and discuss educational problems which are of universal importance. It may not be many years before the computer industry is the largest in the world. The task of educating the very large numbers of personnel who will be engaged in the use of computers is correspondingly great and urgent. It is the hope of the organisers of this Conference, and especially of the IFIP Technical Committee for Education, that there will emerge from its discussions recommendations which will serve as useful guidelines to those responsible for providing computer education in all countries.

R.A. Buckingham
Chairman – TC 3

INTRODUCTION

The Technical Programme of the IFIP World Conference on Computer Education 1970, includes invited papers and submitted papers. During the Conference, also several working-parties were organized and the last day was devoted to a panel discussion on social implications of computers and a recommendation's session.

The invited and submitted papers were originally published in three seperate parts, which were made available to the participants during the Conference. This material, together with other reports concerning the working parties, closing addresses etc, are published now in one volume on 'The Conference on Computer Education'. The book consists of three parts.

Part I contains the final version of the opening addresses, the different invited papers presented during the plenary-sessions, a summary of the panel discussions on the social implications. Furthermore, this section contains a so called 'general report' which reflects the results of the Conference as a whole and focusses on the conclusions from the several plenary – and working-sessions, as well as the Recommendations of the World Conference and those of former regional conferences concerning computers and education.

Part II contains all papers submitted for the sessions of **Education about Computers**; Part III include those sessions on the **Use of Computers in Education**

More than 300 abstracts or papers were originally submitted for consideration by the Programme Committee from authors all over the world, almost half of which were accepted for inclusion in the Conference Book. Our intentions concerning the Technical Programme have been to limit this to reasonable proportions and to cover as many aspects of the role of computers in education as possible. Several papers were received after the suggested deadline, which somewhat delayed the final structure of the Technical Programme, as well as the final selection of papers for presentation at the Conference: both selections have been made in close cooperation with the Programme Committee.

The editing has been primarily restricted to matters of format; however, in some cases minor alterations have been made. The time available for the editing restricted the possibility of contacting authors about their papers; before the Conference was held. The printings of the Conference edition is also used for this final version, with corrections of errors.

Guidelines sent to authors concerning the general structure of the papers, use of titles and sub-titles, etc., have somtimes been disregarded and the form in which the papers are printed may not, therefore be fully consequent; we have however strived to reach the highest possible level of uniformity. We wish to take the opportunity of thanking those who have been involved in the work; in particular we wish to show our gratitude to Miss Viviana Bellanger, who acted as an enthousiastic secretary, especially concerning matters like uniformity, checking proofprints etc., in which duties Mrs. Thea Poortenaar has also been of great help, and to Miss Margo Powell for her work in making required improvements to papers submitted by those other than native English speaking authors. Without those mentioned and several others, our job would have been much more difficult to execute.

Dr. Bob Scheepmaker

Amsterdam, November 1970 — Dr. Karl. L. Zinn

OPENING ADDRESS

His Excellency Mr. J. H. Grosheide, Secretary of State for Education and Sciences

Mr. J. H. Grosheide

Mr. Vice-President, Ladies and Gentlemen,

It was with particular pleasure that I accepted your invitation to open the 1970 I.F.I.P. World Conference on Computer Education with a few introductory remarks.

I **The development of the computer**, which began so tentatively in the first half of the present century, is now going forwards by leaps and bounds.

More and more computers are being used in more and more fields, from space travel down to earth to the selection of marriage partners – if it is allowed to call that down to earth. It is equally certain that in the future computers will find many applications of which we scarcely dare to dream at the moment.

With regard to the use of computers, the stage has long since been reached when it is impossible to work **without** them.

Without any doubt whatever computers must be regarded as an important factor in achieving increasing prosperity, while the **structure of labour** will gradually undergo a fundamental change as more and more computers are introduced.

It is quite obvious that a rapid development of the computer will have its influence on society. This World Conference, which will deal with an important aspect of this problem, is for this reason of particularly great interest.

In the individual sessions will be gone more deeply into the computer in relation to education. The subject falls naturally into two parts:

1. *Learning about computers;*
2. *The use of computers in education.*

I should like first to dwell for a few moments on the first of these: **learning about computers.**

Now, in pretty well every country in which computers are used, there is a considerable gap between the supply of computer personnel and the demand.

Existing training facilities are still frequently inadequate to keep pace with the rapid expansion, while the qualities necessary for good computer staff are not so easy to find.

In the Netherlands the Government at present is faced with this problem on a large scale.

II Many possibilities are being studied and much more is being done with a view to involving the computer more intensively in the educational structure in the Netherlands, as regards both the creation of training courses for computer personnel and the orientation about the possibilities of computers.

Universities and other establishments of higher education are being equipped to an ever increasing extent with computers; facilities already exist in many establishments for getting to know 'the computer' thoroughly, while the possibility will be opened to introduce separate degree courses in data processing and computer technology.

Steps have already been taken to include the computer in a number of different courses of study, for example in the case of economists, engineers, mathematicians, psychologists, and so on. In the longer term even lawyers, linguists and theologists can be expected to have to learn to work with computers.

In the post-secondary professional schools training of experts will shortly be introduced.

The introduction of computer science as a separate subject in technical and certain secondary schools gradually starts working.

There are a large number of committees in existence in this country, on which many interested parties are represented, and each of which is dealing with specific problems.

Many problems, of course, still remain:

1. There is, for example, the question of providing teachers, a problem which must not be underestimated, especially in view of the attractions of a business career.
2. What exactly is the task of the education system in the training of computer staff?

An essential requirement is proper coordination of the efforts of all concerned, including Government, industry, the educational world, research institutes and others, which will demand their close cooperation. Only in this way will the demands on manpower be properly regulated. Moreover, the general educational aspect should not be overlooked. Education has a much wider and a much more fundamental task than just meeting with the manpower demand.

The training of computer personnel is receiving the Government's full attention; **equal** recognition has been given to the need to use computers at a more **introductory** level. This is not so much a question of providing training of a purely technical nature as of making the computer better known in the course of both professional training and general education. Pupils must be made familiar with the world in which they live, a world in which the computer is becoming a more and more important element.

The development of the computer is co-defining for important changes in the image of our world. Education shall have to draw from this thesis the necessary consequences.

None of this can be achieved without knowledge and experience of computer education, which as often as not can only be acquired with difficulty. This conference must provide facilities for a far-reaching exchange of knowledge and experience.

III The second subject announced for this conference is: **the use of computers in education**

If the training of adequate numbers of computer personnel is a matter of immediate importance to computer users, of at least equal importance is the problem of integrating the computer as an aid to learning in the present system.

I mentioned at the beginning that the number of fields of application is increasing rapidly. A very promising field is **education itself.**

The computer has a number of advantages over human beings. These advantages have often been mentioned:

1. The computer gives an immediate answer;
2. The computer suits its speed to the pupil, which means that it is a kind of private teacher;
3. The computer is never tired or bad tempered, its reactions are swift and extremely accurate and its approach is always objective.

An incidental result of programming study material is that it is frequently necessary to consider first the purpose of education.

But, there are many problems and disadvantages as well, for example the absence of personal contact with the teacher, the cost factor and the reduced flexibility.

For the moment it is scarcely possible to say whether the advantages are outweighed by the disadvantages. Moreover, problems may arise particularly with regard to organization, which will require that considerable attention be paid to programming and evaluation.

But that is typical of a new technology, particularly where, as in this case, it affects human behaviour. Mentality and mental attitude are also factors that have to be taken into consideration. Clearly the development of programmed instruction (particularly in relation to computer assisted instruction) will have to be closely followed with a view to finding the most suitable way of encouraging its application.

The use of computers on a large scale for teaching purposes, in the schools and elsewhere, is a possibility which gradually seems to be coming more and more within reach. The questions that remain to be answered are **how** and **when**.

We would greatly fail in our responsibility towards the younger generation, if we would neglect the problems of the use of the computers in education.

It will be essential to bring in experts from various disciplines – educationists, teachers, pyschologists, sociologists and others come to mind.

It is, moreover, particularly important that the experiments and investigations should be evaluated in a scientific manner. Naturally it is very desirable that the work of comparison and building on what has been done by others should go on at an international level.

This, then, is not a matter which can be tackled on a purely national basis. The exchange of information and the study of investigations will be stimulating and fruitful. Less advanced countries will be able to profit from the experience of the more advanced countries.

Without doubt the traditional school will undergo a change of character in the future. The teacher will no longer stand in front of, or if you like, facing the class, but **in** the class.

Mr. Vice-President, Ladies and Gentlemen,

I am convinced of the particular importance of the contribution this World Conference can make towards providing the individual – in other words, the pupil – with the **knowledge** which he will need if he is to function in this society of ours. I do hope that the question as to if and how far the computer can contribute to the development of the pupil's personality, will not be ignored.

Many other questions will doubtless arise. When searching for an answer, with all our faith in the computer, we shall have to keep in mind that the computer must do for us the work 'for which we are not intended'.

WELCOMING ADDRESS

by H. Zemanek, IFIP-Vice-President

It is a particular honor and pleasure for me that the President of IFIP, Academician A. A. Dorodnicyn has charged me to bring his greetings and his wishes to this conference. He wants me to tell you how much he regrets being absolutely unable to be present here. On his behalf I represent the International Federation for Information Processing and all their officers. We are very glad that this conference has been organized and we are happy that so many participants have come. I want to thank the organizers and the conference chairman for their preparations as well as the staff who are working behind the scene.

The official organizers of this conference are the IFIP special interest group on administrative data processing (IAG) and IFIP Technical Committee No. 3 on Education. IAG is an important and very special suborganization of IFIP oriented towards the practical needs of administrative computing centers. IAG since its foundation has had a strong interest in education, and with many of its numerous seminars and workshops has cooperated with IFIP's committee on education. A World Conference on Computer Education is a proper subject for the cooperation of these two bodies and we all hope and wish that this meeting will be successful.

I am personally extremely interested in the subject of computer education; now I have been teaching for almost 25 years at the University of Technology, Vienna, and a good deal of this time was devoted to computer subjects. And within our company, my laboratory staff and I have attacked and partially resolved quite a number of educational problems. Let me take this opportunity to say a few words about the general nature of the subject of this conference.

Education in general

For a new field like computers – the field is now frequently called computer sciences or informatics – the introduction of new people, young and old – is of vital importance.

In our days of particular saturation and general interdependence, the growth of a new field depends on the influx of good people; specialists, researchers, teachers, engineers, and the many people simply working in the field – either as people in their main profession or as temporary users. Only an excellent education can attract and yield all those people necessary for the advance of the new field. The problem is that the usual sources – universities, highschools and professionals – by necessity need a certain developing period before they can offer the appropriate education. The computer, on the other hand, is growing very fast and cannot afford classical delays. Certain educational disproportions are threatening the computer development and shortcomings repel interested candidates from successfully entering the computer field.

In order to sketch the size of the computer education problem, I first want to talk about education in general.

Education may be understood as supervised learning; supervision is done either by a teacher or by some documents for self-study. The subject of this planned learning must not only be a mass of isolated facts or arbitrarily selected rules. Real insight is gained only by facts summing up to a whole entity, by rules forming a system, and by interconnecting facts and rules through their spiritual and historical background, including the many implications for the various environments, and for the society in particular.

There are various kinds of learning. Many years ago, when I studied learning automata, I compiled a list of different forms of learning which might be useful for educational considerations also.

Classification is necessary before any further activity, but on the other hand, proper classification usually happens together with any learning process, it is so to say the maintaining of an order in the acquainted information – whether in simple animal learning or in the highest scientific study.

Memorizing, seems to be unnecessary in our century of storage: books, tapes and computer memories can be filled with any amount of wanted information. Still, no learning without memorizing is possible, and the proper use of our own memory remains at least as important as the proper application of the new technical facilities for storage.

Association or conditioned interconnection is the basis for all higher learning. It is necessary when there are no ordering rules yet or when an escape from the building of established rules is required. Like any other successful enterprise, association carries a certain risk; the interconnection may be based on a hazard, the assumed law may be wrong and so on – but this risk is the only way to new land.

Trial and Error is the application of computed risk: when there is not a priori information, one tries and records the errors; after many repetitions, there may arise the rule which leads into the future.

A compensation for the effort is necessary even in simple animal learning. If the effort does not bring satisfaction, it will at least be interrupted. Compensation is the counterpart of the error.

Search and retrieval are other complementary actions which have to do with learning. Nobody knows everything, even in his own field. But the good specialist knows where to find missing information. Access to good sources is an important part of any kind of learning, and of scientific learning in particular.

Optimization is already a notion after a certain mathematification: measures have to be introduced, and by some theory or at least by some equations the optimal value of one or more parameters is aimed at during the learning process. Optimization of education, therefore, is seldom possible and not frequently wanted. But it should be considered particularly in our logical field of computers.

Imitation is an established method of limiting the effort of learning and study; copy what you have seen with others, since you can anyway not invent everything from scratch. The risk here is in the copied original. Imitation of the wrong person or pattern and imitation without understanding may turn out to be catastrophic.

Instruction or tuition guides learning to make it faster and more intensive. This is the level of learning this conference is mainly concerned with.

Intuition and insight are those ingredients of learning which are outside the algorithmic world, the really human properties which distinguish excellent people from average ones. And it is the slot into which we can put all those phenomena which do not fall in the first 6 categories.

Considering this list and the fact, that the human being in all its activities prefers the triple *mechanics-optics-acoustics*, it becomes obvious that education must be more than the delivering of a set of speeches.

General Educational Problems

There are many general problems which arise with any kind of education, but which have certain specific aspects for the computer

The will to learn definitely is unequally distributed over mankind. Yet it is the motor for successful education. Even with all other points being in bad shape, the will to learn may turn the educational effort into a success. Proper motivation for the students, therefore, is of paramount importance.

The availability of tuition may be a matter of cost and psychology, but frequently it is simply a problem of existence. The different companies do a lot for their customers and for themselves, but they obviously cannot provide tuition for everybody. A university may be far away or there may be one without proper courses. It would be a good project of professional societies to offer seminars and summerschools; but obviously it is very probable that there is a discrepancy between the number of seminar places and the number of candidates – in this situation, the society should restrict itself to offer model courses and to teach teachers, and to leave it to suited bodies to organize then continous educational possibilities. Detailed documentation is an elementary requirement for this principle.

The necessary facilities should not be underestimated. Already the location of the seminar or course may be of decisive importance. But the main problem of computer education is the computer itself which is an expensive tool and, therefore, hard to get for educational purposes. This results in a kind of negative feedback system which turns education for developing countries into a particularly difficult enterprise. And it has been proved in many locations, that education also needs a certain positive and stimulating environment. In a desert of scientific activity with ignorance of informatics, even the best team of teachers may fail in the long run.

Texts and methods of tuition are a problem for fast developing sciences like informatics. Most of the necessary contents of teaching and training has not yet found its classic and simple form of presentation, publications have the rough language of the discoverer and researcher which often explains obvious details while jumping over crucial steps of explanation. Informatics, specifically, is still burdened with unnecessary details, with classical parts of mathematics and electronics which could easily be dropped.

Computer aided instruction is the big hope for computer education. But how much of the problem do we really understand today? Although the computer is a perfect syntactic device, it still is a relatively weak semantic tool: the meaning of data and programs, of questions and answers is hard to formalize. Too many optimists have raised expectations which the poor computer will not be able to fulfill in the near future. The hope really is that the next generation growing up in a computerized environment will handle these problems much better than we can today.

Teachers are the bottle-neck. Who really cares for good education of computer science educators? The success of many national school systems results from the *école normale* principle: a regulating institution which produces the teachers and, at the same time, standardizes the contents of education and methods. Here, a lot remains to be done.

The levels of Education

There are several levels of education in informatics, because there are many purposes of education. First of all we have to distinguish between at least three groups of candidates for computer education

Computer professionals choose the computer as the subject of their profession, they produce devices of programs, or they run them.

Professional computer users are those who in their daily work depend on the computer support, those who creatively use the computer as a tool for computing and information processing.

Routine users finally are those who make use of the computer without paying much attention to it, who want to minimize their computer education because they need no knowledge of the inner processes.

Secondly, we have to distinguish between the different levels of knowledge

The top computer specialists who carry the research and lead the development.

The university graduate in informatics, who chooses the computer as the subject of his studies and who will become an engineer contructing abstract objects: information-processing-device structures or information-processing programmes.

The university graduate in mathematics, physics, electronics, economics and many other fields with particular emphasis on computer knowledge who chooses his classical field as the main subject of his studies, but who intends to contribute to the development of information processing, mainly by joining one of the teams for research, or development, or production.

The university graduate in any field who must learn enough on the computer in order to apply it successfully in his work.

The highschool graduate in informatics, aiming at a computer profession,
the highschool graduate in other fields who intends to make use of the computer as a tool,
and all the people professionally educated on computer subjects by seminars and courses, who either have already a background which enables them to get far with a short-time tuition only or aim at a lower-level activity around the computer.

Computer education, as we can see, is a highly stratified complex of problems and, therefore, gives rise to a lot of misunderstandings; namely if the level on which arguments are used, is not carefully defined.

Computer Education Subjects

Each of the levels, furthermore, has to do with many different subjects of computer education , and any listing, of course, overlaps with items already mentioned.

The construction of hardware is the oldest of the computer subjects; it is in excellent shape of development and improves its parameters every 20 years by a factor of 1000. Originally, this was the field of the electronic engineer, but with the development of miniaturization, it gets more and more into the hands of physicists and mechanical production engineers.

The construction of software is actually the big problem of information processing. A combination of an electronic engineer with a logical mathematician would be required. But since not many people can afford a double study, a new branch has to be created. 'Computer science' would be a good term – the people who question whether computing or information processing is a science overdo linguistic precision; there are many technical sciences which are far below in their theoretical foundations. But in some countries, not least in the United States, computer sciences have moved so much into computation theory (which is essentially the theory of the non-computable anyhow) that software construction was almost beyond the scope. In Europe the term 'informatics' seems now to replace 'computer sciences' and to become a real engineering activity. Still, even in the best cases a lot remains to be done. The classical faculty encounters a series of difficulties when trying to generate a proper curriculum and to have the courses read by the suited people; in most cases there will be a strong tendency towards one of the historic fields, whereby informatics becomes either too much electronics (i.e. too much hardware) or too much mathematics (i.e. theory cultivating instead of construction oriented).

The service of delivered hard- and software needs the same kind of knowledge, reduced however to the debugging requirements.

Operation of computers and organization of computing centres and computer networks as well as all other forms of computer-application facilities require only very general education in the computer sciences and a great deal of administrative skill – not the kind of skill developed by inheritance in a chain of successors, but a logical variety, almost scientific administration; this variety has not yet been pushed as far as the information systems would require it.

Applications, both numeric and non-numeric, are a natural field of computer education; and yet there is a long way to go before the computer becomes a normal tool. Computer-oriented thinking will change a great deal of the different sciences and bring them closer to algorithmic treatment and procedural understanding.

The implications of the computer in philosophy, society, industry and commerce may not look like an integral part of computer education, but restriction to the professional technology is no good anywhere, and for a powerful tool like the computer it appears almost as an obligation to consider the aspects outside the proper information processing problematics.
From all these keywords which I could only touch it follows that this conference attacks a giant problem, and some of you might feel lost one or the other moment during this week. I do not think that this can be avoided. In the future, more specialization in the conference program may be possible and necessary.

The size of the problem

In the last section of this short introduction, let me supplement the diversity of the computer education problems by an estimate of the size of the complex.

Let me make a number of course simplifications and assumptions:

(1) Each installation requires on the average
 1 top specialist,
 3 university graduates,
 5 highschool graduates,
 7 people having passed professional courses.

(2) The increase of the number of computers is 30% per year, i.e. they double every 3 years, and they multiply by 10 every 10 years.
(3) Finally, all countries will reach the American computer density of 1970, namely 60.000 computers for 200 millions of population.

With these assumptions, you can make an estimate of the number of computers and computer specialists in your country as well as an estimate in which time these figures will become true.
Let me give you a few examples.

Normalized to a population of 1 million we get

300	computers,
300	top specialists,
900	university graduates,
1.500	highschool graduates,
2.100	professionals.

For a population of 10 million we get

3.000	computers,
12.000	university graduates,
36.000	others.

A continent of 500 million people will require

150.000	computers,
600.000	university graduates,
1.800.000	others,

and the final global number in the far future for a world population of 4 billion will be:

1.200.000	computers,
4.800.000	university graduates,
14.400.000	others.

A giant task is before us, even if you reduce these shocking numbers to values which you prefer believing in.

This conference cannot possibly exhaust the list of items in computer education nor can it answer all the questions you may bring with you. But it is the first international attempt to answer as many questions as an international conference can answer, and this, we think, is quite something for the time being.

Please enjoy this conference, in the lecture halls as well as in the corridors, restaurants and hotels – for you all know that the papers are always less than half of a conference and more than half are the people you can meet!

Please enjoy the hospitality of the Netherlands which IFIP has enjoyed so many times already and from which IFIP will benefit again in October, when we will be having our General Assembly in Amsterdam, and this meeting will enclose also a one-day ceremony celebrating 10 years of IFIP.

COMPUTER APPLICATIONS IN THE 70's: CONSEQUENCES FOR EDUCATION, FROM COMPUTER SCIENCE TO INFORMATICS

B. Langefors

1. EDUCATION

1.1 *Education – shaping the future*

In planning for education we must search for fundamentals relating to:
problems, procedures and prospects of today.
We need: Liberation from constraining traditions and present problems and details
Informatics – information structures – not merely computing machinery and not merely computer science.

1.2 *Informatics education*

this subject is of special importance because:

(a) Informatics will be highly important for the formation of the future
but –
(b) Informatics (and computer science) is still in its infancy;
hence present problems and methods are likely to become obsolete quickly, except for a small set of fundamental parts.
(c) Computer science already appears now to be too preoccupied with narrowly defined computer problems which, in the (near) future, will presumably be left over for a few experts to ponder and generally forgotten by users.

1.3 *General education*

The subject of informatics needs to be quickly taught in schools in order to:

(a) prepare the general citizen for the computerized society of the future – not only computer-aided work but also computer-aided leisure time will come;
(b) help to achieve understanding of how other fields of knowledge will come to change because of progress in informatics;
(c) improve the basis on which the education and training of future specialists in informatics or its application may start;
(d) encourage the public to put demands on computer systems and reduce demand by computer systems on people.

2. VISIBLE TRENDS IN TECHNOLOGY

2.1 *Extended contacts: people – systems and systems systems*

The future will see:
More terminals (in homes and public service). Convenient terminals (keyboards, pointers, voices, images). Convenient languages, man-machine dialogue. Many local mini-computers in networks with large central computers (computer networks).

Easily available machines. General availability of stored data (data bank networks).

Reduced costs for usage of data systems.

2.2 *Central processing (logic circuitry) costs are becoming almost negligible*

User convenience will be preferred to efficient machine utilization and exchangeability of equipment to machine efficiency.

2.3 *Large memories are becoming available*

More data require more skill in data structuring. New kinds of information services will emerge.

2.4 *Computer structures are becoming amorphous*

Distinct components (arithmetic units, control units-memories, communication units, data retrieval units) joined together in different ways for different applications.

3. TRENDS IN APPLICATIONS

3.1 *From computation and optimization to intellect augmentation*

Man-machine dialogue will be used for the solution of problems not (or not yet) solvable by mathematics. This gives more flexible problem solving and quicker applications. Thus a new perspective on methodology must be developed and taught. A new subject: conversation with machines.

3.2 *From isolated "routines" to large, integrated data systems*

Integration into large systems brings completely new problems:

- not only interface compatibility among subsystems;
- structuring to facilitate implementation of changes (recent systems died because time needed to implement change was longer than time between needs for change);
- data organization for total system availability;
- giving names to data ceases to be a trivial problem;
- the relation between data and information can no longer be handled as if they were vaguely identical. Their difference and their relations must both be well understood.

3.3 *From integration of operations data to integrated control systems*

The integration of operative data processing systems like accounting, invoicing, and inventory control, involves both advantages (enables better co-ordination of logistic activities) and disadvantages (more complex maintenance). Both must be understood. It also paves the way for integrated control and better total information service. To implement integrated control and make it useful, requires new knowledge. **In what ways could integrated management systems give us a better world?**

3.4 *From "total information" for a few to "total information" for many*

A well organized, and equipped information system will be able to serve many people with information and get information from them as well. To make good use of these new possibilities, it is not enough to let managers communicate with the system. The corporation as a whole can profit from having "everybody" involved. Computer-aided training of employees and information about the enterprise and its environment will make employees more useful and motivated and better adapt corporate goals to the desires and needs of people. It will also improve the potential for innovation within the enterprise and its adaptation to the outer world changes.

3.5 *Group communication and co-operation through information systems*

When individuals start communicating with information systems and obtain information from them as well as give information to them, while also getting processing done, then it can be expected that the system will also come to aid communication within groups of individuals. The 70's will see research results in this area and education ought to be influenced accordingly.

3.6 *Information service, developing capacity for semantic retrieval*

Research in information retrieval, semantic retrieval and other types of information service indicate future possibilities to use information systems not only for well-structured data but also for unstructured texts or texts which are only slightly formalized. Not only will it be possible to retrieve information from such texts but also to get it processed so that it can be added to the stored information and so that new information can be deduced from it. New methods will be developed to make this possible on a large scale. **Human language may well become influenced by the dialogues with such systems. Consequences for education may become significant.**

4. WHAT IS IMPORTANT AND FUNDAMENTAL?

4.1 *From machine coding to algorithms to decision tables*

Machine coding used to form the basis of each course in computer usage and appears to remain so in many cases. The fundamental properties of the underlying algorithms naturally get lost in the morass of machine individualities. Tricks which are only useful in individual machines (or machine generations) are permitted to dominate over systematic training of fundamental principles in this way. This approach means that the students need to understand the machine before they can understand programming. However, to understand a computer requires understanding programming. Thus, the way to learning programs and computers gets unnecessarily curvy and long.

Not only is over-emphasis on machine coding intellectually unsatisfactory, it is also impractical at a time when computing power is becoming extremely cheap while programmers and "systemmers" are becoming rare and expensive.

When more people come to use computers, human-oriented, rather than computer-oriented languages, must be given priority. When computing power and storage space becomes inexpensive this can be afforded. Indeed much more is gained in this way through more widespread and more sophisticated use of computers, than it will cost in increased computer load. Algorithmic languages will be preferred to computer-oriented languages, and non-procedural, application-adapted languages, will become still more favoured. Indeed precise information systems precedence analysis (down to elementary messages and elementary processes) **combined with** use of decision tables, together with stored process programs, will eliminate much or most present-day applications programming.

4.2 *From data terms to data structures*

Today's concern with individual data terms (variables, elementary items) or, in simple collections of terms ("arrays", records), is far too narrow for the development towards information systems. The information aimed at in the data processes will be obtained from data structures and information provided, whether through formalized documents or unstructured or semi-structured texts, will be handled in the system as data structures. Information will often be deduced from stored structures rather than being stored as separate elementary messages (object – attribute – value triples). **Consequently, data structures and their relations to algorithms on the one hand, and to information (knowledge) on the other, will be of fundamental importance.** This branch of informatics has close relations to philosophy, linguistics and logic.

4.3 *From data processing to information systems*

The development towards integration of data-subsystems into a company information system brings in the information aspect of data and their processing for different reasons. Thus, it turns out that, in a corporate information system where one wants to use data where they are useful, it will not be possible to define to the data base system which data are wanted except by referring to the information required. This means referring to known parts of the corporation and, thereby, becomes understandable. **However, we need to consider the information aspect not only to be able to retriev the right data. We need it also to make the best use of the system, for the management of the enterprise or for research or education.**

The information system contains information, not only in the form of data, and information processing will be done in the system by people, not only by computers. Thus the information system will contain a non-data subsystem, a non-computerized data subsystem and a computerized data system. **In the information systems era a better understanding of these distinct subsystems and how to make them co-operate will be needed.**

4.4 *From optimum design of subsystems to total architecture based on well substantiated judgement.*

Building from modules. To get the system we want –

not just get the one we get. External properties of systems and modules.

Large complex systems must be built from modules. Distinct expert groups must design distinct modules. When we go over to large systems, the group can no longer extend its expertise to cover the whole. Only by specifying a hierarchy of modules or subsystems with prescribed external properties, to be developed by distinct groups, can large systems be designed. Also, only by developing methods for specifying external systems properties in user terms and yet precisely enough to guide design, or management, can users (top management, society) make sure they get the system they want. The larger the system, the more important that the user controls the job of the specialists. **The development of larger, integrated control systems and information systems that is ahead of us means that methods and philosophy for hierarchical, modular systems are becoming fundamental.**

The design of optimum control systems for separate functions of an enterprise are playing an important part in recent development of computerized management control. A large amount of research is going on in the world on mathematical methods and computer programming for optimal control. As computers become more powerful and, as methods are getting more advanced, one can bring together smaller optimization subsystems into larger systems and thereby move from suboptimization over small subsystems to suboptimization over larger ones. (For instance one may bring inventory control subsystems and production control subsystems together.) One might think that in this way one would eventually obtain total optimum control. Closer analysis shows this to be an illusion, however. Organizations have several objectives, not a single one. These cannot be weighed numerically against each other by management. Therefore, while it may be justified to optimize (rather "suboptimize") subsystems towards a single objective function, it is not feasible to totally optimize the whole system. Indeed, even if it would not have been logically impossible to determine a total optimum, it would still have been impossible for technical reasons. It would simply not be possible to collect and communicate information over the whole system quickly enough for the real executive decision need. Thus the best that could be obtained in the real world, the "executive optimum", would have to be some simplification of the apparent optimum.

The two obstacles to total optimization: multi-objectivity and time to obtain information, are handled by the same method of solution: judgement. Thus corporate control can not be as good as possible by replacing judgement by mathematics and computation. It can only be improved by improving judgement – not by trying to avoid it. It is interesting to note that, while this cannot be solved by mathematics alone, it can be handled by the information system. **Thus instead of searching for total optimization we shall have to be searching for informatics to support well-substantiated judgement.** The future lies not in using computers to **replace judgement.** The future is for computers to **support judgement.**

4.5 *Informatics, technology in general, and changes in society*

The developing technology is changing its social environment and this, in turn, highly influences the technological development. Informatics takes an important part in this. Information systems will also be called upon to help forecasting and planning for the control of the development.

As information systems and control structures develop, they will totally change the possibilities for human co-operation. They will make possible radical improvements in social systems. Political schemes or ideologies will have to take these new possibilities into consideration if they want to be realistic. Indeed this is a revolution now going on. This will probably be hard to get recognized today – just as it was hard to get managers to recognize, a decade ago, that computer technology was likely to radically change organizations and the very functions of management or, just as it has been until recently, hard to make physicians accept that informatics would mean totally new vistas for medical work.

5. CONSEQUENCES FOR EDUCATION

5.1.1 New knowledge and new skill to be taught

The growth of informatics is likely to influence significantly upon other fields of knowledge.

5.1.2 Consequences for general education

Education in the 70's will have to prepare for technology and society of the 70's and 80's at least. Very significant changes will occur. Therefore, as has already been mentioned, it is important to choose as subject for teaching such parts of our knowledge which will not be quickly obsolete, for instance, by such trivial things as changes in computer hardware or software.

Of course, there is some risk involved in choosing for education new subjects as they cannot be well established at the same time. The point is, however, that it is likely to be much more risky to delimit oneself to things more established but instead more trivial and, bound to soon become obsolete for other reasons.

As change will be the main characteristic of informatics – as it will be for society – education will have to train students to face changes and adapt to them. Thus the two aspects:

(a) stressing that which is fundamental and not too much subject to change and
(b) obtaining an attitude which prepares for meeting change

are of utmost importance and must be covered by the education.

The elements of algorithms and computer programming as well as the elements of data processing are simple enough to be taught in elementary schools. They are important enough to justify being placed there. Also computers have made parts of present school subjects less important so that by leaving this out one can well get a place for the computer education. For instance the special algorithms for computation of square roots or arithmetic division may well be replaced by general algorithms methods.
In a computerized society, with computer power available everywhere, like telephones today, training in manual computation will be less important. Such training ought to

be largely replaced by training in how to make computers compute for us. One consequence will be that more people than before could work with computational problem-solving – and like it. **A consequence for education is a broader base for recruiting to subjects where computing is important. This, of course, calls for modifying the courses in these fields.**

Likewise, with computer power and data bases widely available, in man-machine dialogue, memorizing vast amounts of facts becomes less important and – indeed – becomes unjustified. Again the consequence will be that more people than before will be able to successfully study these disciplines and do professional work.

A consequence for education will be that it must be modified so as to make the utmost use of these new, enlarged possibilities.

An important consequence of these changes will be that not only will more people take part in the development but also that people with other profiles of gifts or interests will become involved. The creative potential in these fields are bound to be the result. Education has the duty to care for these opportunities.

It should be obvious that we have to determine the consequences not only for education of informatics in general schools but also for other general school subjects.

5.1.3 Education in Informatics and computers

Informatics greatly amplifies our potential for managing so as to better fulfil our objectives. **It is important to see that this will become pointless if we do not improve our skill in defining our objectives.** Indeed informatics will have to help – and be able to – also in this respect. **This means that informatics has to cover a vastly wider field than mathematics and electronics.** Computer science thus becomes too narrow – as has already been mentioned in our preceding survey. **A consequence for education is that many more students than have mathematical interests must be given education, informatics education.** A consequence of this, in turn, is that it will be highly important to clean up informatics subjects so that they do not contain unnecessary mathematical jargon. **It appears that often we formulate our informatics models in mathematical terms so that we get the impression they need to be expressed in that way, while it is only a result of our habits.**

Examples of informatics methodology, which is fairly independent of mathematics, are the **information analysis** area and, still more pronounced, the methods for **systems acceptance in organizations** where sociology is a much closer scientific field than mathematics. It is obvious to everybody with experience in large information systems implementation and installation, as well as to everyone who knows the theory of organizations, that these problems are even more critical to succesful implemention of information systems than is knowledge of computer programming or optimization, for instance.

Informatics education obviously must be broad enough to enroll both mathematics or electronics-oriented students as such with other orientation. It is important then to have as large parts as possible open of the field to both categories.

5.2 New forms of education

The expansion of the use of computers and the development of the science of informatics is not only going to change the world and, therefore, to change **what** ought to be taught. It also will bring a tremendous change in **how** teaching ought to be done. This is obvious. A revolution in the handling of information is bound to bring a revolution in methods of teaching, including examination of students. When a student can have on-line access to the computing power and the vast amount of data in large data banks, he can be given exercises which are more realistic than before. He can learn by working on fairly realistic problems. He will therefore learn by doing. He will be more motivated to get further knowledge and training. He can, himself, come to be stuck by problems where he finds he will need more training or advice. The computer can check his misunderstandings and mistakes much quicker and more precisely than a human teacher. It can also give him more accurate and detailed advice about where to look for required knowledge.

Educational systems will be extensively supported by computer networks with large quantities of student terminals able to communicate by printed texts, images and voice. Obviously we shall have to re-appraise completely our ways for teaching and for designing teaching material. **For instance, just as computers have tremendously increased our possibilities for integrated management they are also tremendously increasing our possibilities for integrated teaching. In my view the lack of integration of the education in the distinct subjects is one of the weakest points in our present educational system. This is a point where computers are likely to bring a revolution in educational systems!**

5.3 *Snapshots from experience*

In Sweden, university institutes for "Information processing" were started in 1965 with two branches: one **Numerical Analysis-oriented** and the other **Information Systems-oriented.** (Numerical Analysis institutes had existed a few years and formed the nucleus of the new institutes. Courses in Business Information System Theory had also been given in some universities.)

In the information systems-oriented field we have, right from the start, concentrated upon treating the main problems and features of information systems, rather than merely trying to **apply** some method or some tool. We have stressed what was likely to be important for the future. We have not only studied how to design information systems, we have also critically analyzed the way in which they could be useful – and where they would not.

Our experience shows that there is such a thing as a basic information processing science already now – you may also call it informatics. We have also come to conclude that this science would be useful and important even in a world without computers. How to treat data and how to obtain information – as well as how to use it – is important enough in itself. Likewise, what is important, and what can be understood and formalized in the tasks of constructing large, integrated systems has high relevance in many fields of modern society.

About 1,200 students a year are getting one-term courses in information systems, about 500 take the second term, about 100 take the third term and there are about 50 doctorate students. (The numerical analysis branch has almost the same size.)

The ADP staffs in some of the largest companies in Sweden have already some of our earlier researchers or students as managers or as leading analysts.

Many of our students have already had some years of experience. Some of the largest companies, with ambitious information systems development going on, have started to be concerned about their old staff, which have not got the science-based education which they feel is important in the new, large development projects. We are running our courses also as evening courses, to serve those who also have their jobs. In this way, we try to aid the re-training efforts that have come to be important in the field.

We feel quite convinced now that we did right when we chose to stress fundamentals with a potential for the future – at the price of being very brief about the routines of today.

6. *Conclusions*

What is really important in the planning for future education about informatics and computers – as well as in using these- is to take a realistic as well as an open-minded view on the possibilities that lie ahead of us.

In education – the shaping of the future – it is of the utmost importance to understand that realistic planning does not mean conservative planning.

COMPUTER TECHNOLOGY IN EDUCATION– HOW TO MAKE IT VIABLE

Sylvia Charp

1. INTRODUCTION

Educators the world over are facing a responsibility to apply today's technology to improve the quality of the educational process by permitting more personalized and individualized instruction, simultaneously increasing the operating efficiency of the process and, thereby, reducing its cost.

Education is not a discrete enterprise and involving traditional methods are no longer appropriate. Education cannot afford to ignore modern technology. Though living in the computer age, many educators continue to use what now can be regarded as relatively out-of-date techniques for processing information. The application of computers and electronic data processing to educational procedures is a relatively recent development. In comparison with the more widely known independent use and rapidly expanding application of computer technology in the business, military, and scientific communities, its use in education has lagged far behind.

2. EDUCATIONAL TECHNOLOGY

The field of education is, for the most part, using technology in infantile ways. Educators are not certain that what is called educational technology is **educational.** Unfortunately, the educational process is not a scientifically based technology, like putting men on the moon. We have not yet developed a science of learning. We are not able to predict with assurance. The application of technology to the educational process has probably been the single most important response to many problems in education. To date, the applications have been empirical, and not fully validated.

During the 1960's, computer technology reached an honorable acceptance into the educational system. Though the first large scale electronic data processing computer was put on the commercial market in 1950, the field of education lagged business and industry in exploring applications. Now twenty years later, let us examine what has been accomplished with respect to education, what still needs to be done, and what pitfalls are to be avoided. Many of these observations are a result of personal experience.

2.1 *Earlier predictium*

A special report issued in 1968,[1] predicted a change in the school of tomorrow. The student who enters school will have his registration paper processed by a computer. When he graduates years later, he will receive a diploma or degree prepared by a computer. In between, the computer will assist in teaching him, counselling him, scheduling him into classes, testing him, grading his papers, helping him with homework, and providing him report cards. As he struggles through reading and arithmetic, the computer will be a patient tutor. If he needs information, he can not only consult his local library, but also „retrieve" materials instantaneously from other libraries. With the help of the computer, he will be able to solve complex problems that formerly were assigned to more advanced students. When he is trying to decide on a vocation or college, the computer will help him explore different alternatives, and suggest the training he will need. It will provide his administrators and teachers with a printed record of his progress in each lesson so they can determine how to help him and how to make curricular revisions. It can simulate a school in operation to help the educational planner to plan new schools. As of today, the author of that article had pretty good foresight.

2.2 *Some achievements*

Computers have begun to serve education in various ways such as:

2.2.1) Administrative Tasks-payroll, cost accounting, warehouse inventory.
2.2.2) Testing and Evaluation-recording student responses.
2.2.3) Information Retrieval-data banks on students and library information.
2.2.4) Computer Assisted Instruction and Computer Managed Instruction.
2.2.5) Problem Solving and Simulation-setting up conditions to solve a problem whether simulating a flight to the moon or operating an airline reservations service.

Commercial developments have aided the expanded use of computers in education. The most significant is time-sharing, enabling a number of persons at different terminals to communicate with a single computer at the same time. Time-sharing is now making its appearance in primary (first six years) and secondary (second six years) schools, as well as at the university level. Administrative tasks such as: classroom and subject scheduling, record keeping, general accounting, warehouse and cafeteria management, and pupil grading are some of the many current uses of time-sharing. Although these functions could be performed on almost any computer, time-sharing brings to a school the capabilities of a larger computer than the school could normally afford, using programs shared among many schools and users, and a peak level of computer power that is available only when needed.

The nature of the computer's use within a school, unlike industry, requires the computer to be available only at stated intervals. For example, one particular computer system used in the School District of Philadelphia is able to serve the needs of 25,000 students in solving problems using multiple input-output devices.

2.3 *Benefits for the students*

Another commercial development which has enhanced the use of computers in problem solving, even down to young students in the primary grades, is the ability to communicate with the machine through the medium of a simple language, without being required to learn complicated programming. In addition, some computer companies have recently started to design systems specifically for instructional purposes. The existing hardware, though still weak in many ways, has been improving. In addition to teletypewriters are cathode ray storage display tubes (very much like a home television screen) and random slide projectors. Graphs, scatter diagrams, and drawings have been made accessible.

Students in several schools in Philadelphia no longer necessarily move from class to class in fixed groups, but in a more fluid way resulting from provisions made for independent study and group work. Administrators are using the capabilities of the computer for: flexible scheduling, to keep track of each student's progress, and to assign students to classes more effectively. Students personal records are stored and retrieved, as required, to assist in scheduling, attendance accounting, and grade recording.

As integral parts of the mathematics or science courses, the computer has opened areas that could not be taught previously. The general area of using the computer to teach mathematics through problem solving is one of curricular development in which the incremented costs appear to be relatively small. This is so because one of the conversationally oriented languages commonly employed in the computer industry is used as a pedagogical device, simultaneously providing practice and training in the use of the computer. The language, BASIC, is most commonly used for this purpose because of the ease at which it can be learned. FORTRAN is similarly used. By 1972 it is expected 1,700,000 students in the high schools in the U.S. will have been introduced to the computer field.

The ability to simulate real events and processes allows the student to participate in experiments in chemistry and physics, controlling certain steps, trying alternative solutions, speeding up results, and otherwise manipulating the variables of the problem which he otherwise could not do. The computer-based games form of simulation has involved students in learning experiences concerned with simulating the events of a certain historical period, the decision strategies of a legislative group, or the problems of a family group. The student is able to control variables, reverse process, or try alternative solutions. Simulation of a chemical analysis, for example, is not difficult. With color slides sequenced at the student's request, the student can observe what will happen if certain chemicals are used. He types directions to the machine which „performs" the experiment, step by step. In a game for younger students, a student is asked to simulate the decisions necessary to govern the society of a primitive agrarian economy. Events such as flood, fire, and plague of locusts are interpolated at random and decisions are made to anticipate or compensate for these misfortunes. The effect of decisions and the results of disasters are fed back to the player who is responsible for governing the community.

2.4 *Objectives of educational technology*

A primary objective of applying the new educational technology is to individualize instruction in universities and lower school systems. A major premise of such instruction is that it leads to each individual following his own rate or progress and style of learning. Some universities and school systems have programs which embrace technology as a means to better teaching. They have recognized that along with the chalkboard, textbook, and other teaching tools, technological innovations can be used to enhance the teaching-learning process. Concrete evidence exists that individual pupil's needs and differences can be better met when wise use is made of man-machine systems. It has been demonstrated in practice that teacher-pupil relationships are improved rather than diminished when appropriate tools are wisely used. Computer Assisted Instruction (CAI) has been hailed as having such tremendous potential. It is defined here as direct two-way interaction or communication between an individual student and programmed instructional material stored in a computer. It has been shown that the computer can provide a student with instruction of great flexibility at a pace controlled by the student. With proper course material, the computer keeps the student continually motivated. It provides the teacher with a comprehensive record of the student's progress. It has tremendous effect as a teaching tool and its effectiveness depends directly on the experienced individuals who are responsible for developing the programs.

Computer Assisted Instruction is now more than a decade old and is far removed from being just a conceptual idea. It has more than successfully proven its operational feasibility. Moreover, CAI has started to document an impressive array of examples showing increased instructional effectiveness in such curricular areas as elementary mathematics, reading, science, college physics, and teacher training. CAI as a tool fits within a normal curriculum and in an instructional setting. It should not carry the entire instructional load but should be part of a multi-media approach.

The computer is being used by young children in the primary grades for the continued development and rapid improvement of basic skills in reading, spelling, and arithmetic. The computer has been programmed to offer exercises of various degrees of difficulty, assigning each student to his own level according to his past performance. Slower students have been spared the initial experience of public failure and brighter students have moved right ahead. For the slow learner, the computer has been used as a remedial teaching device, making use of the Socratic method of question and answer. He is led step-by-step through a problem, told when he is correct, and helped when he is wrong. For the brighter student who becomes easily bored, and usually is kept back by the rest of the students, the computer offers him the opportunity to work by himself at his own speed or on topics of his own choosing.

The area of counselling and guidance is being aided by the computer. A program being developed now for use in two secondary schools in September will provide for the following. A student meets with the counsellor to discuss personal vocational plans for the future and a question arises concerning the status of the student's course work. The counsellor has a small screen on his desk. He keys in the student's name and there appears the student's school records, his test scores, and his teacher's recommendations. The counsellor then advises him on certain options open to him but tells him to get more information on jobs from the teletype machine in the corner of the room. The student then sits down at the teletype and keys in the job classifications of interest to him. He is provided with information to questions such as: where to find employment, locally and nationally; salary range; type of skills needed; and schooling required.

3. PROBLEMS OF REALIZING CAI

3.1 *Constant benefits*

Although at present, hardware and software operating costs are high, CAI is making some impact. But the real problems are in software, in content materials, and in its most effective uses. Involved here are: curriculum building, arrangements for the creation and dissemination of materials, development of shared data banks, and establishment of compatible and convenient information networks. Included also are better understanding of the learning process, how best to aid learning, when to instruct, or drill, or discuss, or examine with the student.

In order to build a course or an instructional block for CAI, the objectives of each exercise must be distinct, the reasoning sharp, the logic sound and the facts presented clearly and accurately. An hours worth of materials presented, to the student may require 100-200 hours to prepare, including the development of instructional strategies and preliminary testing on students. Experience has shown that using teachers to prepare material for CAI has indicated that those who have participated in preparing material are more likely to accept and utilize the CAI system when it is introduced into the classes. Years of experiences in conventional instruction are valuable to teachers to aid them generate the numerous alternative approaches to the subject matter required in computer program branching. Also, enthusiasm for the material and acceptance of the material is enhanced when it is known that other experienced educators have had a hand in its production.

Any prediction about the future of CAI as recently as three years ago which suggested that Computer Assisted Instruction would be economically feasible by 1970 would today seem very foolish indeed, yet, now at the beginning of the 1970's, some commercial systems and curricula are available which can accomplish routine tasks of drill and practice relating to the development of skills, at a cost not too far out of proportion with the costs of conventional instruction. Of greater significance than costs is the emergent pattern of improved student performance. Within the past year significant results have been obtained of students' exposure to CAI curriculum. However, still greater numbers of students must still be examined.

Critics of computer assisted instruction have pointed out that the benefits have fallen short of what had been anticipated. Perhaps we have expected too much. We expected the learner to interact with the computer as he might with a human tutor. We are still trying to second guess the errors the student is likely to make when we program the materials. We have not been able to use the computer to analyze the unexpected responses of the student. In the United States, although CAI is more than a decade old, it has not progressed substantially beyond its initial endeavors. Drill and practice which lends itself to the automation of simple routine has achieved some success and shown some gains in pupil performance, especially in young children. Tutorial CAI has not been evaluated sufficiently. That research which has been carried on does indicate better performance on the part of the student who is exposed to CAI techniques.

3.2 *Implementation of CAI*

The administrative difficulty in introducing CAI in the traditional educational environment can not be underestimated. The role of the classroom teacher changes. Teachers have to learn how to use the new tool effectively. They become the manager of the instructional process and now make their decisions based on facts presented by computer print-outs. The teacher using the information at his disposal can diagnose the condition of each learner and plan activities which are essential to the learner. As he uses the communication role of the computer to impart information, he is free to providethe intrapersonal relationship with his students.

Computer managed instruction (CMI) is being investigated in various educational institutions and systems. Here the student does not interface directly with the computer nor does the computer actually administer or present to the student any of his instructional programs. The computer serves as an informational system which records the student's learning and academic history and his program of studies, scores tests and examinations, and furnishes, on a retrieval basis, the information to the teacher as requested. The computer issues the „prescription" or the assignment of appropriate required learning tasks to students according to their needs, based on past accomplishments and future expectations. The role of the computer is to handle the scoring, the record keeping, the matching of student performance to appropriate learning materials, the scheduling, and the making of recommendations.

The revolution in the teaching-learning process will be more complete when some way is found to deal with and modify the teacher's traditional role. The teacher can not perceive himself to be the controller of the learning process and the primary input mechanism for each of the learners who is before him. As the teacher becomes the organizer of a system of instruction, a diagnostician of learning problems, a prescriber of instructional strategies, a coordinator of educational „helps" to the learner, CAI and CMI will become more valuable teaching tools. The major problem today is that its current level of attainment is mistaken for its ultimate potential level. Some of the reasons may be:

- Systems are not being used imaginatively.
- Systems are more sophisticated internally than had been imagined.
- Lack of many really exciting and effective educational programs.

It would be ill-advised to introduce CAI on a world-wide scale a panacea for certain shortcomings of education. On the other hand, it would be a grave mistake to reject CAI as a short-lived phenomenum or curiosity that should not be taken seriously. It has been demonstrated that the computer can aid in individualizing instruction, being an aid to both the teacher and student. No other teaching aid, which is what the computer is, can provide the detailed account of each individual student's responses or can organize information dependent upon the characteristics of the individual student. But, regardless of the sophistication that will be gained in educational information systems, in the last analysis, it will be the teacher who must assume final responsibility for its implementation.

3.3 *The hardware-side of CAI*

Unfortunately, concentrated development efforts by major computer-oriented companies in CAI are few. CAI systems are being constructed in very limited quantities. They are presently highly priced to defray development costs and to build up industry's capability. However, with wider use of CAI, mass production procedures eventually will lower cost. Industry must decide to commit enough resources to research and development work in CAI and CMI to reduce cost and improve capability.

Technological problems must be eliminated when using computers for instructional problems. The computer must be just as reliable when its users are school-age children than when its users are sophisticated scientists or experienced engineers. When children are put at computer terminals and the machine does not work as it should, the result is frustration and even chaos as it is for the industrial executive. Present student terminals are poorly developed for such applications. The computer controlled teleprinter has limitations as an input-output device for general education purposes. It has been supplemented by a visual display. Audio capability which is essential to CAI, especially for primary children, is not available economically. Voice sensitive and touch sensitive devices are not widely available, especially on a feasible basis.

The early promise of great instructional economy has not been realized. Most of the hardware devices are still in experimental stages and are very expensive. However, when one contemplates the long range benefits to educational technology, the economic argument should not be overpowering. It is important to recognize that maximum economic advantages will require for their realization maximum adoption. The cost of terminal devices are still prohibitive. Low-cost plasma screen terminals, are being developed which may soon become operational. This type of terminal should overcome some of the current cost problems associated with CAI. One of the basic expenses involved in large system uses of computers on a time-shared basis is the telephone line charges. The gross cost of data transmission may be a major obstacle to the educational use of computers. Cheaper communication, such as, private data transmission networks, consisting of long lines or microwave, coaxial cable, or part of an educational television circuit must be investigated.

3.4 *Organizational adjustments*

Effective implementation of technology in the schools points toward the need for considerable adjustment of the organizational pattern already in existence. The central problem is to bring the human and material resources to bear in the desired learning condition at the proper time and in the proper physical and personal environment. This is no easy task.

The study of the various aspects of the total learning environment is necessary. A data bank on learning problems based on analyzing detailed records of tutorial interaction for better instruction needs to be investigated.

Educational technology provides the partial means, not the ends of instruction.

We have not used the speed and memory capacity of the computer to assign students to the study area, the instructional units, or various media that are most appropriate to his work. We still need to match the school's resources such as: teacher, textbooks, programmed material and laboratory or media equipment to the student's needs. A large portion of a student's study time might be spent at home, where a student would work at a terminal connected to a centralized computer and the space at school be reserved largely for activities requiring student-staff interactions, such as, individual counseling, tutoring, group discussions or activities requiring specialized equipment.

The growing need of standardization has long been a problem. Much of the equipment manufactured even by a single company is not compatible, resulting in complex and serious interface problems.

The mode of using computers for problem solving has been changing. Starting several years ago, a student punched his deck of computer cards, took the cards to the computer and waited until he got a set of diagnostics from the computer or until he ran out of his time assigned to the computer. Schools are gradually phasing out this method to teach programming but still use it to teach hardware and diagnostics. A usual first step taken by a school is to acquire a small computer, but it fast becomes difficult to use due to its limited size and speed. Terminals should not be limited to only typewriterlike devices, but should include any input-output equipment, e.g., high-speed readers and printers, graphical display devices and small computers which can do their own limited processing and which can be connected to a central computer for more complicated data processing and computations.

Time-sharing vendors must become more sensitive to the schools needs. Included in their basic charges should be teacher training, and provision for better equipment reliability.

4. THE TASK AND ROLE OF THE EDUCATORS IN CAI

People are needed who can bridge the gap between data processing and education. The data processing expert has relied on educators for the best applications, but the educator is not aware of the full potential capabilities of the computer and has relied on the data processing experts in industry and business to supply productive applications. Many of the reasons are psychologically-based and are the same as those which were found in the early applications of computers in business and industry. In education, however, social and economic factors are amplified. In addition, a lack of knowledge still exists on the part of educators about the power and potential of computer systems for improving educational programs.

In the past, education tended to buy off-the-shelf items complete enough to be operational by themselves without extensive contributive work by the user. Now, however, problems of developing the programs and providing staffs to implement them are expanding.

The need of having adequate appraisal and sound information as a basis for intelligent planning is essential to increase the effectiveness and efficiency of education. Careful comprehensive objective evaluation must influence any large expenditure of effort and finances.

Technology is a powerful factor in the achievement of educational goals where the instructional program is planned by competent designers and the instruments are employed by properly prepared and skilled teachers.

Judgement and decision must be made on the basis of extensive experience and expert analysis. The persuasion of rhetoric and the desire for institutional status can seduce schools into making large expenditures for equipment which may be poorly adapted to their purposes for which they are illprepared to use successfully. Research and experimentation in this area are expensive and difficult. They must be constructed at a high level of expert competence to avoid eventual waste in money and effort. They inevitably entail risk and the possibility of failure.

To fully implement a total centralized education-oriented computer system might eventually cost 10% of a total education budget over a 10 year period. In view of the inefficiency and expense of taking a piecemeal approach, evolutionary development of an automated system is necessary. The automated system should include comprehensive data processing for appropriate instructional activities as well as for administrative and managerial functions.

One problem facing designers of educational information systems is that educators need to become better informed to understand and effectively apply this emerging technology. In the hands of knowledgeable people, today's computer becomes a powerful tool that can be used to handle problems of great volume and complexity in attacking educational problems. Educators must begin to understand the capabilities of the computer and plan ahead for its use.

Educators must be concerned about computers, must learn about them, must teach about and with them. They cannot ignore them. The computer is not going to go away. Its effects will not fade, its use will not decline, its influence will not disappear. This much is very obvious.

1 Computers – New Era for Education, Education, USA, Special Report, 1968, National School Public Relations Association, Washington, D.C., USA.

FUNDAMENTAL ASPECTS OF EDUCATIONAL TECHNOLOGY (ILLUSTRATED BY THE PRINCIPLES OF CONVERSATIONAL SYSTEMS).

Gordon Pask

1. INTRODUCTION

Teaching situations are usefully classified in a systemic fashion according to the relationship existing between the student and the teacher or teaching device. For example, programmed instruction, using a remedially branching programme, is a **feedback** system since the materials presented to a student depend upon the correctness of his previous responses. By the same token a teaching situation in which the student receives instructions from an audio tape or a radio presentation is (one sort of) **feedforward** system since the tutorial plan must anticipate the students reaction. Other teaching systems, notably those involving perceptual motor trainers, are **adaptive** because a parameter of the teaching device is altered as a function of the behaviour of the lowest level feedback loop. The category considered in this paper is the class of conversational teaching systems which are chiefly addressed to tasks entailing concept acquisition or problem solving.

A **conversational** system is made up of a student in communication with a teacher or a teaching device (often a CAI programme). The dialogue which takes place is partly to do with problems germane to the task in hand (which is true of any system whatever). But some of the discourse is **about** the problem posing and problem solving dialogue and **about** the ways in which problems ought to be solved. The communications is tutorial since it fosters the acquisition of skills or knowledge which ultimately lead to an adequate task performance.

From a Cybernetic point of view the tutorial function is a control function; the teacher (device) aims to control the student's learning process in a prescribed fashion. Since the topic of this paper is **technology**, the discussion is confined to control functions that can be described, at least as heuristics, and which **may**, in principle, be mechanised, (though whether or not they **should** be mechanised is a different matter).

In common with any other controller, the teacher (or device) must operate in terms of a model for the process to be controlled; here, the learning process.

Whilst some aspects of this model can be stipulated in advance on the basis of information about the task itself and the general population of students, other aspects are necessarily individualised and must be built up in the course of instruction. To this extent (at least) the conversational teacher learns about the student in order to teach him.

1.1 *Preliminaries*

Conversational teaching systems are of outstanding interest for two main reasons:

(a) In connection with a range of educationally and industrially important tasks they are effective tutorial agents. For some of these tasks there is reason to believe that conversational systems are more efficient than other types of system. The advantage is likely to be appreciable when the following conditions are satisfied. (a) The tasks can be performed in a number of different ways (i.e. several different mental computations satisfy the same goal). (b) Different students in the target population have varying dispositions towards the task and, left on their own, would learn it differently. (c) It is desirable to encourage motivation or versatility by allowing tutorial freedom rather than imposing a strict training regime.
Under these circumstances, the merits of a conversational system are often significant enough (levels of 0.1% significance have been obtained) to offset its cost. (A mechanised conversational system is generally more expensive than less elaborate alternatives. If the tutorial principles are realised by a human teacher then the price differential does not necessarily exist).
The evidence in support of these contentions is gathered elsewhere (Lewis and Pask (1) Pask (2)-(5)) and will not be discussed in the present paper.

(b) Conversational systems are comprehensive. The organisations of all other (existing) tutorial systems can be derived as appropriately restricted versions of the conversational paradigm, thus forming a taxonomy of the teaching methods currently amenable to partial or complete mechanisation. For example, adaptive systems, feedback controlled systems and feedforward systems are readily treated in this way. This matter is discussed at some length in other papers (Pask (6)-(10)) which also provide references to the source material.
Because a taxonomy exists and because conversational systems lie at the head of it, an educational technology of **conversational** systems adumbrates the technology of **all** educational systems.
This paper lays the foundations of the requisite technology.

1.2 *Contents of the Paper*

It will be clear, from the preliminary comments, that an educational technology of conversational systems has a great deal to do with learning and models for learning. However, the familiar learning theories, focussed on conditioning, adaptation and the like, are not too helpful at the necessary level of complexity. Very little of the discussion bears directly upon the statistical convergence of behaviours; most of it is concerned with 'giving instructions' or 'providing descriptions' and acts of a similar type.

Because of this, a new learning theory has been constructed for the specific object of designing and evaluating tutorial systems. (Pask (11)-(16)). It is outlined in Section 2 and lies at the heart of our approach to teaching. The theory is developed to cover the full conversational system and it is used for this purpose in the present paper, but it can be applied to any other types of system and is probably the simplest kind of theory that will suffice to underpin a general educational technology. The treatment in Section 2 is non mathematical, but the crucial issues have not been glossed and an attempt has been made to express them unambiguously in the language of information science.

Section 3, makes use of his material to describe the structure and operation of a conversational system. It should be emphasised that the theoretical issues of Section 2 are not peripheral to this theme. They are an essential part of the argument. Section 4 contains a brief overview of the taxonomy of teaching systems (Section 1.1) and Section 5 is concerned with their physical realisation.

2. A THEORY OF LEARNING AND TEACHING

The following theory is tailored to act as a framework for the design of conversational teaching systems and as a vehicle for describing fairly complex tasks.

2.1 *Task and Task Analyses*

People learn to do mathematics, to drive motor cars, and to perform clerical jobs. Though these activities are diverse and have varying intellectual content, any one of them is conveniently adumbrated under the rubric 'task area'; a phrase which has roughly the same meaning as the educator's 'subject matter area' (for example, 'history' or 'sociology'). Any task area is composed of many nameable tasks, some of which need to be done (often in a prescribed sequence) when carrying out a particular **assignment** such as writing an essay on the Prince Regent's occupancy of Brighton Pavillion or driving along a given route from Richmond to London or sorting the invoices and delivery notes received from a certain supplier. The nameable tasks that make up a task area have the following important property: **the task names have a commonly accepted meaning.** If the name is announced any member of a competent population knows what to do in order to carry out the task that is named, and moreover, he knows how to do it.

Thus 'Add (specified numbers)' has a commonly accepted meaning. So does 'Pull the lever in front of you'. **Assignments** may also have commonly accepted meanings in which case they are called **assembly tasks** but more often than not their meanings must be clarified by instructions which prescribe a sequence of subsidiary tasks. Of course, the notion of 'commonly accepted meaning' is population bound. 'Mathematical Induction (over a given domain)' has a common meaning accepted by a group of logicians but this meaning is neither accepted **nor** understood by the populace at large. However, it is quite vital to our argument to note that any legitimate task may be named and its execution can be demanded **either by the analyst or by an individual himself (provided he belongs to an appropriate population).** If X is such an individual, then it is equally possible to ask X to do task T_0 or for X to 'ask himself' to do T_0 (for example, in carrying out some assignment, T, of which T_0 is a part).

Thus the meaning of a task is not only appreciated by the individuals in a population but also by the analyst. Because of this, the analyst is able, in principle, to specify, **for each task, a task automaton that does the same job.** More precisely, for each task the analyst knows a goal (or equivalently, a relation that is satisfied if and only if the task is done), he knows a set of preconditions for performing the task which constitute the domain on which the task automaton is to operate and he knows the set of operations which it has at its disposal.

In the last resort, the tasks that make up a task area and which, in that respect, are deemed similar have been selected on cultural or pragmatic grounds. The status of 'task area' in thus akin to that of a linguistic entity. By token of this fact, anyone who discovers or delineates a task area, a curriculum specialist, experimenter, or training officer, is in much the same position as a social anthropologist who works out the language spoken by an alien tribe. Within this analogy the most elementary tasks (the names for which have the most generally accepted meanings) correspond to words and phrases in a vocabulary; more sophisticated tasks, including certain of the assignments, resemble grammatical rules in the language.

Amongst other things, the linguistic analogy suggests (quite rightly) that there is no **absolute** task analysis. Any analysis, including the simple classification of tasks into task areas, is founded on a particular context which consists, at least, in a **population** and a set of **assignments.** Hence (to use Kelly's phrase for it) a task analysis has a limited range of convenience rather than a universal currency. There is nothing pathological in this circumstance. Any psychological construct has a certain range of convenience, so does a grammar and so does a thesaurus; so, indeed, do all normative theories.

Assume that a population is given, for example, 'The students at the R.C.A.' or 'Postgraduates at Brunel University' or 'The staff of System Research'. **One** sort of task analysis (a sort of immediate relevance) is concerned with relations between tasks named A, B and C of the form 'to do A it is necessary to do B and to do C (either in unqualified conjunction or in some sort of **system**: minimally in the systemic order first B and next C). Thus:

(a) To demonstrate a proof (A, the assignment) in propositional logic (task area) it is necessary to manipulate the rule of replacement (B) and the rule of substitution (C) according to a heuristic (the system).
(b) To keep a motor car in motion (A) it is necessary to steer (B) and to change gear (C).
(c) To process documents (A) it is necessary to sort them (B) and to add up the numbers in the left hand columm of the page (C).

Elements such as A, B and C are tasks. Further, relative to **this** type of analysis, B and C are subtasks of A. Any task may feature as an assignment (as in (a) above) in which case the system must be stipulated. Lacking such a stipulation, it is assumed that A names a task pure and simple, in which case the name 'A' refers to a description of the system as well (assumed in (b) and in (c)).

A task analysis of this type will be called a task structure. It has two unambiguous interpretations:

(1) It prescribes a task and a method for performing it which **could** be carried out, on request, by any member of the population.
(2) It describes the task as it is carried out by one particular member of the population on a given occasion.

Rather more difficulty is encountered if the task is to be analysed in a way that described its execution by the population in general. The trouble is that people can solve problems or do jobs using many different but equally legitimate methods. A comprehensive analysis must take this degree of variation and flexibility into account to yield a generalised task structure.

Thus, for a population in general, the statement 'B and C are subtasks of A' does not exlude the possibility that 'B and D are subtasks of A' (it merely happens that the main task can be done different ways). Nor is it always clear that 'B is a subtask of A' excludes 'A is a subtask of B'. Consider the essay writing task as one example. Even though the topic is limited, (the Prince Regent, Brighton Pavillion, circa 1800) the job could be variously attacked. One author might sketch historical notes on index cards (a subtask) and afterwards assemble this material into his manuscript (the main task). Equally, however, a different author might start off with an overview of the place and period, proceeding to the detailed material later. In this case, overview construction is a subtask. True, the self reference of tasks can often be avoided by clever and inoffensive constraints. But it does pose a real problem and leads us to conclude that although a **task structure** is hierarchical a **generalised task structure** is more like an arbitrary network; A generalised task structure is the union of many task structures.

2.2 *Psychological Foundation of Task Analysis*

The psychological presumption underlying this types of task analysis is that anyone able to perform a given task is in possession of a corresponding skill.
A skill may either be intellectual or perceptual motor. It is a mental organisation that someone may be said to have in his repertoire.

A skill is a mental organisation that performs the same type of computation as some corresponding task automation; to be explicit, there is extensional equivalence between skills and task automata (intensional equivalence, which is important later in the discussion, would require that the two entities performed the same computation in the same way). Now skills achieve goals and, consequently, are representable in a cannonical form as goal directed systems (briefly GDS's with goal G). It will be argued that a GDS is a programmed entity embodied in an individual's brain. At all events, it is the basic unit of mentation* and, on closer scrutiny, it consists in (a) a name; for the goal or the corresponding task, (b) a set of prescribed operations, either physical or abstract, which act upon its domain in and are intended to achieve the goal G (i.e. to satisfy the associated goal relation); (c) a description of G; (d) a mechanism for describing the current state of the domain and comparing this with G; (e) directives whereby operations are carried out either until G is achieved or some auxiliary instruction is interpolated.

**Footnote:* *Since it is stable (in the sense of Section 2.8, the* only *stable information structure.*

Depending upon the context, a GDS may be identified with several more specific processors. If the task is symbolic and if problems are posed at discrete instants of time, then a GDS is clearly a problem solver. For a perceptual motor task it is aptly called a control unit which is virtually the same as a skill. For most cognitive tasks a GDS is identical with a concept (using this word is its operational sense). For the present purpose the terms, problem solver, control unit (skill) and concept are used interchangeably.

Any GDS operates upon some domain. This may be its environment or a set of signs designating entities in its environment (for example, by the motions of a limb or by operations upon numbers standing for numerals). On the other hand, the domain may consist in the names G_1, G_2 for other GDS's in which case the GDS in question (say G) musters G_1 and G_2 as subroutines. In customary usage, G will be deemed to be a **higher level of goal** than the subgoals G_1, G_2 achieved by the **subroutines**. We shall insist upon rather straightforward combination rules such that if a system named G is formed from GDS's named G_1 and G_2 then G is a GDS.*

**Footnote:* *A GDS is similar to a TOTE UNIT is the sense of Miller, Gallanter and Pribram (44), though it is not identical to a TOTE. The TOTE hierarchy composition rules, applied to GDS's, produce structures of the requisite type. Less restrictive composition principles may also be employed (11).*

One qualification is necessary. A goal (or subgoal) is defined as a relation. New relations are specified on some domain (and codomain or range) and, consequently, a GDS carries with it a domain specification. In the general case, the elements of the domain are **preconditions** which, taken together with the goal, determine problems. Hence a GDS interpreted as a problem solver* is tagged by its goal and a problem **class** over which it is able to achieve the goal of solving all pertinent problems.

**Footnote:* *Similar comments apply to all other interpretations of the GDS.*

With this caveat in mind, we comment that the GDS's in an individual's repertoire are generally organised in a structure determined by goal subgoal relations and that this structure may be (interchangeably) dubbed a 'concept structure' or a 'control unit (skill) structure' or a 'structure of problem solving programmes' using the words 'subconcept (subskill) and 'subroutine' in place of 'GDS with a subgoal' (it will usually be called a 'concept structure' but this entails no committment with respect to its domain. It could be called, rather barbarically, a 'GDS structure').

Suppose that a certain individual is attending to a particular task, T. As a convenient fiction, assume that all of his GDS's (concepts, problem solvers, etc.) are 'fixed' or 'frozen'. In this case, a correspondence may be established between tasks and GDS's (concepts, etc.) by equating names, goals and domains. The task structure obtained by analysing this individual's performance of T on a specific occasion reflects the concept structure (GDS structure, etc.,) of this individual. Insofar as the assignment of T is satisfied when the uppermost goal is achieved, the subtasks of T (in the task structure) correspond to the subconcepts (subgoals, etc.) and the elementary tasks correspond to the lowest level concepts (the lowest level GDS's). The task structure is one of several members of a general task analysis conducted for a population; the other members reflect the concept structures (GDS structures) that may exist in other individuals of the population.

2.3 *Learning Processes*

The picture considered in the last section is **fictional** so far as teaching is concerned, since it posits a completely learned skill. During the tutorial process, such a picture is manifestly inappropriate and it may even provide an inaccurate description of the mind in general, since it is known that some tasks are **never** completely learned and there is evidence that all skills are being continually **relearned**. The picture has served its purpose and we shall now examine the process of learning itself.

In order to do so, it is necessary to introduce two important notions: (1) The idea that GDS's may either be **perfect** (as assumed) or **imperfect** and (2) The idea of an hierarchy of **control**. This organisation is quite distinct from the (often hierarchical) goal structure discussed previously. With these concepts in mind, we shall go on to image learning as a higher level problem solving activity; as the creation and reproduction of G D S s.

2.3.1 *Imperfect Goal Directed Systems and the Role of Uncertainty*

Goal directed systems may either be **perfect** or **imperfect.** As a rough approximation*, a **perfect** GDS is a programme written and embodied in the brain. It is executed without interruption and each step in it is well defined.

**Footnote: The brain is not conceived as a serial processor. Hence the notion of 'programme', though illuminating, is an approximation to the proposed model. In general, computation takes place concurrently unless this would entail conflict between the operations concerned. Depending upon the course of computation there may be more than one locus of control at a given instant. There are two apposite models for the type of computation envisaged. One of them is the 'Combinatonic System' noted in the appendix to Section 2.8. The other, in some ways its equivalent, is the 'Occurrence System' developed along independent lines by Anatol Holt. (45).*
For models of the requisite type of concurrent computation see Brieske (74) and McCullock et al. (75).

An **imperfect** GDS is also like a programme but certain steps are ambiguous. In particular, certain of the tests and certain of the operations may be underspecified. Unlike a computer, the brain is still placed in an imperative mode and carries out some test or operation (how it does so in general is unknown. We shall consider the process as it occurs in the context of teaching in Sections 2.4 and 2.5).

We now introduce two postulates:

(a) If a GDS with a goal G is **perfect**, then the individual is, at most aware of its **name**, G. On the other hand, if a GDS with goal G is **imperfect**, then its execution gives rise to an experience of **uncertainty** about how to achieve this goal.

(b) (This postulate will be justified later). The human mind is so organised that it **needs** to maintain a certain rate of reduction of **uncertainty** (in the sense mooted in the last paragraph); thus, to render imperfect G D S s more perfect; thus to **learn.**

Since uncertainty will be a primitive variable in a teaching system, a few explanatory comments are in order.

The fundamental measure of the magnitude of an individual's (student's) uncertainty with respect to goal G is obtained by forming an information measure on the veridicially sampled* subjective probability or confidence estimates over a set of alternatives (responses, etc.) pertinent to G achievement.

**Footnote: 'Veridicial' in the sense that the estimates are obtained using one of Shuford's (28) 'scoring schemes' or the equivalent. (Baker (72)).*

The value of this quantity may be **estimated** in suitable conditions by forming an information measure over objective indices such as correct response probability or latency weighted correct response probabilities. Objective estimates of this types will be called **proficiency** measures. As a rule, any proficiency measure with respect to G is the direct negative correlate of an uncertainty with respect to G.

The quality or type of uncertainty experienced by an individual depends upon the currently named goal. To comprehend the discussion up to this point, it is enough to distinguish between an **uncertainty about how to solve a specific problem** (i.e. an imperfect subgoal G D S is in operation with a precondition given) and an **uncertainty about how to assemble named problem solving routines** (i.e. there is an imperfect G D S associated with the task goal and a repertoire of named and perfect G D S s able to deal with each of the subgoals). Either of these uncertainties will be designated H^0 (with a subscript to indicate the pertinent goal, i.e. H^0_ρ for goal G_ρ). Later it will be necessary to consider an **uncertainty about how to learn** which is often engendered by the act of selecting a learning strategy. This quantity will be denoted H^1.

2.3.2 *Levels of Control in the Learning Process*

So far we have considered G.D.S.s that solve problems (control, conceptualise, etc.) with reference to an environment. The evironment may be more or less abstract, depending upon the location of the pertinent goal directed system in a concept structure (G D S structure) and, as in the last section, the G D S.s may be perfect or imperfect.

Now it is often very convenient to talk about the collection of G D S.s in an individual's repertoire as though it was a problem solving machine or a cognitive machine. For example, this manner of speaking was employed in Section 2.2. To capture this notion, the problem solving machine will be Designated M^0 and it will be said to reside at level L^0 in an hierarchy of **control.** M^0 is a machine with a goal. This goal will be defined as the goal of the uppermost G D S in the concepts structure to which the individual is currently attending or with which he is currently computing. If treated in general this definition gives rise to a number of interesting and knotty problems. Fortunately, most of these can be avoided in the specific context of teaching and the special sorts of free learning considered in this paper. Here, the uppermost goal, G_ρ, is (a) Whatever goal the student is currently required to achieve (or learn to achieve) or (b) whatever goal he has selected and announced to an experimenter, on his own volition. With this in mind, we tag M^0 as M^0_ρ if the head G D S . (possibly an imperfect G D S .) has goal G_ρ.

Returning to the control hierarchy, it should be noted that its levels also designate levels of interaction or of discourse in a stratified object language, $L = L^0, L^1, \ldots$ insofar as the individual communicates with any other person or device. Thus L^0 expressions designate preconditions (that are interpreted by M^0 as problems) and solutions (at the output of M^0). In computer jargon, L^0 is the level of object programmes and M^0 is a set of object programmes.

But we are also at liberty to consider processes higher in the hierarchy of **control,** in particular, those residing at level L^1. Indeed, we are impelled to do so in order to speak:

(1) of selecting an index, p (M^0_ρ rather than M^0_q) which is a prerequisite of any change in the task goal or the field of attention, or

(2) of modifying the G.D.S.s in M^0_ρ, as, for example, in perfecting them or adding to the repertoire.

Let us suppose that there exists a set, M^1, of L^1 processes. The processes in M^1 are characterised as G D S.s (of exactly the same sort as the L^0 G D S,s) but they operate upon a domain of L^0 G D S,s in M^0 (rather than the environment). Interpreted as problem solvers, the L^1 G D S.s solve the problems engendered by deficiencies in the L^0 problem solvers so that the control hierarchy may also be conceived as an hierarchy of problem solving. Hence, the level L^1 of L is occupied by expressions designating goals to aim for (selecting M^0_ρ) or expressions directing the activity of L^1 G D S.s. In turn, level L^2 is occupied by statements of L^1 goals (we shall call them tutorial goals) of the form 'Construct an L^0 G D S in order to be able to satisfy the (L^0) goal G'.

Just to emphasise the point, the levels L^0, L^1 and L^2 are introduced for descriptive convenience and to facilitate the design of teaching systems. In the jargon of information science, these levels are needed in order to conceive the mechanism of the mind as though 'impure programming' were prohibited. Alternatively it is useful to conceive them as the levels in Von Neumann's (29) theory of reproducing automata (L^0 the input and the output of an operating automaton: L^1 the reproducing automaton, reveiving a description of the automaton to be reproduced; L^2 the automaton that organises the process).

The requisite notation is provided by Fig. 1 in which each box may contain an arbitrary concept structure (G.D.S. structure).

In general, the L^1 processes reduce an individual's uncertainty by perfecting or constructing L^0 G.D.S.s Postulate (b) of Section 2.3.1 may thus be alternatively rendered 'No imperfect L^0 G.D.S. exists in isolation'. The minimal couple consists in an L^1 G.D.S. acting upon an L^0 G.D.S.

As currently conceived, any individual has a limited (and somewhat idiosyncratic) range of L^1 operations at his disposal. For example, people can concatenate strings of L^0 G.D.S.s. they can substitute strings of extensionally equivalent G.D.S.s, they can perform various types of complementation and generalisation and they can carry out analogy operations (transferring an L^0 G.D.S., A with domain D_1 into a domain D_2 so that it becomes an L^0 G.D.S., B). Likewise, they can pick out a sequence of L^0 subsystems on which the L^1 operations are brought to bear. The facility with which these and other L^1 operations can be mustered varies a great deal between individuals and we shall define an individual's competence (which is quite a measurable quantity) as the profile or efficiency distribution of his L^1 processes in respect to a given task.

It is theoretically important to recognise that, although M^0 and M^1 are coupled together, they are concurrently acting or quasi independent systems (Like a pair of asynchronous automata). It would be improper to represent them as one system and, at the same moment to preserve the descriptive artifact of 'levels in a control hierarchy'.

2.4 *Learning and the Resolution of Uncertainty*

Consider a single subtask with goal G_ρ. Suppose that the student has no L^0 G.D.S. for G_ρ and suppose he has agreed (with a teacher) to aim for the tutorial goal of learning to achieve G_ρ. This state of affairs is symbolised in Fig. 2 (I) where the student is represented (as in Fig. 1) by two boxes, M^0 and M^1, of which M^0 contains an imperfect L^0 G.D.S. with goal G_ρ, whilst M^1 'directs the student's attention to G_ρ' (i.e. makes M^0 into M^0_ρ by giving it the stipulated content). In a pure case, the L^0 G.D.S. is virtually non existent (Section 2.2). There is a partial specification of G_ρ, a specification of a domain and a specification of a set of operations to be used in achieving G_ρ. This much information is introduced, as a 'programming' instruction, by a teacher (man or machine) who is represented by the two further boxes T^0 and T^1 of Fig. 2(I). Due to the act of L^1 communication imaged in this figure, we say that the teacher has commanded the student to aim for G_ρ and that the student has agreed to obey him (a normative situation later conceived as an experimental contract). In order to do so, however, the student must construct an appropriate L^0 G.D.S. In the pure case envisaged, the G.D.S. must be built up from scratch; In general (and the general case is considered below) it may be partially constructed but imperfect.

The teacher now presents a precondition under G_ρ* which M^0 interprets as a problem.

**Footnote: Recalling that G_ρ is a relation, some element in the domain of the relation.*

This act is depicted in Fig. 2(II).

Now M^0 tries to solve this problem by executing whatever fragments of a G.D.S. exist. But, since the G.D.S. is imperfect there will be some ambiguity which engenders uncertainty, and this uncertainty is always resolved by communication between M^0 and some quasi independent system; either M^1 or the teacher or both of them.

(a) The uncertainty may be resolved by questioning the teacher. Typically the student asks 'what predicate do I examine in order to test for G_ρ achievement?' or 'what operation do I apply to get nearer to G_ρ?'. An answer to this question, provided by the teacher, resolves the uncertainty. By the same token, the teacher may anticipate the student's question and provide cueing information (the answer to a tacit enquiry) or he may simplify the problem by performing part of the problem solving computation on behalf of the student. Fig. 2(III) grossly depicts any one of these co-operative interactions.

The degree of cooperation may, of course, be varied to suit the circumstances Box T^1 is responsible for this adjustment. Thus assisted, the student produces a response, in general a complex response with several components, that designates the solution he believes to be correct. This act is diagrammed by Fig.2 (V) (omit Fig.2 (IV) for the moment. We return to it later). In case a subjective probability estimation method is employed (Section 2.3.1.), the response selection of Fig.2 (V) is replaced by a distribution of confidence estimates over a set of response alternatives. Of course, the solution that the student believes to be correct need not be correct and (since uncertainty was experienced) its rectitude awaits confirmation or denial.

(b) The uncertainty may be resolved by guessing or exploring the problem space and submitting a tentative solution. The process cannot be usefully diagrammed but leads directly from Fig.2 (II) to Fig.2 (V) and it involves communication between the quasi independent systems M^0 and M^1.

In either case, (a) or (b), the student believes that he has solved the problem (i.e. there is a 'test achieved' output from an imperfect GDS). Since the GDS is imperfect (i.e. since the student experiences uncertainty), this belief is open to confirmation or denial by comparison with knowledge of results information, provided by the teacher

(Fig.2 (VI)). The difference signal obtained from this comparison modulates the student's uncertainty and serves as an input to the L^1 processes in M^1 which operate constructively upon M^0 (Fig.2 (VII)). As a result, an internal test is built up which replicates the external test procedure responsible for providing knowledge of results. Briefly the goal is **internalised**.

In general, the act of co-operation, noted in (a), also provides an input to M^1 since stipulating which tests should be made and what operations should be performed, has the effect of programming these tests and operations, i.e. it acts as an auxiliary command. Fig.2(IV), deliberately omitted during the discussion of (a), depicts this type of interaction.

The whole **cycle** of operations, Fig. 2 (I) to Fig. 2 (VII) is repeated as further problems are posed under G_ρ until a **criterion** is achieved. Fig. 2(VIII) is an overview of the entire procedure.*

Footnote: The procedure is usefully embellished by providing proficiency feedback evaluating performance over many problems or by providing detailed knowledge of results evaluating each component of a response (rather than a crass assertion that the entire response is correct or mistaken). But we shall not consider these refinements.

Though the cycle of operations has been presented as though it referred to an L^0 G.D.S. acting upon the domain 'environment', the argument is in no way dependent upon this presumption. Fig. 2(VIII) is equally valid if the L^0 G.D.S. in M^0 acts on a domain of perfect G.D.S.s. To secure this interpretation, the operations of M^0 are defined as selections of the names of the (subgoal) G.D.S.s in question.

Finally, notice that M^0, M^1, T^0, T^1, are all organisations. The distinction between the M processes and the T processes suggest that the former are embodied in the student's brain or a teaching machine. This interpretation is intended. However, it is also possible to conceive all of these processes lodged in the student's brain, i.e. the student acts as his own instructor; as it were, he is equipped with an 'internal' teaching machine. Labelling apart, the figure is unaltered and this interpretation is also valid. It will be used, for example, in Section 2.6. In general the T (teacher) M (student's brain) identification holds good. When the alternative interpretation is intended this fact will be pointed out.

2.5 *Teaching Requirements*

Under what conditions should the tutorial cycle of Fig.2 (VIII) be operated and what criterion should the teacher insist upon attaining? I contend that the conditions should be adjusted to satisfy the following limits upon H^0 of Section 2.3. (and this, of course, constitutes a theory of teaching).

(1) $\quad {}_0 0 > a > dH_\beta^0/dt$

(2) $\quad b > H_\beta^0 > c > 0$

Here *a*, *b* and *c* are either empirial constants or adaptively manipulated parameters. Techniques for determining *a*, *b* and *c* are discribed in other publications, (17) - (27) where it is also argued that for certain skills, dH_β^0/dt (thus the rate of learning) can be maximised by setting H_β^0 as near as possible to *b*. Without special commitment on this point it is maintained, for the present purpose, that if *b* of condition (2) is exceeded, neither problem solving nor learning can take place and if condition (1) is contravened, that the student will be unable to focus his attention upon the pertinent goal (i.e. M^0 may no longer be characterised as M_β^0).

To summarise; the intention of (1) is that the student's uncertainty about how to archieve G_ρ should be decreasing or, equivalenty, that M^1 should be kept active. The intention of (2) is that the student should not be overloaded to the extent that problems become unintelligible or, equivalently, that M^1 should be held in a working region where it **can** usefully operate on M^0.

Now the maximum uncertainty (maximum value H_β^0) call it I_ρ, depends upon the choice of G_ρ and upon the **degree** of co-operation provided by the teacher when G_ρ is given. If the degree in question is μ, than the operation level of the maximum uncertainty (given G_ρ) is bounded at $I_\rho(\mu)$*.

**Footnote: In general, μ is a vector with as many components as there are error factors in the skill. Problem simplification is a multidimensiona business. Likewise, H_β^0 has several components as well.*

As a pragmatic criterion we certainly require that the student's uncertainty shall vanish when no co-operation is provided,* (otherwise he will not have learned the skill).

**Footnote: Recall that indices of uncertainty are negatively correlated with proficiency measures. This clause simply demands a high proficiency with no assistance given.*

Hence, the recommendation is that if G_ρ is selected, μ and thus $I_\rho(\mu)$ be modulated (as a function of indices H_β^0 and dH_β^0/dt in such a way that (1) and (2) are satisfied, as μ tends to zero.

Example 1. Teleprinter Operation. During one phase of training, the subgoals G_ρ correspond to subskills that comprise the manipulation of subsets of the keys; hence, subsets of the complete repertoire of finger movements. For example, one subskill entails the central row of keys (the 'rest keys' which provide standard fingering locations); another subskill, G_ρ is the (one to one) relation between alphabetic characters and finger movements from the rest positions. T^0 poses problems by displaying characters via an alpha-numeric indicator. The student responds by striking a key on a keyboard which is wired to provide an electrical output. This ouput is compared, by T^0, with a coded specification of the correct key, thus generating a knowledge of results signal to tell the student that he is correct or not. H_β^0 is, in this case, objectively estimated from the comparator output (which gives, over a sequence of trials, a correct response probability) and from the correct response latencies (using a Hick's law model). Problem simplification is achieved either by varying the required pace *of operation or, in a self paced mode, by providing cue information through an auxiliary display of lamps arranged as a keyboard replica; the illumination of one lamp signalling which key should be pressed for the current stimulus character. In the first case, μ is inversely proportional to a (variable) delay between stimulus presentation and the appearance of a* cueing *signal.*

Example 2. Intellectual Tasks. The majority of academic subjects may be decomposed into aggregates of subskills, for which the goals, G_ρ, specify abstract relations, such as the relation between a number and its logarithm, between n tuples of numbers and their products, between matrices and *their inverses, between the names of kings and the period during which they reigned, etc. In such a case,* T^0 *presents problems in a standard teaching machine format by posing questions appropriate to the subskill; for instance, 'During what years did George III reign? ' The student solves these problems if he can and responds by citing the date. The response mode may be 'constructed' or 'multiple choice' and, in either case, the direct response may be replaced by a confidence or 'subjective probability' estimate over specified or constructed alternatives. Knowledge of results is computed as in Example 1.* H^0_ρ *is obtained* **either** *by objective estimation over a block of trials or,* **much** *more effectively by a subjective probability distribution on each trial.* T^0 *simplifies the problems by partially solving them and generally by providing cue information that is adjoined to the problem and restricts the range of plausible or permissible response alternatives. Notice that all of the following (and many more) are legitimate items of cueing information: (a) George III came to the throne in 1760; (b) George III went mad during his reign; (c) There are, in all, six King Georges in English history. Each of* **a,b,c** *offers a different sort of partial solution. The degree of simplification,* u*, must thus be defined with reference to (a), (b) and (c) separately. In respect of (a), for instance, to (a), (b) and (c) separately. In respect of (a), for instance, the following are partially solved versions of the orginal problem,* u *increasing from left to right. a.1. = ⟨During what years did George III reign?⟩, a.2. = ⟪a.1.⟩ ⟨George III came to the throne during the 1700's⟫ a.3. =⟪a.2.⟩ ⟨George III died during the 1800's⟫ a.4. =⟪a.3.⟩ ⟨The regency was during the last part of his life⟫ a.5=⟪a.4⟩ ⟨He was crowned in 1760⟫ a.6=⟪a.5⟩ ⟨He died in 1820⟫ a.7. = ⟪a.6.⟩ ⟨The Prince Regent assumed office in 1811⟫ a.8. = ⟪a.7.⟩ ⟨George III reigned from 1760 to 1811.⟫*

Roughly speaking, the task difficulty $I_\rho(u)$ decreases as a student's uncertainty decreases or, conversely, as his proficiency increases. But all this is based upon two assumptions: (A) that meaningful co-operation can be provided and (b) that if G_ρ is selected then for $u=u_{max}$, $H^0_\rho > I_\rho(u_{max})$ and for $u=0$, $I_\rho(0)>b>H^0_\rho$. (Notice $I_\rho(u \max)$ is the lowest and $I_\rho(0)$ the highest level of the maximum uncertainty).

Assumption (A) receives an immediate comment. Assumption (B) is covered in the next section.*

*Footnote: * *The teaching model of this section is clearly based on the supposition that an individual who is learning is a* self organising *system in the sense of Von Foerster (33). The condition in question is that* $dR/dt>0$*, where R, the Redundancy, is* $1 - H^0_\rho/I_\rho(u)$.

The possibility of meaningful co-operation depends upon the existence, in T^0 of Fig. 2, of a single intensionally equivalent model for a G.D.S. or a set of intensionally equivalent models, (Section 2.2.). Notice that the (extensionally equivalent) task automaton is insufficient. To co-operate, the teacher must be in a position to solve problems under G_ρ in the same way as the student; failing this, a partial solution (or its description) is just as likely to be misleading as it is to be helpful. In case there is one model, the teacher requires the student to learn to solve the problems in one way. In case there are several, he allows the student to question T^0 selectively. Often it is possible to provide one or the other. But the requirement for doing so justifies the original insistence on a cogent **model** for the learning process, in this case at the level of the constituent subtasks.

2.6 Learning to Perform a Complicated Task

Consider a complicated task with a generalised structure obtained by using the analytic method of Section 2.1. Let the task goal be G and designate the goals of subtasks G_ρ. Suppose a novice has agreed to learn this task. How does he set about the job.

Although unsuccessful students may flounder on aimlessly, it is intuitively clear that the successful ones proceed as follows. First of all, the task is reduced to constituent subtasks, thus providing a task description which is isomorphic with one of the task structures that might be specified by an analyst. Generally speaking, even the novice will know how to carry out some of the subtasks (i.e. he has the requisite G.D.S.'s in a perfect form). These are noted. For the rest, we shall assume that the student is unable to tackle the assignment (with goal G) as a whole. If he tried to do so, condition (2) of Section 2.5. would be contravened. Because of this, he is forced to partition the task, guided by his task description, and to learn how to perform manageably sized subtasks in sequence.

The plan for doing so, taken together with the side conditions which have to be fulfilled and the repetitions, alternations and so on, is called a **learning strategy**. It is usual for a successful student to have at least one learning strategy in mind, though it may exist in an embryonic form that is developed in the course of learning.

Guided by this strategy, the student attends to the first **subgoal and generally recapitulates the cycle of Fig.** 2 (VIII).

Since he is free learning, rather than being taught, he takes over most of the functions of T as well as M in this figure; thus, for example, he selects problems and poses them to himself. Likewise, he is responsible for the conduct of questioning (e.g. he overtly consults his colleagues, watches demonstrations, or consults reference books).

In (successful) free learning, it is thus possible to observe the operation of two internalised (self) teaching systems. One of them is tantamount to a replica of T (Fig. 2 (VIII)) embodied in the student's brain. The other is concerned (a) with the selection of systems like ⟨T, B⟩ of Fig. 2 (VIII), which are responsible for building up G.D.S.'s in respect to a particular goal G_ρ and (b) with mediating the overall learning strategy. To complete the picture, it is only necessary to notice that the domain of the L^1 processes in M^1 may, by definition, include any L^0 G.D.S.'s in the student's repertoire. So, for example, they may operate on and make use of GDS's previously built up in respect to a different domain. This happens, for instance, in the following ubiquitous case. A goal, G_ρ is superordinate to goals G_i and G_j as in the fragmentary task structure of Fig. 3. Suppose the student has built up perfect GDS's for G_i and G_j, now addressing himself to G_ρ. In this case, the **domain** M^0_ρ of M^1 is precisely $M^0_i M^0_j R_\rho$ where R_ρ represents any additional relations entailed in constructing a GDS with goal G_ρ (that is, the 'systemic' relation of Section 2.1.).

Example 1 **Number Series** *In a recent study, Gagne (47) considers the skill of finding formulae to express a number series such as 2,4,8,16,32. The full task structure is fairly complex but, in practice, the task is experimentally* *tractable because there is a natural and hierarchical concept ordering. In it, the highest level goal is to 'Find formulae for the sum of n terms in a number series'. Beneath this there are subgoals such as 'Supply symbols and operations for general equations between numerical quantities having particular spatial relationships in a table'. Beneath these are further subgoals of the form 'Use symbols to identify spatial relationships between numbers in rows of a table'. Each subgoal is associated with a class of problems which are solved by exercising a subskill (i.e.* **having** *an appropriate* L^0 *GDS). The successful free learning student turns his attention to a subskill, learns it, and proceeds to another. He ascends in the hierarchy only when all lower level subskills are mastered.*

Example 2 **Logical Operations** *Consider a facet of symbolic propositional logic such as the task of defining the connectives '∧' and '∨' by their truth tables in 2 variable expressions. One account of the task structure places the concept 'Truth table' at the top. Beneath it are subconcepts such as 'Truth Value' and beneath these '2 valued variable', formal specifications of '∧' '∨' and negation, beneath these informal concepts of 'and', 'or' and 'not' and of statements with certain values attached to them and a certain form. Each subconcept corresponds to a subgoal and a subskill which the free learning student* **can** *and* **does** *rehearse as he wends his way up the hierarchy (this structure, incidentally, is redundant in the sense of Fig.4). The trick in this example is as follows: A* **few** *students see things differently. They are abstract thinkers and symbolists. Literally, they learn the syntactic form of a truth table* **first** *and* **secondly** *derive the concepts of '∧' and '∨', which are finally related to their notions of 'and', 'or', in natural language expressions. Of course, this approach inverts the hierarchy sketched out above and no doubt there are other task structures that do similar violence to this neat and tidy picture. In fact, the seeds of disruption are contained in the highest level goal (concept) i.e. 'Define the* **connectives** *in terms of a truth* **table**', *which suggests that any terminal concept structure must be an* **heterarchy** *rather than a hierarchy. (We return to this important question in Section 2.8. For the moment it is enough to comment that since most students do learn according to one or another variant of the hierarchical task structure, this structure is an acceptable practical approximation to reality).*

Example 3 **Manual Tasks.** *Task structures and concept structures are delineated in terms of the ubiquitous 'levels' of perceptual motor grouping.*

Example 4 **Procedural Tasks.** *Typical instances are fault detection procedures and clerical skills. Due to the serial character of these routines, a specific performance 'algorithm' is often mandatory. Given two further constraints, this algorithm leads to a task structure in which the student learns. The constraints are (a) That segments of the algorithm serve meaningful goals or subgoals, e.g. 'Inform the manager' or 'Check with the engineers department' or 'Load the aircraft': (b) That the algorithm calls for the execution of specific subskills. On the whole, successfully free learning students attend to the meaningful subgoals one at once. Inspection of the algorithm shows the subskills that must be exercised to achieve this subgoal. These are learned and later the goal achieving algorithm is learned.*

How can these commonsensical observations be reified for incorporation into the design of a teaching system? Of course, the system designer can start out with a generalised task analysis and, in this framework, he could ask students to give retrospective accounts of their learning strategies and/or the L^1 processes they employ to assemble L^0GDS's. Though this method of reporting is useful, it is open to the criticisms usually levelled at introspection and in practice it **does** give an incomplete picture. For preference, the learning strategy should be externalised as a **directly** observable stretch of behaviour and for a few tasks it has been possible to achieve this objective by using a **co-operative externalisation technique** or C.E.T. Since the C.E.T. is one ingredient in any conversational teaching system, it will be considered separately in Section 3 but the following results are obtained using a C.E.T. to externalise the L^1 organisation of learning.

2.7 Some Features and Pathologies of Free Learning

The L^1 processes in a free learning individual belong to one of two categories; (I) Selective processes which generate the sequence of subgoals in a learning strategy. (II) L^1 processes which are used to construct novel L^0 GDS's and to unite or integrate those that exist. Typically, they are of the form **concatenate** (string L^0 process A in sequence after L^0 process B), **substitute** a concatenate (from a unitary L^0 process that acts on the same domain as B after A), **generalise**, form the **complement** of (some larger L^0 process) or find an L^0 process **analogous** to some other (or to some part of a larger) L^0 process. Clearly, types (I) and (II) lie at the **same** level in an hierarchy of **control**. But type (I) processes resemble assembly tasks (Section 2.1.); they are higher in a goal subgoal ordering than type (II) processes they call as subroutines. The student's **competence** (Section 2.3.2.); is evaluated over the type (II) L processes he has available .

**Footnote: No attempt is made to give a general and formal statement of the L^1 processes. In the context of a specific task these processes can be stated and simulated; rather simple minded examples of concatenation, construction and substitution are discussed in (II); the designers of 'artificial intelligence' programmes deal with other and more complicated instances as a matter of course. It is doubtful whether anything would be gained by trying to give (say) a general set theoretic picture. Essays in this direction all involve elaborate symbolism but do not, so far, have much utility.*

To illustrate the distinction, consider the acquisition of the skill of Fig. 3. The student may first **attend** to the domain of G_i (a selective part of his strategy) and construct a G.D.S. with name i and goal G_j (**construct** is a type (II) process which might also be dubbed 'define' or 'write'). Having done so, he **attends** to the domain of G_j (Type I) and reapplies **construct** to yield a G.D.S. with name j and goal G_j. He next attends to the domain of G_p which contains problems that are solved by the concerted action of the G.D.S.i and the G.D.S.j (held in some specific relation). Depending upon the calibre of this relation, a G.D.S. named p (with goal G_p) is constructed by combining and possibly elaborating the existing L^0 G.D.S.'s i and j. For example, if G_p is achieved when G_i and G_j are both achieved in sequence, he applies **concatenate** (a Type

II process) to assemble the constituents. This transformation is symbolised:

$$\langle G_i\rangle + \langle G_j\rangle \rightarrow \langle\langle G_i\rangle + \langle G_j\rangle\rangle \equiv G_p$$

If seriality is prohibited, **substitute** (a Type II process) is applied to the concatenate. This transformation is symbolised:

$$\langle\langle G_i\rangle + \langle G_j\rangle\rangle \rightarrow \langle G_i, G_j\rangle \equiv G_p$$

Other operations are possible. Complementation, generalisation and analogy have already been mooted. But though any adult is equipped with a basic repertoire of this sort, it is also possible to 'define' or 'construct' quite arbitrary L^1 G.D.S.'s; in fact, any L^0 G.D.S. can probably serve (in the L^1 domain) as an L^1 G.D.S. If the analogy operation is universal, we may, of course **infer** the existence of a general $L^0 \rightarrow L^1$ process transformation.

In order to discuss the design of teaching systems, it is necessary to make just five points about this fascinating topic. The points are considered in the following subsections.

2.7.1 *L^1 Uncertainty*

In common with an L^0 GDS, any L^1 GDS may either be perfect or imperfect. In the latter case, ambiguity in execution leads to L^1 uncertainty (H^1 of Section 2.3.1.). On empirical investigation, most of the L^1 uncertainty turns out to be either of the form 'which subgoal do I next select' (the learning strategy is embryonic, the Type I process is imperfect) or of the form 'which (Type II) subroutine do I employ.' The Type II processes themselves usually appear to be perfect.

2.7.2 *Knowledge Hierarchies and Concept Structures*

If the L^1 processes of Type II are **restricted** so that only certain of them (for example construct, concatenate and substitute) can be employed in the conduct of learning, then it is possible (for L^0 GDS's A, B and C) to define hierarchies under a relation of the form. 'To construct A (to learn A), it is necessary to have B (to **know** B) and to have C (to **know** C). Gagné (47), who has studied a number series completion task in precisely this manner, calls the resulting structure a 'hierarchie of knowledge'. Clearly, this is a concept structure (GDS structure) in the sense of Section 2.2. and it is tied to a task analysis subserving the relation 'Being able to do A **entails** being able to do B and being able to do C'. Notice that the task analysis of Section 2.1. uses a deliberately constrained version of the **entails** relation (i.e. is necessary to do). Even so, the hierarchy of knowledge often does correspond to one of the present task structures.

2.7.3 *Strategies and Hierarchies of Knowledge*

If the L^1 processes are **unrestricted**, there is **no** guarantee that knowledge is hierarchical; we raised the issue earlier and will raise it again. But **if** an hierarchy does exist, then the selective aspect of a learning strategy can be mapped onto it as a path and the entire learning strategy can be represented if nodes on the path are annoted to specify the Type II L^1 process in use.

The matter is illustrated in Fig. 4, which refers to a relation learning skill involving 4 variables, A, B, C and D. The subproblem classes or subgoals of Fig. 4 are shown in a concise notation. Thus $\{\langle ABCD\rangle\}$ is the class of 4 variable problems (solution of which satisfies the task goal; $\{\langle ABC\rangle, \langle ABD\rangle, ...\}$ are 3 variable subproblem classes; $\{\langle AB\rangle, \langle AC\rangle, ...\}$ 2 variable subproblem classes, $\{\langle A\rangle, \langle B\rangle, ...\}$ the subproblem classes involving only 1 variable.

2.7.4 *L^1 Matching*

The 'selective part' or **plan** of a learning strategy is generated by a Type I L^1 process. The feasibility of this **plan** depends upon the existence or construction of an appropriate battery of Type II L^1 processes. In general, the efficacity of a learning strategy depends upon the extent to which its plan is **matched** to the student's **competence** (Section 2.3.2).

One obstacle in the way of efficient free learning is a tendancy to generate strategies which are, in this sense, grossly **mismatched**. One reason for this impediment is that students are generally **unaware** of their competence unless evaluative information is externally provided.

2.7.5 *Cognitive Fixity*

If a concept structure (GDS structure) is erected then it is prone to persist, a phenomenon called 'Cognitive Fixity'. Cognitive Fixity can be explained by invoking any one of several resource allocation mechanisms with the property that structures on which computing effort has been expended are reproduced (by the L^1 system) and thus preserved. These executive procedures will not be considered in this paper.

Any type of conservation, beneficial or otherwise, calls for 'Cognitive Fixity' in the mind. Unfortunately, however, there is little discrimination between the conserved structures. In particular, once a mismatched learning strategy has established a concept structure, this structure and the strategy itself are perseverated and may only be dislodged with difficulty. It is thus extremely important to prevent the student from establishing mismatched learning strategies in the first place.

2.8 *Criteria for Learning and Memory*

When is a concept (GDS) learned and what does it mean to say that a concept is in memory. This matter is often treated under the heading of retention in which case, learning is equated with the establishment of bonds or associations.

From the present point of view, this approach is misleading and, consequently, the whole topic of information storage has been suppressed during the discussion. Of course, there is a physical subtrate for memory (probably there are many storage systems) and, as a rule, the various processes can be located in one or another of the **functionally** demarcated compartments of 'immediate' and 'working' and 'long term' storage (for example, in Fig. 2 (VIII) the GDS in M^0 occupy working storage, whilst the data and tag information is lodged in immediate storage), but these matters are relatively unimportant. The crucial issue is the organisational concomitant of 'heaving learned' or 'being in memory'.

In this respect, I take a similar point of view to Von Foerster (31). He maintains that memory of a concept is a mode of computation. The present theory, saying much the same thing in words that are tailored to human teaching situations, asserts than an L^0 concepts (GDS) is learned (is in memory) insofar as the GDS in question can be **reproduced** by the L^1 system of the mind. The basic function of M^1 is thus taken to be concept **reproduction**. It serves as the reproductive automaton in Von Neumann's scheme (Section 2.3.2) whilst the L^0 GDS's play the part of the automata that are reproduced. The existence of a reproductive cycle (in respect to a given GDS or a class of them with the same goal) is what I call **memory** of this G.D.S.

Now, in fact, the reproductive cycle is open to variation (via the environment, via teaching or in other ways). In fact, GDS programmes have to compete for embodiment in storage facilities of limited capacity (in particular they are subject to interference, abrasion and decay when lodged in working storage). In fact, certain cooperative interactions take place. These facts together convert the reproductive cycle into the **evolutionary** process of **learning**.

Two sorts of reproductive processes are usually distinguished; reproduction in the **environment** of some system, e.g. in the environment afforded by a reproductive automaton and self referential reproduction or self reproduction. (Until recently it was maintained that the notion 'self reproduction' led to an inconsistency; this is the content of Rosens's (32) paradox. But Loefgren (33) has shown that the inconsistency is not inevitable and that self reproducing systems may be axiomatised. He also points tot the isomorphism between 'reproduction' and 'explanation' that is implicit in the idea of conceptual reproduction).

For the moment, we are wholly concerned with reproduction of the first sort. Here. the L^1 processor accepts a description of a G.D.S. (the goal description given to it by a teacher) and **produces** an L^0 G.D.S. as a result (perhaps after remedial or cueing information has been supplied). Typically, the production has several stages which constitute an explanation chain or concept chain (analogous to a proof sequence with the L^0 G.D.S. as the terminal item). An individual student has learned the concept (G.D.S.) insofar as his L^1 processor is also able to take the L^0 G.D.S. and to produce a **description** of it which, in turn, allows for the **reproduction** of the original G.D.S. Thus, to symbolise the matter, the following transformations are prerequisites of memory

(a) M^1 (Description A of G.D.S.i) $\rightarrow$ G.D.S.i
(b) M^1 (G.D.S.i) $\rightarrow$ Description B of G.D.S.i
(c) M^1 (Description B of G.D.S.i) $\rightarrow$ G.D.S.i

where Description A and Description B may, in some cases, be indentical. Reinterpreting the word 'memory' in its everyday sense, the existence of this reproductive cycle is equivalent tot the assertion 'the concept is held in long term memory'.*

*Footnote: *The following additional postulates are implied by the previous discussion and allow us to deduce the earlier part of the theory (1) Only G.D.S.s may be reproduced (2) Any information structure held in working memory that is not reproduced (thus any structure that does not become a G.D.S.) is deleted by the competitive processes of abrasion and interference. The theory is generalised and its underpinning is exhibited in the appendix to this section.*

Note. *In specific cases, it is not too difficult to demonstrate the existence of explanation chains or concept chains and to indicate their character, using the CET (Mentioned in Section 2.6. and described in Section 3). Work of this type has been done in various fields: for example, it can be argued (72), for the task of Fig. 4, that reconstruction of the lower order GDS's (for ⟨AB⟩, ⟨AC⟩,etc.) depends upon the existence of a* **complementation** *operator* and *upon the existence of a higher level (type ⟨ABCD⟩) GDS able to deal with a* class *of problems; an ungeneralised higher level system is insufficient. The last point, by the way, is a restatement of the prerequisites for* closure *in the sense of Gestalt psychology. Currently, Scott, Brieske and I are working on similar processes in more complex recollection tasks. The detail of these specific experiments is lengthy and its assimilation would be, in the present context, quite onerous. Hence, the reader is asked to take the rigorous statement of concept chains or explanation chains on trust and is presented, at this point, with a few intuitive and readily appreciated instances that illustrate salient features of reproduction. All of them are concerned with recall since the existence of concept chains is best exhibited in this context. But the processes revealed in recall appear to operate quite generally.*

Example 1. **Tying a Tie.** *A description is given of how to tie a tie. This is used, together with feedback and prompting from a mirror to build up GDS's made from a sequence of perfect (automatic, unconsciously, executed) GDS's that determine motor actions and provide the appropriate control signals for the physical operation of tie tying. At this stage, the original description cannot usually be retrieved (the reader is asked to* **describe** *how* **he** *ties his tie). On the other hand, there is a sense in which the concept of tie tying is in memory, provided that the original prop of a mirror is provided. If, for some reason, your perfect GDS's become imperfect, you can reconstruct the original description and, from it, part or all of the skill. Specifically, the individual looks in a mirror* as *he is tying his tie,* **observes** *the sequence of motions (thus, using his observation of the motor process as a primitive description in its own right) and constructs a* **visual** *or symbolic* **description,** *from which the motor process is reconstructed. This sequence of events is especially noticeable to someone like the author, who wears a* **bow** *tie but who learned, as a child, to tie an* **ordinary** *tie. Bow tying interferes with ordinary tie tying. It is quite easy to trace out the reconstruction of ordinary tie tying on those rare occasions when it is necessary to put on an ordinary tie.*

The mainpoint of this slightly facetious example is that, in it, the feedback loops required for concept or skill reproduction are, in a sense, external to the brain. A **mirror** *is essential to concept reproduction.*

Example 2 **Concept Recall of the Term 'Numinous'.** *A typical protocol is:*

(a) As a problem, the individual is presented with the requirement for a word that means 'Godlike' (in the sense of taking an omniscient overview of something). He becomes aware that such a word exists. (b) **Deified,** *in contrast to 'Reified' (made factual). (c) Greek stem* **D≈en.** *(d) Informal check of classical knowledge to ascertain that there is no such word. (e) Search through alphabet, particularly from L to T, settling on N. (f)* **Numismatist** *(coin collector). (g)* **Numismatic** *(subject said no such word although, in fact, there is). (h) Recall of Greek stem* **Numen** *(God). (i)* **Numenistic** *(sensed mistaken). (j) Find similar Greek stem,* **Lumen.** *(k) Analogy Process* '**Numen** *is to ? ? as* **Lumen** *is to* **Luminous.** *(l)* **Numinous** *as solution.*

This example is intended to show (I) that concept reconstruction often relies upon a very large body of knowledge; (II) that the distinction between L^0 and L^1

processes is context bound and meta descriptive. For instance, is this an example of L^0 problem solving (find the **word** *'numinous') or is it an example of reproducing a* **concept** *(an L^1* process that reconstructs an L^0 *GDS named 'Numinous'). This depends, of course, on the context but, insofar as the protocol was obtained whilst the student was writing, rather than searching a word list, it is safe to assume the latter. Whilst agreeing with Elzhout and Elzhout (69) that learning is a matter of problem solving, I maintain the need to distinguish these levels of problem solving.*

Example 3. **The Skill of Finding Your Way Around a City.** *People are said to know their way around a city insofar as they possess various subskills that take them from one point to another point. Readers who are unacquainted with Amsterdam are invited to construct their own examples, bearing the following points in mind: (I) The concept is usually represented by a visual or spatial description and by a verbal or 'immediate neighbour' (set of 'street directions') description. (II) Before the concept can be reproduced, i.e. before the reader has it in his memory, a critical mass of subskills must be accquired (this is the prerequisite for closure, mentioned earlier). Below the critical point it is impossible to reconstruct one description with the aid of the other.*

The reader will also find it illuminating to document the extent to which his concept relies upon recognition cues, i.e. objects in the environment.

Example 4. **The Skill of Teaching a Class** *It is necessary to teach a class about the experiments of Ynetema and Mueser on information processing. It is maintained that an individual* **has** *the concept of these experiments, just insofar as he can teach it to other people. Typical, but rather lenghty concept chains are detailed in Reference 72.*

By hypothesis,* all of the elements in a concept chain or explanation chain are G.D.S.s; in particular the terminal elements have this calibre and so do the descriptions.

Footnote: This postulate, though included in the theory, is not quite essential. If the postulate is accepted then any memory has a* **dualistic *or* **parallel** *character inherent in the pair or more of G.D.S.s required to form the cycle of reproduction.*

Now **these** G.D.S..s are, by definition, members of the student's concept structure for the task in hand. Hence, it is clear that in **general** a structure of knowledge is **not** hierarchical but heterarchical (Recall Section 2.7.3.).

Operationally, a concept may be (usually is) **constructed** as part of an hierarchy **determined** by a limited set of Type II L^1 Processes (as in Section 2.7.). But, if this concept is **reproduced** then it ceases to have unique ancestors. For example, concept A, in Fig. 5, is derived by **constructive** operations from concepts B and C. Likewise, A may be reconstructed from B and C as a **production**. But the reproductive cycle will also include transformations whereby B or C are derived from A. Suc transformations occur as a matter of course if a complete set of L^1 processes is allowed to operate (for example, if analogy is included).

The heterarchical character of skills or knowledges **once they have been learned** accounts for the rather pedantic caveats surrounding the more straightforward process of of concept construction as it was outlined in Section 2.7. Also, one of the main difficulties of educational technology is that heterarchical structures, though hard to describe, must **be** described.

2.8.1. *Empirical Support.*

These comments suggest that any remembered concept should be multiply represented; for example, in different modalities (visual, verbal) or in different forms of the same modality (pictorial map, directed graph). They also suggest that it should be possible to inhibit remembering by interfering with the cycle of conceptual reproduction (e.g. by blocking the transfer of a description or by placing irrelevant material in the explanation or proof chain that is exhibited when the process is opened up).

Both predictions can be supported (1) By experiments which show the existence of reproductive cycles (explanation chains) in the case when concepts are well remembered (2) By experiments designed to inhibit reproduction of a concept and thus to block remembering. The general empirical data is also in consonance with the hypothesis. For example, (3) (substantiating (1)) Many faceted concept representations are ubiquitous and one may be translated into anonther (Bartlett's(34) pioneering work on memory schemata; Bruner's(35) treatment of visual and verbal representations). Similarly (4) (substantiating (2)) the body of data concerned with cross modal interference.

2.8.2 *Canons for Tuition in Conversational Systems.*

The following practical definitions are immediate consequences of the theory if Fig. 2 (VIII) is interpreted (depending upon the item) either as an organisation **in** the student or as an organisation lodges **partly** in the student and partly in the teacher.

(1) A concept is learned when a student can reproduce it himself
(2) To teach a concept to a student, is to reproduce it in the student's mind, in such a way that (1) (above) can be satisfied by the student's L^1 processor.
(3) To determine when a concept is learned it is necessary to ascertain whether the student can teach it to himself.
(4) As an approximation to (2) (above) the teacher might require the student to teach it to **him**. But this approximation would be a good one only if the teacher had the same L^1 and L^0 concept structure as the student.
(5) An (ideal) conversational teaching system consists of a student and a teacher or teaching device. Hence, it resembles Fig. 2 (VIII), straightforwardly interpreted. Only T, in this figure, is augmented as shown in Fig. 6 by a further piece of apparatus, T*, which learns about the student and places part of T^1 in correspondence with what it has learned about M^1.

In operation, the conversational system acts as follows: T* (of Fig. 6) uses T to teach the student in the context of a particular task for which, at least, the generalised task structure is available. In turn (and as part of the same process) T impels the student to teach **it**, in the same task environment. Thereby T* learns about the student and approximates its own receptive characteristics to his own. The student has learned the task when, as a result of this interaction, he is able to teach the task successfully to the resulting configuration of T*.

The **ideal** system of (5) is not yet realised in educational technology. But the conversational systems developed in the following sections usefully approximate this paradigm.

The theoretical underpinning of the present learning theory may be of interest to the reader with a philosophical turn of mind and has an important, though slightly peripheral bearing on the immediate argument. For a long while, it has been intuitively clear that a G.D.S. is a system for reproducing a relation (namely its goal) and that this constitutes a canonical representation of the G.D.S. Such a system, however, reproduces states rather than functions which can be given an imperative interpretation and the G.D.S. is, itself, an automaton (or imperatively interpreted function). At a similar level of discussion, memory is evidently the system called conceptual reproduction and memory of X by individual Y a cycle involving X and Y's L^1 processor, M^1. This, also is a G.D.S., though its operations span both levels of control, L^0 and L^1. Here, the reproductive event does involve an automaton so that M^1 features as an automaton for reproducing other automata. It is identical with the finite function machine in Von Foerster's theory. (36)

Going one step further, we ask what is the least system which reproduces itself, i.e. what is self-reproducing in the sense of Loefgren? (Section 2.8). The answer is an individual; in the sense of a psychological individual, i.e. the organisation of which it is proper to predicate personality, the having of concepts, memory, etc. This intuitively derived nesting of systems (individual; memory; G.D.S.'s) is attractive insofar as it leads to several novel and useful reappraisals.

An adequate mathematical foundation for it emerged, quite recently, from the work of Chiaraviglio and Barralt on an interpretation of Curry and Faze's combinator logic called 'Combinatonic Theory'. (37) Their work is primarily addressed to the representation of computer hardware and computer software in terms of a combinatonic system and amongst other things they have pointed out that the customary distinction between programme and data is not obligatory. Indeed, it may be embarrassing if the computations of interest are performed by (say) a biological cell rather than a digital machine. The cell is equally well a combinatonic system (lacking some of the special restrictions introduced for talking about computers). Cognitive processing appears to have the same calibre and Barralt has interpreted the G.D.S. model as a combinatonic system. A nested series G.D.S.: memory; individual is fully comptible with this formulation (for example, to represent the G.D.S. it is necessary to invoke a replicative combinator which is the analogue of Loefgren's self reproducing operator; hence, a G.D.S. is a restricted self reproducing system. By the same token, memory is a less restricted self reproducing system. (This work of Barralt's is so far unpublished and was presented in a series of seminars at the Georgia Institute of Technology. It will appear as part of his dissertation).

The question remains, 'Why is memory organised as it is? Why are G.D.S.'s reproduced in the environment of an L^1 process, rather than being self replicating without constraint'? (Alternatively, 'Why is the fabric of a mind so organised that it is useful, if not imperative, to talk about levels of control'?). Why, indeed, do individuals regarded as organisations, have the hierarchical structure which has so often received comment? (For example, from Koestler, (38, 39), Bateson (40) and others (41), (42).

Since, in many respects, a mind is analagous to the organisation of cellular replication and metabolism, the question may be partially answered along the lines suggested, in the latter context, by Michie and Longuet Higgins (43). They proposed that cellular reproduction involves the rewriting of discriptions and occurs only in the environment of the metabolic machinery because (a) this preserves a distinction between compiler and object programme (akin to our distinction between L^1 and L^0) and (b) because the preservation of this distinction has survival value on the assumption that compilation facilities are employed for many purposes and to process many programmes. Apter's models are motivated by similar ideas. (44) Applied in the conceptual domain, this proposal seems eminently reasonable. Its tentative acceptance gives rise to some interesting deductions about the nature of education and social psychology as a whole.

3. CONVERSATIONAL SYSTEMS

Until Section 3.2.2. we shall assume that the concept structures and descriptions used by the student and the teacher can be hierarchically ordered, i.e. that the L^i constructive processes are, in practice, restricted in the sense of Section 2.8.

The student in a conversational teaching system is assumed to be an intending, anticipating and sentient individual (in Section 2 we rejected the alternative possibility that man is a reactive automaton). If a human being has such a status, then he can agree to a contract with a teacher or (a harmless anthropomorphism) with a teaching device. The contract stipulates (1) That the individual will aim for the goal, G, of satisfying a task assignment and (2) That all of his dialogue with the teacher will take place in the object language $L = L^0, L^1, \ldots$ of Section 2.2. which is interpreted with respect to the generalised concept structure of the task in hand and which is used to talk about this structure, the concept structures derived from it and, hence, the student's own descriptions of the task. There is some precedent for calling the contract an 'experimental contract' though 'tutorial contract' would be better in the present context. An individual who agrees to, and abides by, the experimental contract is a **student** provided that he is not already well versed in respect of the task.

A conversational system is synthesised (a) by using an experimental contract to set up a subsidiary system which embodies a cooperative externalisation technique (CET) to glean information about the student's learning process and (b) by constraining the CET system in various ways. (I) to mediate the uncertainty regulation procedures prescribed in Section 2.5.; (II) to avoid the cognitive maladies outlined in Section 2.7.

The CET system itself is described in Section 3.1. The constraints that yield the conversational system are introduced, in two stages, in Section 3.2. Of these, the arrangements described in Section 3.2.1. account for currently operating or immediately planned conversational systems. Section 3.2.2. deals with systems of the future, which are likely to embody the ideas outlined in Section 2.8.

3.1 *CET Systems*

Accepting the experimental contract places the student under duress since, as a novice, he does not have the mental equipment needed to achieve G. Phrased differently, the directive to aim for G conveys a **latent** command that the student cannot obey immediately and that he will only be in a position to obey, **on his own**, after he has learned. G is a **tutorial** rather than an **operational** goal.

According to Section 2.7., the student must partition goal G into subgoals in order to learn at all. Of course, a great deal of this activity could go on provately and unobservably in the student's head. But an observer who wishes to see what occurs can take advantage of the student's embarassment over achieving $G\rho$ in order to encourage the student to externalise his learning process as a segment of L dialogue. The requisite technique is the CET. It is closely related to the technique of 'Paired Experiments' used by Luria (47) and his associates. The bones of the CET are shown in Fig. 7.

As a first step, an imperative is introduced by providing problems to be solved. These are selected by a problem source, P.S. of Fig. 7. In order to achieve G with these problems given, the student needs cooperative assistance. Hence, the student is provided with a potentially cooperative agent, labelled S (for 'collection of surrogates'). S may be the observer himself, acting in a participant role, or it may be a computing machine. In either case, S is placed in communication with the student via a channel that uses language $L = L^0, L^1, \ldots$ and it is convenient to use a console at the interface (so that L is a mechanical language, expressions in which are unambiguously interpretable). The cooperative agent can provide various sorts of assistance either in solving problems or helping the student to learn how to solve them. It contains facilities, available to the student on demand, that act as surrogates for L^0 or L^1 processes which the novice does **not** have in his mental repertoire but that **will** be built up as he learns (in Fig. 7 the L^0 surrogates are labelled S^0 and the L^1 surrogates S^1). For example subgoals of G can be **selected** in the following sense. If a problem x, is to be solved under G, then the subproblem, x_ρ, under a subgoal of G_ρ of G is presented to the student but the surrogate solves the rest of the problem on his behalf. The surrogate is constructed as a perfect (omniscient) apparatus so that if x_ρ is correctly solved (by the student) then x is correctly solved by the student and S acting in concert.

Now we noted that the novice cannot solve problems under G on his own but the coupled system (Student, S) can do so. Hence, the student is impelled to make use of S in order to satisfy the experimental contract* and thus to engage in an L discourse that can be recorded (Fig. 7).

**Footnote: A note is required in order to bring this account into line with the literature. It is possible to introduce an auxiliary goal into the experimental contract; namely to define a score or proficiency with respect to the currently selected subgoal and to insist that the score be held above some limit. With this restriction, the student is literally forced to use S. In practice, this expedient is rarely necessary though it was incorporated in all of the earlier systems.*

If the CET is employed in a learning experiment, then the students is told (a) He must satisfy G; (b) He must ultimately satisfy G without the help of the cooperative agent. Under these circumstances, he makes provident use of the surrogate facilities and relinquishes them as soon as he is able to do so. Whilst he is a novice, he uses many of them, but still quite selectively; once proficient, he uses none. The L record shows the way in which he originally selected amongst different surrogate facilities and, through the withdrawal pattern how he builds up GDS's of his own. The constraints imposed in a conversational teaching system are not identical with (a) and (b) but the principles of the CET are essentially the same.

The flow charts of Fig. 8 (I) (an L' process, α) and Fig. 8 (II) (an L^0 process, β) illustrate the operation of a CET at a practically interpretable level. Roughly speaking, α, depicts the organisation of S^1 and β of S^0 but there is some overlap. It will be convenient to assume that the student asks for blocks (subsequences) of $k = 8$ or 10 problems and that once a block has been demanded, the problems are generated automatically, by P.S. of Fig. 7. The blocks are indexed $m = 1, \ldots m_T$ and the trials (problem posings) are indexed either directly ($n = 1, \ldots K m_T$) or within blocks ($n_m = 1, \ldots K_m$). In practice, K_m need not be constant ($k = K_m$).

Let us turn to Fig. 8 (I). Initially, the student undergoes a competence pretest which (depending on the task) is either a specific procedure or a collection of aptitude tests such as a part of Guildford's battery. The resulting data is stored by the cooperative agent; it constitutes the initial state of a competence profile which is periodically updated. Next, the student is presented with a description of a generalised task analysis (the task structures that the agent can 'understand') and he is also told what L^1 processes it can 'understand'. Both of these descriptions are open ended and the student can add to them (though in the systems so far realised, this **particular** student is not able to make use of his amendments). The rest of the process depicted in Fig. 8 (I) takes place at the end of each trial block. It consists in a number of cycles (glossed, for the most part, as execution statements) in which the student is asked to **say something** after which he is given some information or assistance **in return**. The student is invariably in a position to reject the assistance offered and ultimately he must do in order to achieve G **without** any help.

In α (the flow chart we are considering) the student is asked to say something about his L' processed; on the one hand his Type I L^1 processes (or the **plans** they generate) and on the other hand about his Type II L^1 processes. A surrogate cannot actually **give** him an L^1 process in return (whatever that would mean) but it can and does give him (A) Proposals for the **plans** that might be generated by a Type I L^1 process (B) Suggestions for which Type II L^1 process to use and (C) Information evaluating probable success. This information is of two sorts: (I) Evaluations based on competence profiles derived from the competence pretest and periodically updated, and, (II) Performance data collected with respect to his past history. The latter consists in a distribution of 'proficiencies', 'certainties' or (negative correlates of $H\beta$) with respect to the subgoals, G_ρ, so far examined. It comes from the operation of the L^0 procedure, β, which will be considered in the next paragraphs.

The statements of (A) and (B) above are not delivered in the concise nomenclature of this paper but in a form that the student can readily appreciate. For all of the experiments so far carried out, it has been possible to display the task description graphically, (in the manner of Fig. 4) Ref. 17, 18. Plans are sequences marked out on this graph. Suggestions for using certain Type II L^1 processes present rather greater difficulties but the following verbalisations are typical:

Jargon Statement	Procedure Statement
(a) Concatenate GDS_i and GDS_j and, (b) Substitute the concatenated string by a GDS_ρ	(a) Notice that you could solve p problems by solving a j-problem after an i-problem. Do these operations separately (select G_i first, G_j next) and tackle G_ρ (select G_ρ) taking your time over it.
	(b) However, in practice, you will not have time to do this 'one after another' sort of problem solving. You must try to 'see p problems as a whole'. To do so, after satisfying recommendation (a), select G_ρ and practice going directly from p problems to a solution.

Apply **analogy** to GDS_i to obtain GDS_j (it being assumed that A is the domain of G_i and B its range; that C is the domain of G_j and D its range; that $[A(G_i)B]$ R $[C(G_j)D]$. Where R is an analogy relation.	(a) Experiment to find the rule relating A to B or obtain its description (selecting G_i for this purpose). (b) Make the assumption that C is related to D as A is related to B. This assumption is not quite accurate but it is a working guess. Select G_j and discover in what way the assumption is false. (In an alternative mode the student might be offered a description of R instead of having to find the difference).

It will be observed that the questioning and cooperating cycles refer either to strategies (the student is able to assert certain plans for learning and the Type II L^1 processes he will employ) **or** to the next subgoal he intends to learn about. In the latter case, the student may either specify one particular subgoal he intends to aim for or he may provide a preference statement (or confidence estimate) over a set of alternatives. In the latter case, his L^1 uncertainty (H^1) is computed and recorded and his doubt about what to do is resolved by a random selection device which picks one of these alternatives with weights proportional to the preferences.

As a result of these manipulations, a particular subgoal, G_ρ, is selected as the **next** (either directly or as part of an agreed strategy) and the student accepts a block of problems to be posed under G_ρ. At this point control is transferred to β of Fig. 8 (II) until the end of the current block of trials.

Procedure β is organized, like α, in questioning and cooperation cycles. It is repeated for each value of n_m (the index over problems in a block of trials). p, the index of G_ρ (obtained from the previous pass through α) is a parameter of procedure β, and determines the subgoal, i.e. the subproblem class from which problems are selected.

In order to evaluate the student's performance or to compute an H^0_β, β must have access to a task automaton or problem solver that is extensionally equivalent (Section 2.2) to GDS_ρ (it must, at least, have an appropriate function table; no distinction is made between β 'computing the solution to a problem' and β 'looking up the results of a computation', perhaps at various intermediary stages). This is a coarse grained or molar picture of things. At a molecular level, β has several **different** surrogate problem solvers that are **intensionally** equivalent (Section 2.2) to the GDS's the student might build up and which correspond to different problem solving methods. The number of these is limited by practical considerations and the number of L^0 problem solving methods that the population of students is so far known to adopt (the list of L^0 surrogates is updated by post experimental enquiry).

Example 1. **Teleprinter Operation.** *Students employ two or more methods ((a) and (b)) of solving the problems posed by T^0 when this skill is being instructed. Each method consists in an arrangement for constructing a key pressing response from components such as 'select hand', 'select finger', 'select direction of motion' and 'select modifier' (starting from the fiducial rest positions) (65). Method (a) is based on a fingering scheme in which the keys are coordinated in a 'Right Left' fashion and Method (b) is based on an 'In Out' fingering scheme ('in' or 'Out', relative to a centre line that partitions the keyboard). If T^0 delivers cueing information according to these molecular models for problem solving (65) (rather than using the gross procedure outlined in Section 2.5., Example 1), then it is first necessary to ascertain in which way the student conceives the keyboard (initial questioning).*

Example 2. **Intellectual Skills.** *Since nearly all puzzles and mathematical problems can be solved in several clearcut ways, the distinction between different, but extensionally equivalent methods is fairly obvious in the intellectual domain; much more so than it is in the instance of Example 1. Differing but distinct methods are also adopted in connection with problem solving of an open ended or innovative type. For example, Elzhout and Elzhout (69) have described two distinct strategies employed in solving 'apparatus test' problems (the 'apparatus test' is open ended. The student is presented with an 'apparatus', for instance, a 'chair' or a clock and is asked to describe a pair of improvements upon it. One method leads to fairly trite improvements. The other leads to more radical innovations).*

The questioning and cooperation cycles of β are nested as follows:

(a) If the student selects a problem block he may receive, if he desires, knowledge of results evaluating his performance over this block of trials, i.e. a score value.
(b) If the student tries to solve a particular problem he may receive, if he desires it, knowledge of results evaluating his solution.
(c) If the student is willing to specify (by specific questioning or overtly) which one of several extensionally equivalent problem solving methods he employs, then he may receive cooperative information specifying the partial computations carried out by the surrogate he named when he selected a method. Depending upon the task, this information appears as cueing information or prescriptive information.

At the end of a block of trials ($n = n_m$), H^0_β is calculated, control is returned to procedure α and the value of H^0_β is used, as its negative correlate, to update the performance or certainty data.

Several refinements are introduced to avoid modes of enquiry that would be cumbersome if repeated too often; for example, if a strategy or a plan has been instituted, α is designed to 'assume' that this plan is currently in use unless the student makes an assertion to the contrary. But, in principle, the CET organisation is now completely specified.

It will be noted that the operation of a CET involves modelling the student and that though this model has an initial part consisting in a generalised task structure and an initial competence profile (obtained from the competence pretest) it is modified and reconstructed as the dialogue continues. Hence, in a limited sense, the cooperative agent 'learns' about the student. The information comes entirely from the L dialogue (a) As the measure H^0_β; (b) as H^1; (c) As the student's assertions that pick out a plan and a task description (from the generalised task description); (d) from assertions that define specific Type II L^1 process; (e) from the specification of methods or L^0 surrogates.

These data gathering manipulations form part of the flow charts for α and β but are distinguished in Fig. 7 as the special box concerned with adaptation.

3.2.1 *Currently Operating Conversational Teaching Systems*

The student in a CET is learning as he wishes and the process exhibits all of the defects noted in Section 2.7. The conversational teaching system is based on a CET but is designed to anticipate and avoid these pitfalls.

Consider, first, the L^0 operations of S^0; roughly speaking, of procedure β. In free learning, H^0_ρ may fluctuate wildly as the student runs into periodical overload. In a conversational system β is replaced by an adaptive system β^* that instruments the uncertainty regulation strategy of Section 2.5. Apart from an initial phase of enquiry to determine the **type** of simplification required, the questioning procedure is replaced by an arrangement which picks out an appropriate **degree** of simplification or cooperation (Section 2.5.) as a function of H^0_ρ. The result, shown in Fig. 9, is an L^0 subcontroller, T^0, with parameter p (i.e. a set of subcontrollers, T^0_ρ, with different G_ρs).

Turning to level L^1, the free learning student faces two main difficulties, already noted in Section 2.7., These are (1) He may experience high levels of uncertainty about how to learn (manifest as high values of H^1) because of which it proves impossible to adopt any coherent plan for learning; (2) supposing a plan is adopted, the student may still be thwarted by cognitive fixity with respect to a mismatched learning strategy.

Of these, (1) can be remedied by imposing an externally chosen **teaching** strategy upon the student, an expedient that is adopted, explicitly or not, in any feedforward teaching system. But the imposition of a teaching strategy, whilst reducing H^1, also eliminates the student's freedom of choice and with it the information needed to determine which of several teaching strategies is fitted to this individual.*

**Footnote:* *This is only one reason for preserving freedom of strategic choice. The other reason is fundamental but entails presenting the learning theory in terms of concurrent processing which is deliberately avoided in this paper. Broadly, it can be argued that any human being who attends to one goal must be aware of the other goals to which he* might *attend (Ref. 16). This proclivity explains the exploratory drive and man's* need *to learn (Ref. 15).*

Hence, the expedient is self-defeating, unless a definite teaching strategy can be prescribed on independent grounds (for example, cost or logical necessity).

Fortunately, it is possible to use an alternative method of reducing H^1 which also avoids the hazard of initiating mismatched strategies (difficulty (2)). This method consists **in providing the evaluative information necessary to resolve the student's L^1 uncertainly** (but still allowing him freedom of choice) whilst making the execution of **any** learning strategy **contingent** upon the stable operation of the subcontroller, T^0.

One realisation of this method is outlined below and consists in applying several restrictions (a) to (i) to the CET routine, α, thus producing a modified routine. This routine has been realised in a partially mechanised form for different tasks. For instance a flow chart specific to the task of Fig. 4 appears in Ref. 17.

(a) Given a generalised task description and the current competence profile (initially the competence pretest data) it is possible to exclude certain learning strategies as grossly mismatched and to recommend others as well matched, on the evidence so far available. Once a strategy has been selected as the current teaching strategy (as in (d) below) it is reevaluated by matching against the competence profile (which is updated as in (f) below).

(b) At each block of trials where a strategy is selected or where the current selection is altered, the excluded strategies are displayed to the student together with **the reason for their exclusion.** Likewise, the recommended strategies are displayed together with - **the reason for their recommendation.** These displays replace the less specific information delivered by α.

(c) The flow chart of α is modified to prohibit the selection of an excluded strategy. (A) If the student announces his intention of adopting it, his selection is disallowed; (B) If he selects a sequence of subgoals delineating this strategy whilst the prohibition is still in force, then his subgoal selection is disallowed (this awkward condition is necessary because the accretion of evidence, whilst the student maps out a strategy **in extenso** may change the prohibition. Hence, the procedure must keep track of subgoal sequences even if the subgoals are selected singly.

(d) The student is forced to select **some** learning strategy and though he is advised to select one of the recommended strategies, he is not **required** to do so. In this connection, plans that 'revisit' subgoals, for example, the 'redundant' wholist plan of Fig. 4, are perfectly legitimate bases for strategies. Further, strategies of this type are frequently recommended.

(e) If the student's selection is a member of the recommended set, then it is adopted as the agreed **teaching** strategy. If it belongs to the excluded set, it is rejected (as in (c)) with a reason for its rejection.

(f) If the strategy selected by the student is neither recommended nor prohibited, then (A) at the first trial it is accepted as the **teaching** strategy. (B) At the end of any subsequent block of trials, it is accepted as the **teaching** strategy providing the student can pass a mandatory competence test with respect to its first subgoals. Thus certain of the competence tests, which are optional in α, become obligatory. The information gleaned from them is used to update the competence profile.

(g) The continued currency of a teaching strategy is contingent upon the stable operation of T^0_ρ (Fig. 9) when assigned the values of p determined by the subgoals, G_ρ, that are specified by the current strategy. From Section 2.5., T^0_ρ is **stable** if and only if $O > a > \frac{dH^0_\rho}{dt}$ and b $H^0_\rho > c > o$. In the simplest case, stability is determined over a single block of trials*.

**Footnote:* *In general, stability is determined over a certain interval, t, and the test value is either 'T is stable' or 'T has been unstable for longer than Δt'. Further, as previously noted, the block of trials is generally not of fixed length.*

If T^0_ρ is not stable, then either the student is overloaded or he has learned all there is to learn with respect to G_ρ.

(h) At the end of the mth block of trials, T^0_ρ (i.e. T^0 with the parameter p defined by the selection of G_ρ) is tested for its stability.

(i) If T^o_ρ is stable, cycle m + proceeds on the assumption that the currently selected strategy will be pursued: If not, the student is tagged. In these circumstances, a look back procedure is instituted. In subsequent blocks of trials the performance (or certainty) data is examined over all blocks during which the student was tagged. If the evidence indicates a run of high uncertainty (i.e. high values of H^o_ρ and by definition low performance indices) then this is taken as a sign of cognitive fixity with respect to a mismatched strategy. In this case, (A) The strategy in question is excluded (notice, the uncertainty data overrides the competence match on the basis of which it was previously not excluded). (B) The student is warned of cognitive fixity, he is given advice based on the current evaluations, and is required to select a different strategy. As the system stands, this directive is given verbally by an experimenter but the operation is susceptible to mechanisation in principle.

At least two refinements of this procedure are desirable. The first is some method for adjusting the constants a, b and c of the subcontroller as a function of an initial test (quite easy) and of termination in the states of clause (i) (more difficult). The other refinement is some mechanism inferences about L^1 processes can be made on the basis of information accumulated (by T^o) regarding the student's L^o processes.

However, even as it stands, this is a primitive conversational teaching system. It is outlined in Fig. 10 where T = [T^o, T^1, T^2] is a conversational teaching machine. (Here [T^o,T^1] is identical with the structure is Fig. 2.). Its operation can be glossed as follows. T effects a compromise (the agreed teaching strategy) between the learning strategies proposed by the student and the strategies that it proposes on the basis of a continually updated model for the student's learning process.

The compromise is such that the student acts as a self organising system (Section 2.5.) when coupled to all aspects of the task environment that are covered by the teaching strategy.

3.2.2. *Conversational Systems of the Future*

The main defect of the conversational teaching system described in the last section is that 'having learned' is equated with achievement of a given level of proficiency or value of the correlated variable, certainty. This criterion is open to the criticism levelled at the familiar 'terminal behaviour' criterion and most of them are quite valid. In Section 2.8 we introduced an alternative form of criterion ('learning to teach' or, briefly, the 'teach back' criterion) which is generally more defensible and which is canonical within the learning theory of Section 2. The following section reviews some of the issues involved in incorporating the 'teach back' criterion into a conversational system.

It should first be observed that a student in the system of Section 3.2.1. usually has learned to teach, though no explicit use is made of this fact. He has acted as a teacher insofar as he takes part in selecting the current teaching strategy and insofar as this strategy might be used to teach someone else. Next, observe that the system of Section 3.2.1. does have a growing model for the student. As it stands, the model cannot be directly addressed to problems posed by an environment. But, since the model is built up from utilisation tagged surrogates (T^1, T^o and M^1, M^o of Fig. 2 are symmetrical) it is quite a trivial exercise to transform the model into a problem solver and a device that learns to solve problems. In one special case, a rule application task, the requisite transformation has been carried out and learning simulations have been run using different versions of the programme.

Let Z^1, Z^o (Fig. 11) be the operational transform of a copy of the model in T , T and let the information stores of Z^1, Z^o be set to suitable initial values (in general, such that Z^1, Z^o is 'ignorant'). It is not difficult to interface Z^1, Z^o with the student so that he can teach it the task (thus realising the proposal set out in Section 2.8.) and to evaluate his tutorial performance (via the device E of Fig. 11). Nothing is lost by making Z^1, Z^o into an unrealistically fast or even (one shot) learning since (Section 2.8.) we are interested in the student's ability to reproduce concepts and are quite unconcerned by his patience in dealing with an unwilling or forgetful pupil. Hence, the teaching test can be performed in 'fast time' and made to occupy an acceptably short interval of time. However, it is necessary to recall that the model in T^1, T^o (and, consequently, Z^1, Z^o) is built up in the course of the tutorial conversation and that the remarks of the last paragraph refer to a terminal test conducted at a moment when the model has matured.

For simple skills, it is quite easy to instrument this 'teach back' procedure via a supervisor (shown as D in Fig. 11) that switches from the normal to the 'teach back' mode, meanwhile engaging the test evaluator, E. In fact, at this level of sophistication, the teach back paradigm has already been instrumented. For example, Bailey, McKinnon Wood and I (48) embodied it in our learning and teaching simulation, EUCRATES, during the late 1950's and Lewis and I (49 - 55) have used the evaluation of teaching back (between real life students, interacting via mechanised interfaces) in a group learning system keyed to a concept acquisition task.

But certain difficulties arise in connection with really complex tasks. When, for example, should D introduce the teach back mode? What initial 'knowledge' should Z^1, Z^o be given when it acts as a dummy student (in the simple case, it is fair to assume 'no knowledge'. But if the student is to teach Z^1, Z^o at intermediate stages, then presumably it should have some concepts established in its repertoire already). This is a tricky problem because of the difficulties considered in Section 2.8. If a teach back criterion is a good one, then we must discard the restriction introduced at the beginning of the present Section and admit that the structure of knowledge is heterarchical (rather than following the hierarchical arrangement induced by limitations on the primary constructive processes).

This is true, of course, for the 'simple' systems of the last paragraph. But they owe their 'simplicity' to a peculiarly simple heterarchical plexus and to the fact that teach back is **terminal**. As a result, the heterarchy does not need to be manipulated. On the contrary, if teaching back occurs from time to time in the course of tuition, the system must contain a description of and must prescribe operations on a growing relational net. Now this is not impossible. Workers in the field of 'artificial intelligence', especially Minsky and Pappert, Selfridge, Quillien, Reitman, and their colleagues have exhibited such structures. Chiefly, though, they have been concerned with descriptive and/or static structures though these may, perhaps, be reproduced or reconstructed in many different ways. It would be generally agreed that the case of reproducing the representation of a system (a process, a dynamic entity) is far less tractable. Yet such cases are very common in teaching (to cite a couple of instances that Mr. Scott and I are experimenting with at the moment; the (biological) concept of an 'Operon Repressor, Control Cycle' and the (everyday) concept of 'finding your way around a town'. In each case, the basic concept is dynamic and in each case students freely exchange verbal and visual representations as part of its reproduction).

However, if the (probably technical) difficulties of representation were surmounted it would be possible to employ the teaching back information gathered through E_o in place of most (or all) of the information currently garnered from the competence tests. In that case D should be designed to alternate the normal mode and the teach back mode, in order to reach a satisfactory balance between the basic procedures of learning about the student and teaching him.

4. DECOMPOSITION OF THE CONVERSATIONAL SYSTEM:

As noted in Section 1, the organisation of a conversational system can be decomposed to yield the organisation of any other teaching system. An outline taxonomy is exhibited in Fig. 12 (a detailed account is provided by Refs. 6 - 10, which include a full bibliography).

To begin with, there is the conversational system itself (not shown in Fig. 12). Apart from the laboratory arrangements discussed in Refs. 17 - 27, it is typified by C.A.I. systems, such as subroutines in Kopstein's and Seidel's IMPACT (56), a few of the devices in use at Stanford (Suppes and his associates), the enquiry mode of PLATO (Bitzer) (58) and some of Stolhurow's (59) systems.

Fig. 12 (I) shows an adaptive teaching system. In common with all of the examples in Fig. 12, the system is set up in the normative framework of an experimental contract and the establishment of this contract usually involves 'off line' bidirectional multi-level discourse between teacher and student. However, the 'on line' interaction at L^1 and L^2 is unidirectional only. The uppermost level contains a strategy (some C.A.I. systems, the arrangements described by Bennett and Hodgson (60)) or a parameter variation scheme (perceptual motor trainers, (17 -27), (91), 62, (63). The lower level is T .

Fig. 12 (II) represents a feedback controlled teaching system and is identical with the subcontroller T°, given a constant parametric input re with T°_{ρ}. Branching and skip linear instructional programmes belong to this category of system, together with a number of training devices (17-27), (64), (66). To show their equivalence, it is only necessary to open out the organisation of a branching programme as a TOTE hierarchy (8), (44).

Fig. 12 (III) depicts a feedforward teaching system in which instructions are given to guide constructive operations at L^1. Referred to an intellectual task, the figure represents a perspicuous, but preprogrammed, lecture or audio visual representation accompanied by due explanatory comment. The sight and sound method of typewriting instruction is a good example of an application to perceptual motor training.

Fig. 12 (IV) is a simple feedforward teaching system. The L^1 instructional sequence is deleted. The system represents the delivery of an unimaginatively pre-programmed lecture or the tedious business of copying another person's performance of a skill.

5. THE REALISATION OF TEACHING SYSTEM

The first decision to be made in applying educational technology should be a tentative choice of system type; a conversational system or one of the decompositions in Fig. 12. The theory presented in Section 2, provides some guidance in this respect. For example, it is only worth considering the conversational system if (a) the generalised task structure (obtained from a task analysis) permits several specialised task structures; (b) if a number of these are actually submitted by members of the student population and (c) if it is either true (A) that the teaching must be idiosyncratic or (B) that it should be. Of these, (A) pertains when a student is required to solve problems in many different ways. (B) pertains when the criterion is specific (so that, on these grounds, a rigidly imposed teaching strategy is acceptable) but when there are psychological reasons (motivation, personality of students) for rejecting this expedient. Similar arguments apply to other types of system and are discussed elsewhere. (11) (12)

The tentatively chosen system type may still be rejected as too costly or too cumbersome. To evaluate it in this respect, the designer must consider its physical realisation.

It is nearly always true that a conversational system can be realised in a humanly operated, a partially mechanised or a fully mechanised form. The same comment applies to the derived systems of Fig. 12. Choice of one form or the other is a matter of expediency (are human teachers available? Is there a computer and programming team?).

If the system heuristic imposes an intolerable burden upon a human instructor (or group of teachers), the load can be lessened by partial mechanisation. The chores of obtaining feedback, interrogating the students and presenting modules of course material, may be relegated to inexpensive teaching aids, such as marking devices, film loops, audio and visual tapes, television programmes eliciting suitably monitored comment. The organisation of these instruments to form a properly designed but partially mechanised tutorial system, is an important application of educational technology; currently the most important application there is.

Complete mechanisation may, of course, be justifiable. If so, the conversational heuristics impose a number of constraints upon the 'hardware' and 'software'. For example, no simple teaching machine is able to handle a fully conversational system and although special purpose computing equipment has been used for this purpose in the laboratory, it is utterly impracticable in the field. Hence, a computer is mandatory and so are certain facilities in its peripheral equipment:

(1) It is necessary to store the generalised task analysis and the curricular materials in a form that is rapidly accessible to all of the students handled by the system.

(2) An appreciable immediate storage capability must be dedicated to each student.*

**Footnote:* *Some such requirement must be met if it worth using a computer in the first place, regardless of the system type. In some quarters, C.A.I. has fallen into a modicum of disrepute simply because computers have been unprovidently employed as terminal switching devices that execute trivial tutorial routines at the level of an individual.*

(3) An economic design will incorporate summarising and statistical routines, the products of which are employed

in rewriting the task analysis and the teaching strategies. Neither these programmes nor the terminal selecting programmes have been considered in this paper.

(4) If 'tutorial' programming is to be carried out in a convenient language, then this language must be rich enough and flexible enough. Languages like COURSEWRITER have a wide range of application but are subject to limitations at levels L^1 and L^2. In contrast, languages like TASKTEACH, though admirable in this respect, are specific to a narrow range of tasks.

(5) The interface requirements are crucial. For example, the print rate of a teletypewriter is unacceptable and so is the single modality it accommodates. Several satisfactory configurations of peripheral equipment are commercially available but are expensive. However, their cost, (like the cost of core storage) is likely to decrease rather rapidly.

Nearly all of the large C.A.I. facilities can be used in a conversational manner and it is surprising that so few of them are thus employed. But conversational teaching may also be instrumented through less ambitious apparatus if it has sufficient flexibility and a modular design. One example which also illustrates the possibilities of partial mechanisation, is the RALF system at the Georgia Institute of Technology.*

**Footnote:* *The basic student console is equipped with an electrowriter for graphic output, a headset for audio output and a telephone touch pad for input. Each console is linked through a telephone connection to a central computer (in the basic version, a PDP8) via which, (1) The student can access 5 or 10 minutes length audio graphic course modules referred to specific subconcepts or (2) The student can be presented with a programme of course modules determined by a teaching strategy. In the system as it stands, the data is stored on a randomly accessed tape bank and the indexing of concept structures is external to the basic programme. But a prototype system with digital storage is under development and this will incorporate the links and indices required The central computer interprets student responses (as well as student commands) so that any programme can be feedback controlled or (within limits) adaptive. For a few subject matter areas, this hardware configuration allows for quasi conversational instruction, provided that appropriate software is added. In general, however, the realisation of a genuinely conversational mode entails augmenting the hardware as well as the software. For example, the console arrangements can be extended to include teletypewriter input, CRT display, local storage of material and random access slide projection.*

In conclusion, let us turn to desideratum (1) (storage and retrieval of a concept structure). Throughout this paper we have emphasised the importance of task structures and of concept structures. All teaching systems depend upon them. But we have also confined our attention to the structures involved in immediate tuition, albeit of a complex task such a symbolic logic or matrix operations. Because of this constraint and because of the hierarchical ordering implicit in much of the argument, the structures have had quite modest proportions. Represented as relational nets, they contain no more than 150 nodes and these are partitioned into densely connected substructures of, at most, 25 nodes each. But all of the structures involved in immediate tuition are embedded in a network representing knowledge of the entire subject matter area (a task area in the sense of Section 2.1.). This is a prodigious net and, in general, a growing net as well.

Now it can be argued (I) that a full educational system should, by definition, have access to this much knowledge and (II) that a conversational system embodying the teach back paradigm will sometimes have occasion to access 'distant' parts of the structure, even if it is teaching a specific task (just how 'distant' may be gauged from the examples in Section 2.8. which are neither capriciously chosen nor whimsical). The indexing scheme recommended in this paper specifies relations between nodes in the network that depict the L^1 processes which might be used to get from one to another. Of course, this indexing scheme could be humanly operated. But mechanical storage and retrieval is clearly desirable and is likely to be economic, insofar as the mechanism has a capability for parallel search or can execute a functionally equivalent process.

Though the mammoth C.A.I. facilities have their place in education, the appeal of a grand design has been, perhaps, unduly seductive. As an alternative, it is worth considering the merits of modest facilities that are malleable enough to accommodate changing educational requirements, whilst rich enough to realise the conversational mode at least in a partially mechanised form.

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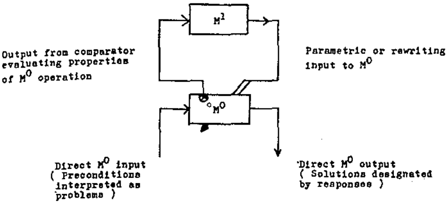


Fig.1. Control Hierarchy.

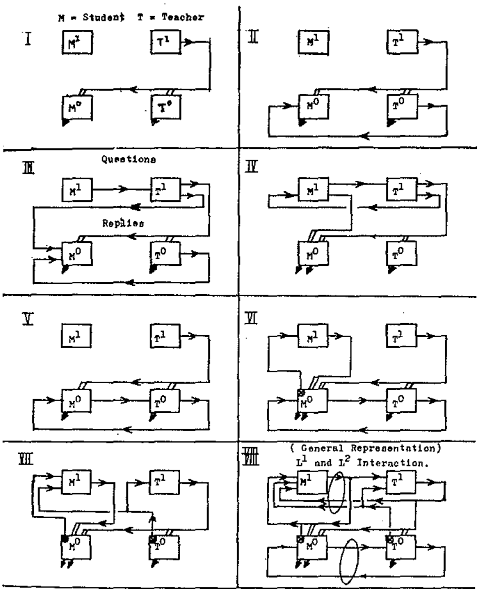


Fig.2. Tutorial Cycle and its General Representation (Part Vlll).

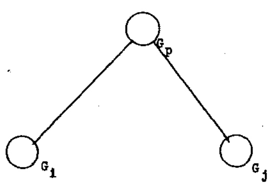
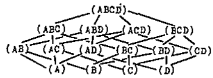


Fig.3. Fragment of a Task Structure.

Task Structures.



Redundant,(and, in this case, generalised,)task structure.

Task Structure α (defined under concatenate and substitute only).

Task Structure β (defined under concatenate and substitute only).

Learning Strategies.

(1) "Partist" Strategy.

(A) ⟶ (B) ⟶ ((A) + (B)) ⟶ (A,B) ⟶ (C) ⟶ ((A,B)+(C)
Construct Construct Concatenate Substitute Construct Concatenate

⟶ (A,B,C,) ⟶ (D) ⟶ ((A,B,C,)+(D)) ⟶ (A,B,C,D,)
Substitute Construct Concatenate Substitute

"Partist" Plan (mapped onto structure α)

(A) → (B) → (A.B) → (C) → (ABC) → (D) → (ABCD)

(2) "Holist Irredundant" Strategy.

(A) ⟶ (B) ⟶ ((A) + (B)) ⟶ (A,B) ⟶ (C)
Construct Construct Concatenate Substitute Construct

⟶ (D) ⟶ (AC)+(D)) ⟶ (C,D) ⟶ ((A,B)+(C,D)) ⟶ (A,B,C,D)
Construct Concatenate Substitute Concatenate Substitute

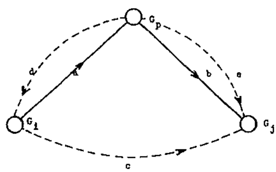
"Holist Irredundant" Plan. (mapped onto structure β)

(A) → (B) → (AB) → (C) → (D) → (CD) ⇆ (AB) → (ABCD)

If L^1 processes other than construct , concatenate and substitute are permitted, then certain strategies may only be represented on the redundant structure . For example, if analogy is permitted, students employ a "Holist Redundant" strategy with a plan of the form:-

(A) → (B) → (AB) → (C) → (D) → (CD) → (ABC) ⇆ (BCD) → (ABCD)

Fig. 4. Simple Task Structures, Plans, and Learning Strategies.



a Derivation of G_p from G_i and G_j by concatenate and substitute.
b Derivation of G_p from G_i and G_j by concatenate and substitute.
c Derivation of G_j from G_i by analogy.
d Derivation of G_i from G_p by analogy.
e Derivation of G_j from G_p by analogy.

Fig.5. Conceptual Heterarchy derived from the structure of Fig.3.

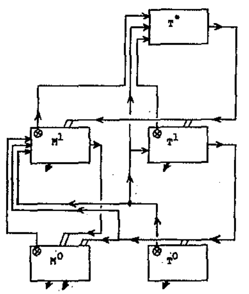
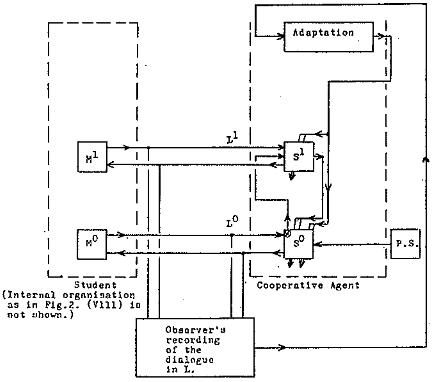


Fig.6. Outline of Conversational Teaching System.



P.S.:- Selects a sequence of precondition or trial indices. These are modified by the student as problems(x) under the current subgoal. The intention of this remark is clarified by the following comments.

S^0 consists in a collection of surrogates that are able to solve subproblems of a given problem, x.

At any trial the student may selectsome of these to act on the problem,x, in parallel, so that only a part of x remains to be solved.

The comparator ⊗ in the figure above, evaluates the total solution as correct or not. But, since the surrogate problems solvers are perfect, the total correctness depends only on the student's contribution to the process.

Fig.7. A C.E.T System.

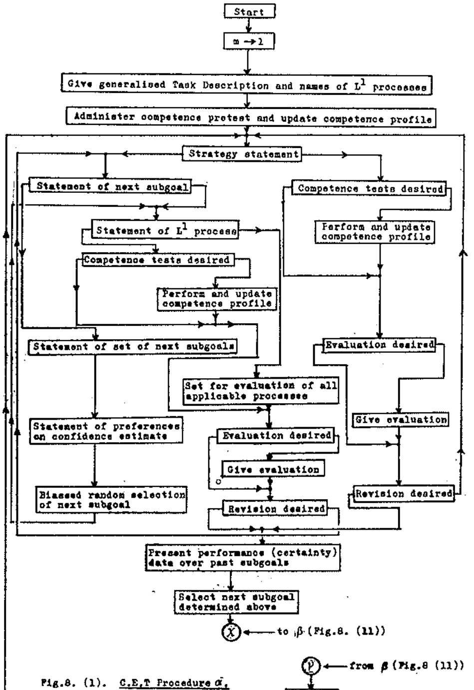


Fig.8. (1). C.E.T Procedure α.

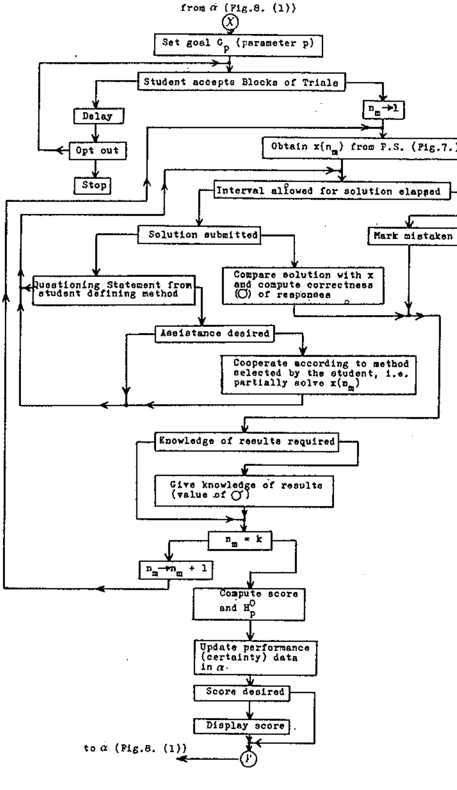


Fig.8. (11). C.E.T Procedure β.

Note (1) σ stands for correct or mistaken

(2) Solutions may be submitted (as shown) by definitive responses or by confidence estimates over response alternatives. In the latter case, H^0 is computed directly and the displayed value of $^P\sigma$ is replaced by an indication of the right alternatives.

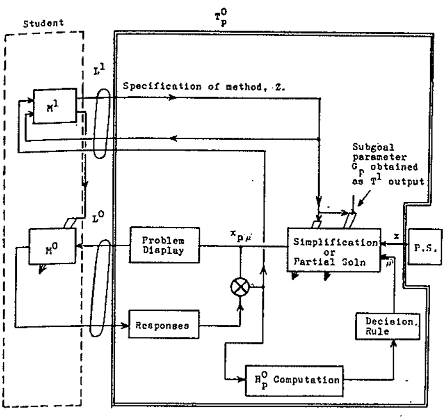


Fig.9. An operational form of T^0. The notation stems from Section 2.5 P.S is a source of problems (x). The simplification box contains, in general, several models for problem solving methods (the surrogate problem solvers of the text) which simplify x. μ is the degree of simplification (or partial solution) of problems (x_p) posed under subgoal G_p. If only one problem solving method is employed (or permitted) μ is a scalar quantity. In general, however, there are several methods. One of them may be indicated by the signal, Z, in which case μ remains a scalar. Otherwise μ is multidimensional. $x_{p\mu}$ designates a problem of class p simplified to degree μ. H_p^0 is the student's L^0 uncertainty. The decision rule varies μ as a function of H_p^0 in order to secure the stable operating conditions of Section 2.5.

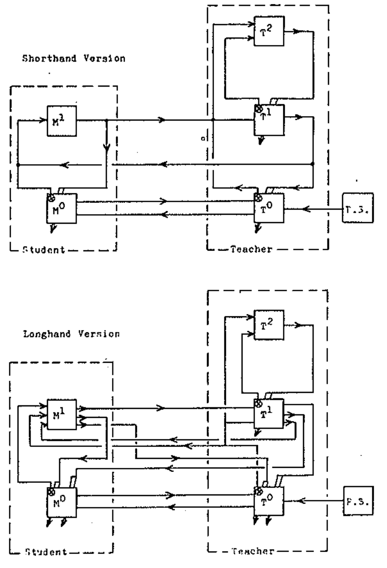


Fig.10.
A Primitive Conversational Teaching System. The Operation of T^0 is Described by Fig.9., and the Operation of T^1 and T^2 is described by the Modified Form of Procedure α, discussed in the Text. The Shorthand Version is used in the Construction of Fig.11.

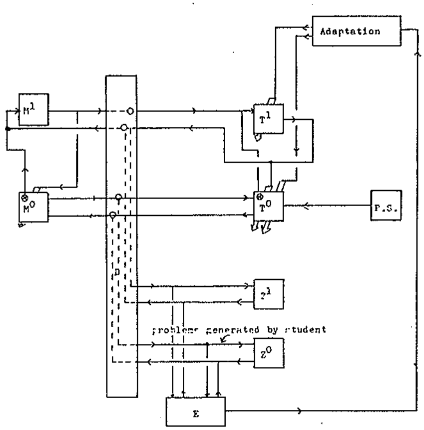


Fig.11.
A complete conversational teaching system. This is a more detailed version of Fig.6.

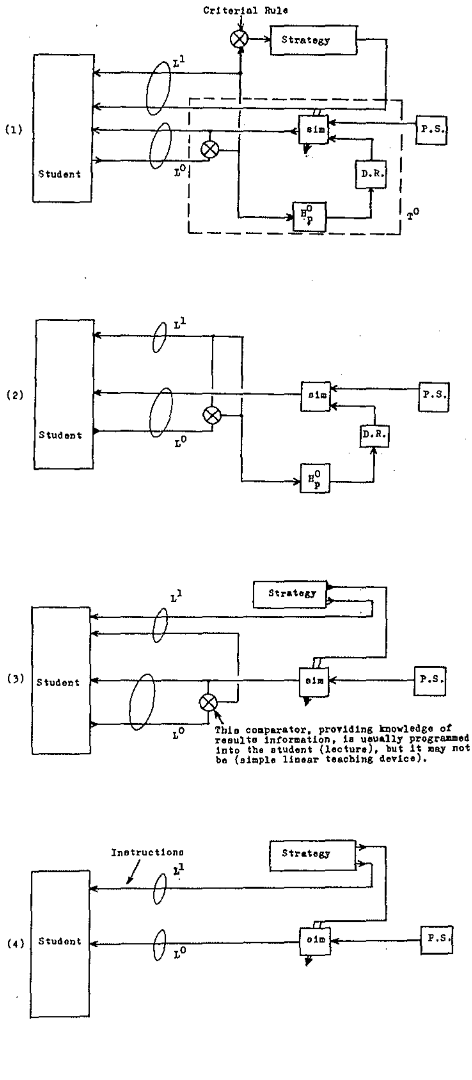


Fig.12.
Some of the teaching systems obtained by decomposing the conversational system. These are gross decompositions. Much more detailed decompositions are obtained by omitting or including different facilities.

COMPUTER SCIENCE AND MATHEMATICS

Preston C. Hammer

1. WHAT IS COMPUTER SCIENCE?

Computer science might variously be called the science of algorithms, the science of computing machines, or the science of digitized information. However none of these is satisfactory. I prefer to think of computer science as the science devoted to the extension of the uses of machines in the service of mankind. The computers, as we know them today, comprise the first set of machines which challenges the intellect in depth. Machines of the present and future are capable of saving the efforts of people – saving our history – in ways which related devices such as books, films, video tape, recordings do not do. Computers not only store „facts", they store ways of processing facts and they will put us better in touch with the work of others when we have done our jobs satisfactorily.

It is basically up to the next generations to really make computers work. Those who have lived with computing ideas since the age of, say 10 to 15 years, for a period 10 to 15 years may be expected to make the breakthroughs of the future. Computer science today provide the main hope of generating natural philosophers. Everyone comes to the computer and by studying the relationships of the various modes of thought the computer scientist may come to understand many areas. There is no other area now in which such interaction takes place.

At this time computer science is a distillate from mathematics, engineering, and language. The reasons that it is a separate field are numerous. Among these are the withdrawal of mathematicians and engineers from the rest of society. Mathematicians have declared themselves independent, engineering schools ignore their responsibility for education of non-engineers and so it is up to computer scientists to develop and teach cogent theories which technically are mathematical, to teach computer languages which neither engineers nor mathematicians seem to comprehend, to increase the relevance of computers to man, and to guide their future designs.

The organization of curricula in computer science is difficult since basically it should be conceived at the outset as a dynamic curriculum – one which adjusts without requiring crises to force adjustment.

Computer scientists should write the texts for and teach the teachers of arithmetic, a field of mathematics which now belongs to computer science. Since algebraic manipulation will come to be much better done by machine, algebraic algorithms also form a part of computer science. In both these instances it is clear that the computer scientist works on strategies and gets machines to do work. This higher level of thinking required to use computers effectively is providing the stimulus which will mean that the best mathematicians and engineers of the future will have been taught computer science when young.

There is some concern among computer scientists holding graduate degrees in mathematics that students will fail to learn the mathematics they have learned (and do not use!). Have these Ph.D.'s learned mathematics? The answer, I say, is no, because mathematicians haven't yet sorted out what mathematics is about.

I hear some colleagues speak of youngsters very enthusiastic about computers as computer bums. I consider these colleagues as educational asses. Do we call enthusiasts in other areas bums? In chess? In medicine? In mathematics? In bridge? In physics? Enthusiasm should be cherished, and if helpful, guided.

Now computer science departments must teach languages and they must teach the theories of machines which, incidentally, embraces all binary operations. Boolean algebra, graph theory, numerical analysis, computer modelling and simulations. Logic, universal algebra, lattices, category theory, function and relation theory, combinatory analyses are all areas which may well be taught in computer science. Classical topology is of limited use now but its usefulness will increase when we have more successes in managing problems of analysis by machine,

Applications of central interest should be taught in computer science. Among these are information retrieval, artificial intelligence, computer network organization, simulation of systems, compiler-compilers and adaptive programming.

The misinterpretation of theories is unfortunate. Good theories capsulize information, making it easier for the young to learn. They predict, and they suggest new creations. The theories associated with computer science are just in a language suitable for 100 years ago but certainly out of date now.

The most important place to have sound education in computer science is the undergraduate level. The reason is that much of computer science should be taught in the schools and teachers cannot be prepared in either mathematics or engineering departments. Another reason is that the only way to master computing is by doing it and the learning of any language is best done by the young. While the backwardness in using computers by many departments in universities and colleges is regretable, if we do our jobs we will find the younger generation forcing more users. By providing elective courses in depth at the undergraduate level future college teachers in all fields will be prepared to make use of computers. The adjustment requires qualitative changes of instruction. That is one reason that it is done so little now.

Now the demands of business, industry, government and schools make the undergraduate program mandatory.

Hence they make graduate programs even more necessary since college and university teachers come from the graduate programs. Sooner or later there will be teachers well prepared to teach in colleges and the level of instruction can be upgraded. As well prepared students go out to make the computers more effective, the demand will increase for even better and more advanced preparation. As computer manufacturers face knowledgeable purchasers they will, perhaps, be compelled to demonstrate more fully the merits of their merchandise. Nothing hurts the profession and science more than the ineffective and stupid use of computers. Knowledge and ability combined with integrity and social consciousness is what is needed.

2. MATHEMATICS EDUCATION

I have observed that many computer scientists have a deep nostalgia for mathematics. Some who are certainly not mathematicians like to label themselves as mathematicians. Yet, I know of no field of science which the practitioners understand so poorly as mathematics. I have developed some mathematical systems myself and I have studied the relevance of mathematics in some depth. My conclusion is that the records of mathematicians shows them to be opposed to understanding. A.B.S. major in mathematics will have no concept of the social significance of mathematics and neither will a Ph.D

If I were to make a scale of difficulty of mathematical subjects, I would place most algebras as easier than geometry and analysis. Arithmetic is more difficult than algebra. Non-numerical functions and relations may be considered as belonging with algebra. To my knowledge there is no basic treatment of functions and relations in any mathematics curriculum. Why not? Usually complicated functions are used to illustrate the concept, for example powers, radicals, and trigonometric functions.

Geometry is a complex subject which should be treated throughout the school curriculum. The finite calculus should be presented before the calculus, which is a limiting case and easier to manipulate. If differential and integral calculus comprises very important aspects of mathematics in the sense that almost everyone should know about them then, obviously they must be taught in the schools.

General principles of mathematics are discussed nowhere. There are no discussions of what theorems are or what proofs are. As one example, I mention a very important concept: Continuity. The notion of continuity is not well explained by neighborhoods, or epsilons and deltas. In fact continuity is not well-examplified in the current concepts in analysis and topology. Continuity and invariance are dual aspects of the same thing and they are meaningful concepts in all aspects of society.

Measure theory has been misnamed since the measures defined in measure theory comprise a trivial subset of the examplifications of measure. Measures which are not embraced in measure theory include exterior measures, projection measures, mean values and moments (of functions), norms, metrics, cardinal number (of a set), dimensions (of spaces), diameters of sets, and so on. It is nonsense to think and it is harmful to pretend that measures are necessarily realvalued, necessarily defined on sets, or necessarily additive if defined on sets. Now if you think about this example as typical of mathematics education, you will see why education in mathematics is in such poor shape. Measure theory has trivialized a big concept.

The calculus and linear algebra are excellent areas yet they are taught in a language suitable for 100 years ago but certainly out of data now. Only reinforced incompetence can account for the sorry state of education in these areas.

Probability and statistics are as completely misinterpreted as measure theory. These areas arose by using the practical device of degrading the quality of information in order to obtain models in which exactness is now impossible. However, interpreting probability as representing the actual state of affairs rather than reflecting our inability to otherwise interpret data or events is, to my thinking, nonsense.

In general way, I should say, the results of mathematics are often useful but the education in mathematics is asinine. General principle and concepts should be taught early. The relevance and non-relevance of mathematics should be brought out. Computer scientists should be in a position to understand what the theories accomplish and what they do not since they are often constrained to produce results to specifications they did not choose. We cannot afford to have the coming generations wasting time on nonsense and misinterpretations.

3. WHAT'S IN A NAME?

Among the various names suggested for computer science, I prefer computer science. To me information science or communication science are too pretentious since the terms information and communication are not to be pre-empted in any one discipline. To me information is the interrelationship of things, events and phenomena in space-time. To deal with certain aspects of information all areas develop their own mechanisms, theories and observations. The information theory of Shannon and Weaver has rather little to do with information in the large sense. In its way communications science is just as bad as information science. Should my department teach drama, speech, writing, journalism, radio, telephones, television, typing, shorthand, foreign languages, printing, radar, sonar, photography, and so on? I think not.

Now „cybernetics" is another idea. However, cyberneticians have yet to form a discipline since they have not settled on what cybernetics is. However, it seems to me that computer science might well embrace systems theories which do embrace cybernetic theories. I like „computer science" because it indicates a modesty of approach. The alternative „computing science" seems to me an attempt to avoid a fact: The actual mechanisms available now and in the future should be a matter of great concern to the field. If no better ideas for machine design come from computer science it fails a most important aspect of the job.

4. CONCLUSION

Computer scientists should not emulate mathematics and other areas which stifle undergraduate education by failing to make the subject matter timely or important. They should realize that the field as such has enormous intellectual prospects but they should also realize that accomplishments mainly lie in the future and will come only after diligent work. We should avoid undue emphasis on personal prestige but keep in mind that everyone needs some encouragement to do his best work. We need better machines, better literature, better software, sensible standards of terminology, more applications, and professional ethical standards. All of these can result only if we educate increasingly better.

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APPENDIX A

The Penn State Program

I assume I was asked to present this lecture on the basis of having initiated two computer science departments, at the University of Wisconsin and at Penn State. Moreover, I was one of the first to recognize that undergraduate programs are necessary and do something about it.

At Penn State we currently offer B.S., M.S. and Ph.D. programs. The M.S. and Ph.D. programs were started first in 1965 and the baccalaureate program in 1967. The B.S. program has now the largest number of majors of any department in the College of Science, about 330. My philosophy is simple. Any concept, technique, or fact which is important enough that every manager of a computing center should be aware of it must be available to undergraduates. Intensive specialization and research into the frontiers is what graduate schools are for. Since much of computer science is actually better for an earlier age level, we are preparing teacher education programs. When students entering college know quite a bit about computers and computing our undergraduate program can be up-graded.

Our B.S. program has raised the quality of our graduate program. Skill in computing, like playing pianos, can best be acquired with practice from a young age. Studying classical mathematics or electrical engineering does not provide adequate preparation for computer science. Our admission standards are as high as those of any department, our students are as good as any others.

At my suggestion the undergraduates have elected a committee and so have the graduate students. The chairmen of these committees attend our faculty meetings. Their charge is to help us improve their education (and ours!). Curriculum changes suggested by students and alumni will be initiated. We treat students as adults in this way and they become more responsible by exercising responsibility.

Several difficulties arise. A major one is that of getting the faculty members up-to-date. Another is due to the hostility engendered by success. However, we are boot-strapping ourselves into a better position each year. We are getting a small laboratory dedicated to instruction and research in the department started this year.

Our language courses are still inadequate and our research in languages is weak. The theoretical aspects of computer science have yet to be felt adequately in language and numerical analysis instruction. The relevance of computer science and a view of it as a whole is still inadequately presented. We have developed some strength in some applications areas and, by employing a few of our best Ph.D. students, we are building in systems programming.

The period directly ahead, in a cooling economy, comprises an acid test and will enable us to sort out the real contributors from others. I trust we will emerge as a leading academic department contributing to the improved use of human beings, but I also hope that others will continue to do the same since computer science is big.

APPENDIX B

Functions are verbs!

It might be thought by those who have some appreciation of mathematics that my remarks concerning mathematics education are made in frustration rather than from due consideration. I provide in this appendix a little of the flavor of my thinking in order to indicate that my remarks are not idle.

The work „function" came into mathematics I am told by Professor K.O. May due to a misinterpretation of a proper usage of the word in a communication of Leibnitz by one of the Bernoulli's. This, I may remark, seems not at all unusual in mathematics where a remarkable disregard for language is often displayed. Just recently, it suddenly occurred to me that functions (mathematical) are verbs and I find that this insight turns out to be very useful.

Suppose f is a function and let $y = f(x)$ for a given x in the domain of f. Then I may say in various applications any one of the following.

x goes into y
x is labelled y
x is represented by y
x implies y
x is near y
x determines y

All of these indicate the verbal character of the functions. The unfortunate terminologies „transformation" and „map" should be replaced by „transformer" and „mapper" and this conveys the idea. In this context the terminology „value of f" is not usually attractive.

Now in computer science we have also the imperative and subjunctive modes of the verbs which are functions. These are part of the control apparatus of the computing machine. For example „do" or „let" and „go to" are imperative modes and „if – then – else" are in the subjunctive-imperative mode. The central function (monitors etc.) tells other functions when to act and on what. From my standpoint, it is then suggested that models of computers should be based on this view of functions. In fact a computer itself may be interpreted as a function, and the theory then decomposes this function into component functions (submachines).

Moreover the various tenses of verbs now suggest enriched grammars of functions. Thus I can say „x will become y": „x will have become y at time t", „x might have become y" or „it is probable that x will go into y".

Now I ask. Why is it that functions have been around in mathematics for over 300 years without recognition of their verbal character? Yet this recognition makes it possible to present functions with a vitality which the present treatments ignore. It is a fact that computer science should force us to a much better understanding of mathematics. Mathematics of today is valuable for its particular algorithms and results. It is otherwise comparatively useless for providing the language structure we need in computer science. Direct consciousness of matters not dealt with at all by mathematicians is important in computer science. We must teach functions realistically!

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INFORMATICS AND COMPUTER EDUCATION

Jacques J. Arsac

1. INTRODUCTION

I have been a professor of Informatics since 1964, and was a member of the IFIP Technical Committee for Education from 1964 until 1968. So far I remain unconvinced that a general solution to the problem of curricula for Computer Education has yet been found and, further, one which has universal agreement. We may be astonished by such a situation. In fact, the real problem relates to a conception of informatics as a science, or as a set of technics. Each curriculum is a definition of informatics and each professor estimates such curriculum in accordance with his own definition.
I do not know any alternative for solving the problem which is, in my opinion, defining informatics; and, from the resulting definition, designing a curriculum.

I do not hope to provide a solution of such a question here, but just wish to start a discussion.

2. INFORMATICS AS A SCIENCE

2.1 *Information.*

Several definitions of informatics or computer science have been given, none of which is entirely satisfactory. Some people say that a science of informatics does not exist. There are mathematics and information processing technics which give the possibility of performing the algorithms defined by mathematics*. There are supporters of computer science. This science merely concerns computers and their applications. We may wonder if such a science can exist. Professor Perlis once gave me some remarks about the fact that computers are effectively a matter of science.

I shall use the term 'INFORMATICS' instead of 'COMPUTER SCIENCE', to insist on *information* which is the object of this science, and not on *computers* which are only tools for information processing.

Now, I must define more precisely information. The main lines of such a definition are well known. Let V be a variable, and E a finite set. Information is the indication of the value taken by V. in E. This definition is a classical one and may be accepted by everyone.
Nevertheless, it has important consequences. By saying that information is the *indication of the value*, and not *the value itself*, information is made a simple mark, or a label. I completely dissociate the string of characters used to realize the information, from the meaning it can bear, which is the value itself.

In other words, I can say that information is a character string, taken in a given alphabet; a string able to bring knowledge or a meaning. So I distinguish carefully the formal or syntactical aspect that I call information from the meaningful or semantic aspect, that I call knowledge. I have no other reason to do so but, noticing that this effectively happens in some fields (in the central core memory of a computer, in programming, compiling, automatic translation, pattern recognition...). I just generalize such an idea as a fundamental principle (or axiom) of informatics.

2.2 *Informatics*

I define informatics as science of information processing, but I have distinguished information from knowledge. The human brain performs a lot of 'knowledge processing'; each fact it obtains is compared to and associated with other knowledge. It may be disgarded or integrated in coordinated sets. Those who are still listening to me may compare my ideas to their own opinion and conclude that they are evident, without any interest, or entirely stupid.

Such a knowledge processing is not a matter of informatics, according to my definition of information. This science will be concerned only by manipulation of characters strings, without any reference to their meaning. We may wonder if such a manipulation has any interest for the human brain. Experience tells us that we can effectively use this processing to obtain new knowledge. There are some connections between information processing and knowledge processing.

The connections are performed by the various ways of information representation, coding, languages. In many cases, we can find grammatical rules strong enough to ensure that the syntactical form of a text implies its meaning. It is then equivalent to manipulating the character string or the meaning attached to it. An information processing brings new knowledge.

Only the methods will be different. When a man translates a French sentence into an English one, he associates mental images with the French sentence, then tells such images in English. When a compiler translates an ALGOL instruction into machine-code, it performs a syntactical analysis of the ALGOL text, then builds a machine code text syntactically equivalent; the syntactical equivalent implying the semantic equivalent. It only manipulates strings of characters, without any reference to the meaning of the algorithm written down in ALGOL.

So we cannot design a method for information processing which would not be an automatic one. Informatics cannot make any reference to the meaning of a text. All the possible grammatical structures must be foreseen, and what is to be done in each case must have been previously stated. We cannot make the right decision in case of difficulty without looking at what that means. It is the reason why the definition I give here implies this other one: informatics

* J. Kuntzmann, Où vont les mathématiques? Paris, Hermann 1967

is the science of *automatic data processing*. According to me, the word 'automatic' is redundant. The only possible information processings are automatic ones.

Automatic data processing can be performed on an appropriate machine. It is the reason why computers are so important in informatics.

Theoretically, every information processing can be done on such a machine. But some are too much sophisticated to be performed on real computers. Nevertheless, this is only a technical problem. From another angle, the computer is not an indispensable tool for information processing. Some recordings may be performed with paper and pencil: the policeman who enters in his notebook the number of a car illegally parked makes information processing: he just notes a character string, without any significance. This is a reason why I don't think that a computer is the essential fact of informatics; it is only a tool, but a particularly well-fitted one.

2.3 *The informatics method.*

Let us be given a problem of knowledge processing; the solution of this problem by informatics is generally performed in three stages.

2.3.1 Analysis

We want to process knowledge. Firstly, we must transform this knowledge into information by choosing a well-fitted coding, or an appropriate language, if the knowledge structures are to be made apparent by language structures. Coding or language must be chosen so that the form of texts implies to knowledge they produce. In many cases, numerical coding is used. This coding is so old and so frequent that it does not look like a coding, and the analysis stage is not apparent in such cases; nevertheless, it exists.

2.3.2 Algorithm.

Secondly, we must define a procedure for information processing and make it useful for informatics; it must always be expressed with a finite number of operations on finite character strings. In many cases, mathematical considerations give an abstract or theoretical algorithm; this must be transformed into a concrete algorithm, as I have just said. This is the major problem for numerical analysis (approximation).

Transformation of a problem into a numerical problem is a way of performing analysis. Mathematics says something about existence and uniqueness of a solution and gives methods in which to approach this solution. We have still to build a concrete algorithm able to give the solution in a reasonable number of operations, with a sufficiently well – known precision. This is sometimes a very difficult problem in which mathematics gives only a small aid.

In some specific cases, (such as structures in finite sets: graphs, combinatories, syntactical analysis...), a concrete algorithm is identical with an abstract algorithm. In those cases, algorithm design is purely mathematical.

In other cases (management for instance), the concrete algorithm is a direct consequence of analysis; no mathematical preparation is necessary.

2.3.3 Processing.

Having built an algorithm, we must perform it with appropriate means: paper and pencil, computer, analogue or hybrid computer... We must prove that this processing effectively performs the required algorithm. According to what has been said about information and signification, programming consists of writing an algorithm, designed at the semantic level, in a form sufficiently precise to be usable on a computer, whatever the programming language may be. It is necessary to verify the agreement between the syntactic form of the programme and the meaning it bears, syntactical correctness being only partial proof.

2.4.1 Fundamental Informatics

Informatics is a science with a specific object: information processing. It is in itself a matter of studies and research. It can be considered in a partial independance of possible applications. It must always improve its methods, make more efficient and easy its tools: programming, software, computers... Like other sciences, it must recognize in practical applications universal structures and formalize concrete situations to give abstract descriptive schemes, in order to widen the field of application.

2.4.2 Applied Informatics

Information processing can be adapted to very varied situations. It is a tool for other sciences. We know a lot of examples of informatics applications. Some are recognized without any contesting as in medical informatics, computer-aided education and information retrieval. Other applications are sometimes considered as an integral part of informatics. This is due to insufficient definition of this science.

There is an application of informatics when the method of this science, such as I have described in the previous paragraph, is used in an specific field to get results interesting in this field. In a given application, the interesting thing is not improvement of informatics methods, but the results provided by this method. For instance, the problem of analysis is, at fundamental level, a problem of properties of coding or languages.

At an applied level, it is the choice of a specific coding, or design of a new grammar fitted to a specific field of meanings which must first be defined. Such is the case for data collection in management, transformation of naturel grammar for automatic translation, design of a pattern language for pattern recognition... For these reasons I say that numerical analysis is a chapter of mathematics using informatics; in a similar way, operational research, and management are specific fields of applied informatics.

2.4.3 Connections between Fundamental and Applied Informatics

This is not a new situation. There are pure mathematics and applied mathematics, fundamental physics and applied physics. Confusion of these can be prejudicial for students. Applications are infinitely varied and diversified. Each application presumes the knowledge of the specific context in which it is developed. At the other end, fundamental informatics does not need accurate knowledge of those contacts. This gives very different aspects to courses in the two fields.

The distinction between these two aspects is fundamental for education, but does not lead to deep separation between them, as has happened in France during several years between pure and applied mathematics. Applications can become more and more efficient only by advancement of fundamental informatics. Fundamental informatics can get new ideas and new problems to be solved only by the study of various applications.

Fundamental and applied informatics are like both sides of a coin; they are absolutely distinct and indivisible without killing informatics itself.

2.5 *Connections with other sciences.*

Informatics has a specific object which does not belong to any other science: information, according to the previous definition, and information processing, but it is not independant of others. Comparison with other sciences will state more precisely connections between informatics and mathematics or physics.

Physics observes phenomena, builds abstract models of these phenomena, and uses mathematics for their study. In the same way, informatics builds models, creates structures for information and processing. Mathematics is useful for models or structures study. Some physicists can themselves perform a mathematical study of models, but they always do so with a 'physical mind' and results are sometimes suspect (remember the y Dirao-Delta function').

Mathematicians are interested in some problems extracted from physics: potential or relativity... Some books of mathematical methods for physicists have been published, e.g., Courant and Hilbert, Morse and Fescbach, etc...

We have already some books of mathematics for informatics (Finite mathematics, etc.). Language theory is a difficult chapter of mathematics and we must be careful in respect of the real difficulty which is having good mathematics useful to informatics. But physics is not a chapter of mathematics. For these reasons, I say that informatics is not a chapter of mathematics.

Connection of informatics with other sciences may be compared with the connection of mathematics. Like pure mathematics, informatics is a matter of research in itself. Like applied mathematics, informatics is a matter of research in itself. Like applied mathematics, it is a tool for other sciences. It does not bring the same services as mathematics, as informatics is more than automatic calculus.

Simulation is a very powerful method, different from mathematical modeliation. Files manipulation is another important application of informatics. In many cases, practical calculus is a difficult thing without any mathematical problem. The correct use of a computer is a matter of informatics, not of mathematics.

3. INFORMATICS EDUCATION

3.1 *General situation*

At the present time, the situation of informatics in schools and universities in not very well defined; it varies from country to another. I shall speak only of what is done in France.

At first, we had courses of numerical analysis, with technical details on computers and programming; they were given as courses in applied mathematics. Today, the informatics department, when it exists, is still a part of the department of applied mathematics.

Nevertheless, it was evident from the beginning that informatics could not be reduced to a chapter of mathematics. For instance, many theses in informatics cannot be considered as mathematical ones, and appreciated with criteria of this science. We cannot ask all our students to know Hilbert spaces or topological vector spaces theories.

We had FORTRAN or ALGOL short courses for users of computers. It appeared that this was not valuable as a course of informatics. It is just an aid for those who are able to analyze a problem and build an algorithm. Even in this case, it leads to misuse of computers. The essential thing is to give users a way of understanding of what informatics is and what aid it can bring.

For these reasons, we developed informatics as an autonomous science. In some universities there is teaching of informatics, distinct from courses on mathematics or electronics. This is, in fact, fundamental informatics teaching.

In October 1968, we began to develop courses in applied mathematics (Paris University) for some thousand students of various disciplines (from mathematics to geography or economics).

This situation is not conforming to what I have just said about informatics. This new science must be taught as such at various levels, by specific professors, just as is done for mathematics. It is only for historical reasons that many professors of informatics are, at the present time, mathematicians or physicists. It is in fact a difficulty for the proper development of this science.

I shall briefly consider three levels for informatics education.

3.2 *Informatics for everybody*

All other sciences are present in secondary schools (mathematics, astronomy, geology, physics, etc.) and this is sufficient reason for introducing informatics in these schools, but I think that there are more serious arguments.

The problem is not to say something on an important technic; there are too many technics to say something of each of them. From another viewpoint, it is not necessary to immediately start to prepare the formation of informaticists. Experience shows that we can get good results with university courses alone.

Informatics is a specific way of looking at and processing information. It is a very important discussion on languages, as a representation of knowledge and connection between syntax and semantics. It certainly gives an aid to the development of thought and of expression.

According to the previous scheme, it is necessary to begin with examples in which the semantic aspect is simple and very well known, to bring an accent on the syntactic aspect. The important thing is not what to say, but how to say it. Algorithms of calculus, (multiplication, devision, square root, Euclid algorithm, binary or octal numeration) can give very efficient exercises in connection with mathematics courses. They are essentially concrete and practical exercises. Reading organigrams or little programmes in appropriate languages is an easy thing even for young pupils. It is not evident that writing such programmes could be possible. Some organigrams in the field of syntactical analysis of simple expressions could give some ideas on relations between syntactical structures and semantics, just as Latin courses did. I do not know if courses on computers are requisite or useful at this level.

At a higher level, every university student must have some general courses on applied informatics, since he may become a user of this science; informatics being at least as useful as mathematics in other sciences. These courses must not be restricted to numerical calculus, which is only a particular part of information processing. They must show the exact nature of informatics and present the difficult problem of analysis. Some courses on computers are indispensable to give a right view of what they can do.

3.3 *Applied Informatics*

For specific applications, informatics must be taught in the main disciplines to students interested by this new discipline. Such is the case in medicine, economics, linguistics, history and, naturally, in physics, chemistry, biology, mathematics (why not?). Applied informatics courses must not be restricted to numerical analysis, but include something about information and its representations, data structures, computers and their languages (machine or assembly languages), algorithmic languages. In each specific field, practical works are chosen in the context familiar to students. These works are an introduction to an analysis, since it seems impossible at the present time to give courses on this subject. The importance of assembly language must not be minimized. A good intelligence of what informatics is and what it can do is impossible without a good knowledge of computers which gave rise to this science. Even if students will never use such a language, they must know one. The experience gained in Paris in 1968-1969 has been very fruitful.

Management is, in my opinion, a matter of applied informatics. It consists of the conjunction of two types of courses. On one side, there are courses on economics, management, administration. On the other side, there is very wide field of applied informatics. To general courses as previously described we must add courses on big computers: input-output systems, backing storages (tapes, drums, disks...), files, and all the connected problems (labelling, maintenance, access control and security...), programming systems (overlay, file-oriented systems, commercial languages, data banks, remote access...). This is a very important part of management, even if the mathemetical aspect is a very small one. It remains a particular case of applied informatics.

3.4 *Fundamental Informatics.*

Fundamental informatics concerns a more restricted public than applied informatics. We have a deeper experience of this field, which has been taught in France for several years (Paris, Grenoble, Toulouse). Its actual curriculum merely consists of:

3.4.1 Information and its representation

3.4.2 Mathematical background: algebraic structures (finite sets theory, monoid..) combinatories, arithmetic, coding theory. Some courses on numerical analysis operational research, are typical examples of mathematical studies bringing algorithms.

3.4.3 Formal languages theory.

3.4.4 Algorithmic methods and their languages: Algol, Lisp, simulation...

3.4.5 Computers and their languages from the functional point of view

3.4.6 Hardware (general considerations. This is not an advanced course).

3.4.7 Software and operating systems. Input-output supervisors.

3.4.8 Compiling problems. Syntactical analysis. Memory allocation.

These are only main guidelines of a curriculum. Each point is given at a general level. It may be developed for specialists. The importance of a mathematical background depends on specialization. Informatics is at an observation and experimental stage. We must collect concrete experiences in various fields (software for instance) from which we may recognize general structures or concepts, then design abstract models giving new realizations. This is the general growth process of every science. At first, spectros – copy consisted of photographing spectra. From collections of spectra, general laws were inferred, verified by new experiences. No spectroscopy is a powerful means for matter-structure studies.

Actually, we need experimenters very familiar with computers, working on difficult programming problems: files, backing storage management, operating systems, multiprocessing, programmes testing... Their mathematical knowledge may be rather slight, as with chemists for instance (it is different, essentially based on algebra). Things will change. As any other science, informatics will use more and more mathematics.

The curriculum I have presented here is not accurate agreement with what I have said of informatics. There are only few things about the precise nature of informatics, the part of languages as transforming data into information (this is given only for some specific applications, as pattern recognition, artificial intelligence, automatic translation).

3.5 *Critical points*

Some points are still very difficult to teach: analysis, software, practical programming, as it appears in various applications.

For all these problems, we have no mathematical description no general concepts nor structures. In my opinion, the exact nature of these problems was not clear enough, but is more apparent by the definition of informatics as I have given it here.

Analysis is not generally presented as a transformation of semantics into a syntactical written form. We speak of data collection in management. In fact, what is collected is not information, but pieces of knowledge, coded by use of specific sheets, the answer to questions being the codification transforming knowledge into information. In all cases, it remains a problem of codification, as it was for programming at the beginning.
Using some specific language with appropriate grammar could simplify data collection and reduce the rate of mistakes.

The difficulty with software is the same. We did not make evident the semantic concepts and the associated syntax. A more precise description of things manipulated by systems could give more efficient presentation of systems. There are some experiences of system oriented languages. They are only built for simplification of system programming. We need a correct semantics of systems.

The more difficult problems of effective programming are of the same type. Using assembly languages makes unapparent the fundamental concepts in each application, and the way of giving them an adequate formal representation. We have no possibility of describing all the possible applications to students. We have no general way of approaching these problems.

I think that the solution of such difficulties is to study the representation of knowledge by information. If what I have said about informatics is correct (I am not at all sure of it!) we have a general line of research for analysis. It may lead to important improvements in computer education. It may also lead nowhere. The future will tell us where the truth lies.

TEACHING CHILDREN THINKING

Seymour Papert

1. INTRODUCTION

This paper is dedicated to the hope that someone with power to act will one day see that contemporary research on education is like the following experiment by a nineteenth century engineer who worked to demonstrate that engines were better than horses. This he did by hitching a 1/8 HP motor in parallel with his team of four strong stallions. After a year of statistical research he announced a significant difference. However, it was generally thought that there was a Hawthorne effect on the horses.

The phrase 'technology and education' usually means inventing new gadgets to teach the same old stuff in a thinly disguised version of the same old way. Moreover, if the gadgets are computers, the same old teaching becomes biased towards its dullest parts, namely the kind of rote learning in which measurable results can be obtained by treating the children like pigeons in a Skinner box.

The purpose of this essay is to present a grander vision of an educational system in which technology is used not in the form of machines for processing children but as something the child himself will learn to manipulate, to extend, to apply to projects, thereby gaining a greater and more articulate mastery of the world, a sense of the power of applied knowledge and a self-confidently realistic image of himself as an intellectual agent. Stated more simply, I believe with Dewey, Montessori and Piaget that children learn by doing and by thinking about what they do. And so the fundamental ingredients of educational innovation must be better things to do and better ways to think about oneself doing these things.

I claim that computation is by far the richest known source of these ingredients. We can give children unprecedented power to invent and carry out exciting projects by providing them with access to computers, with a suitably clear and intelligible programming language and with peripheral devices capable of producing on-line real-time action.

> Examples are: spectacular displays on a color scope, battles between computer controlled turtles, conversational programs, game-playing heuristic programs, etc. Programmers can extend the list indefinitely. Others can get the flavor of the excitement of these ideas from movies I shall show at the IFIPS meeting.

Thus in its embodiment as the physical computer. computation opens a vast universe of things to do. But the real magic comes when this is combined with the conceptual power of theoretical ideas associated with computation.

Computation has had a profound impact by concretizing and elucidating many previously subtle concepts in psychology, linguistics, biology, and the foundations of logic and mathematics. I shall try to show how this elucidation can be projected back to the initial teaching of these concepts. By doing so much of what has been most perplexing to children is turned to transparent simplicity; much of what seemed most abstract and distant from the real world turns into concrete instruments familiarly employed to achieve personal goals.

> Mathematics is the most extreme example. Most children never see the point of the formal use of language. They certainly never have the experience of making their own formalism adapted to a particular task. Yet anyone who works with a computer does this all the time. We find that terminology and concepts properly designed to articulate this process are avidly seized by the children who really want to make the computer do things. And soon the children have become highly sophisticated and articulate in the art of setting up models and developing formal systems.

The most important (and surely controversial) component of this impact is on the child's ability to articulate the working of his own mind and particularly the interaction between himself and reality in the course of learning and thinking. This is the central theme of this paper, and I shall step back at this point to place it in the perspective of some general ideas about education. We shall return later to the use of computers.

2. THE DON'T-THINK-ABOUT-THINKING PARADOX

It is usually considered good practice to give people instruction in their occupational activities. Now, the occupational activities of children are learning, thinking, playing and the like. Yet, we tell them nothing about those things. Instead, we tell them about numbers, grammar and the French revolution; somehow hoping that from this disorder the really important things will emerge all by themselves. And they sometimes do. But the alienation-dropout-drug complex is certainly not less frequent.

In this respect it is not a relevant innovation to teach children also about sets and linguistic productions and Eskimos. The paradox remains: why don't we teach them to think, to learn, to play? The excuses people give are as paradoxical as the fact itself. Basically there are two. Some people say: we know very little about cognitive psychology; we surely do not want to teach such half-baked theories in our schools!

And some people say: making the children self-conscious about learning will surely impede their learning. Asked for evidence they usually tell stories like the one about a millipede who was asked which foot he moved first when he walked. Apparently the attempt to verbalize the previously unconscious action prevented the poor beast from ever walking again.

The paradox is not in the flimsiness of the evidence for these excuses. There is nothing remarkable in that: all established doctrine about education has similarly folksy foundations. The deep paradox resides in the curious assumption that our choice is this: **either** teach the children half-baked cognitive theory **or** leave them in their original state of cognitive innocence. Nonsense. The child does not wait with a virginally empty mind until we are ready to stuff it with a statistically validated curriculum. He is constantly engaged in inventing theories about everything, including himself, schools and teachers. So the real choice is: **either** give the child the best ideas we can muster about cognitive processes **or** leave him at the mercy of the theories he invents or picks up in the gutter. The question is: who can do better, the child or us?

Let's begin by looking more closely at how well the child does.

3. THE POP-ED CULTURE

One reads in Piaget's books about children re-inventing a kind of Democritean atomic theory to reconcile the dissappearance of the dissolving sugar with their belief in the conservation of matter. They believe that vision is made possible by streams of particles sent out like machine gun bullets from the eyes and even, at a younger age, that the trees make the wind by flapping their branches. It is criminal to react (as some do) to Piaget's findings by proposing to teach the children 'the truth.' For they surely gain more in their intellectual growth by the act of inventing a theory than they can possibly lose by believing, for a while, whatever theory they invent. Since they are not in the business of making the weather, there is no reason for concern about their meteorological unorthodoxy. But they are in the business of making minds – notably their own – and we should consequently pay attention to their opinions about how minds work and grow.

There exists amongst children, and in the culture at large, a set of popular ideas about education and the mind. These seem to be sufficiently widespread, uniform and dangerous to deserve a name, and I propose **The Pop-Ed Culture.** The following examples of Pop-Ed are taken from real children. My samples are too small for me to guess at their prevalence. But I am sure very similar trends must exist very widely and that identifying and finding methods to neutralize the effects of Pop-Ed culture will become one of the central themes of research on education. Examples of Pop-Ed thinking are:

(a) **Blank-Mind Theories.** Asked how one sets about thinking a child said: 'make your mind a blank and wait for an idea to come.' This is related to the common prescription for memorizing: 'keep your mind a blank and say it over and over'. There is a high correlation, in my small sample, between expressing something of this sort and complaining of inability to remember poetry!

(b) **Getting-It Theories.** Many children who have trouble understanding mathematics also have a hopelessly deficient model of what mathematical understanding is like. Particularly bad are models which expect understanding to come in a flash, all at once, ready made. This binary model is expressed by the fact that the child will admit the existence of only two states of knowledge often expressed by 'I get it' and 'I don't get it.' They lack-and even resist-a model of understanding something through a process of additions, refinements, debugging and so on. These children's way of thinking about learning is clearly disastrously antithetical to learning any concept that cannot be acquired in one bite.

(c) **Faculty Theories.** Most children seem to have, and extensively use, an elaborate classification of mental abilities: 'he's a brain', 'he's a retard', 'he's dumb', 'I'm not mathematical-minded' The disastrous consequence is the habit of reacting to failure by **classifying** the problem as too hard, or oneself as not having the required aptitude, rather than by **diagnosing the specific deficiency** of knowledge or skill.

4. COMPUTER SCIENCE AS A GRADE SCHOOL SUBJECT

Talking to children about all these bad theories is almost certainly inadequate as an effective antidote. In common with all the greatest thinkers in the philosophy of education I believe that the child's intellectual growth must be rooted in his experience. So I propose creating an environment in which the child will become highly involved in experiences of a kind to provide rich soil for the growth of intuitions and concepts for dealing with thinking, learning, playing, and so on. An example of such an experience is writing simple heuristic programs that play games of strategy or try to outguess a child playing tag with a computer controlled 'turtle'.

Another, related example, which appeals enormously to some children with whom we have worked is writing teaching programs. These are like traditional CAI programs but conceived, written, developed and even tested (on other children) by the children themselves.

(Incidentally, this is surely the proper use for the concept of drill-and-practice programs. Writing such programs is an ideal project for the second term of an elementary school course of the sort I shall describe in a moment. It is said that the best way to learn something is to teach it. Perhaps writing a teaching program is better still in its insistance on forcing one to consider all possible misunderstandings and mistakes. I have seen children for whom **doing** arithmetic would have been utterly boring and alienated become passionately involved in writing programs to teach arithmetic and in the pros and cons of criticisms of one another's programs like: 'Don't just tell him the right answer if he's wrong, give him useful advice.' And discussing what kind of advice is useful' leads deep into understanding both the concept being taught and the processes of teaching and learning.)

Can children do all this? In a moment I shall show some elements of a programming language called LOGO, which we have used to teach children of most ages and levels of academic performance how to use the computer. The language is always used 'on-line', that is to say the user sits at a console, gives instructions to the machine and immediately gets a reaction. People who know languages can think of it as 'baby LISP', though this is misleading in that LOGO is a full-fledged universal language. Its babyish feature is the existence of self-contained sub-sets that can be used to achieve some results after ten minutes of instruction. Our most extensive teaching experiment was with a class of seventh grade children (twelve year olds) chosen near the average in previous academic record. Within three months these children could write programs to play games like the simple form of NIM in which players take 1, 2, or 3 matches from a pile; soon after that they worked on programs to generate random sentences – like what is sometimes called concrete poetry – and went on from there to make conversational and teaching programs. So the empirical evidence is very strong that we can do it, and next year we shall be conducting a more extensive experiment with fifth grade children. The next sections will show some of the elementary exercises we shall use in the first weeks of the course. They will also indicate another important aspect of having children do their work with a computer: the possibility of working on projects with enough duration for the child to become personally-intellectually and emotionally-involved. The final section will indicate a facet of how more advanced projects are handled and how we see the effects of the kind of sophistication developed by the children.

5. YOU CAN TAKE THE CHILD TO EUCLID' BUT YOU CAN'T MAKE HIM THINK

Let's go back to Dewey for a moment. Intellectual growth, he often told us, must be rooted in the child's experience. But surely one of the fundamental problems of the school is how to extend or use the child's experience. It must be understood that 'experience' does not mean more busy work: two children who are made to measure the areas to two triangles do not necessarily undergo the same experience. One might have been highly **involved** (e;g; anticipating the outcome, being surprised, guessing at a general law) while the other was quite **alienated** (the opposite). What can be done to involve the mathematically alienated child? It is absurd to think this can be done by using the geometry to survey the school grounds instead of doing it on paper. Most children will enjoy running about in the bright sun. But most alienated children will remain alienated. One reason I want to emphasize here is that surveying the school grounds is not a good research project on which one can work for a long enough time to accumulate results and become involved in their development. There is a simple trick, which the child sees or does not see. If he sees it he succeeds in measuring the grounds and goes back to class the next day to work on something quite different.

Constrast this situation with a different context in which a child might learn geometry. The child uses a time-shared computer equipped with a CRT. He programs on-line in a version of the programming language LOGO, which will be described in more detail below.

On the tube is a cursor point with an arrow indicating a direction. The instruction

```
FORWARD 100
```

causes the point to move in the direction of the arrow through 100 units of distance. The instruction

```
ROTATELEFT 90
```

causes the arrow to rotate 90°.

The child knows enough from previous experience to write the following almost self-explanatory program:

```
TO CIRCLE
FORWARD 1
ROTATELEFT 1
CIRCLE
END
```

The word 'TO' indicates that a new procedure is to be defined, and it will be called 'CIRCLE'. Typing

```
CIRCLE
```

will now cause the steps in the procedure to be executed one at a time.

Thus:

1st Step:	FORWARD 1	The point creeps ahead 1 unit.
2nd Step:	ROTALEFT 1	The arrow rotates 1°.
3rd Step:	CIRCLE	This is a recursive call; naturally it has the same effect as the command CIRCLE typed by the child. That is to say, it initiates the same process:
1st Step:	FORWARD 1	The point creeps on, but in the new, slightly different direction.
2nd Step:	ROTALEFT 1	The arrow now makes an angle of 2° with its initial direction.
3rd Step:	CIRCLE	This initiates the same process all over again. And so on, forever.

It is left as a problem for the reader to discover why this point will describe a circle rather than, say, a spiral. He will find that it involves some real geometry of a sort he may not yet have encountered (See answer at end of paper). The more immediately relevant point is that the child's work has resulted in a certain happening, namely a circle has appeared. It occurs to the child to make the circle roll? How can this be done? A plan is easy to make:

Let the point go round the circle once.
Then FORWARD 1
Then repeat.

But there is a serious problem! The program as written causes the point to go round and round forever. To make it go just once round we need to give the procedure an **input** (in more usual jargon: a variable).

This **input** will be used by the procedure to remember how far round it has gone. Let's call it 'DEGREES' and let it represent the number of degrees still to go, so it starts off being 360 and ends up 0. The way this is written in LOGO is:

```
TO CIRCLE: DEGREES        :DEGREES means: the thing whose name is 'DEGREES'.
IF :DEGREES = 0 STOP
FORWARD 1
ROTATELEFT 1
CIRCLE :DEGREES - 1       Each time round the number of degrees
                          remaining is reduced by 1.
END
```

Now we can use this as a sub-procedure for ROLL:

```
TO ROLL
CIRCLE 360
FORWARD 10
ROLL
END
```

Or, to make it roll a fixed distance:

```
TO ROLL :DISTANCE
IF :DISTANCE = 0 STOP
CIRCLE 360
FORWARD 10
ROLL :DISTANCE - 1
END
```

Or we can make the circle roll around a circle:

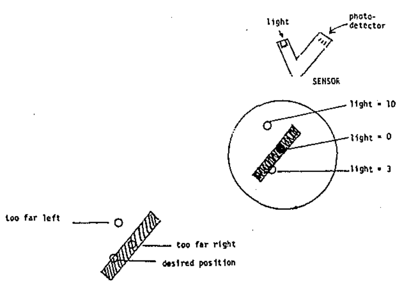
```
TO FUNNYROLL
CIRCLE 360
FORWARD 10
ROTALEFT 10
FUNNYROLL
```

These examples will, if worked on with a good dose of imagination, indicate the sense in which there are endless possibilities of creating even more, but gradually more, complex and occasionally spectacularly beautiful effects. Even an adult can get caught up in it! Not every child will. But if he does, the result is very likely to be a true extension of his experience in Dewey's sense. And evidence is accumulating for the thesis that there is scarcely any child who cannot be involved in some computational project.

The next two sections will discuss two other peripheral devices suitable for a computation laboratory in an elementary school: a programmable vehicle and a music generator. There is, of course, no end to what one could invent. At M. I. T. we are thinking in terms of soon adding mechanical manipulators, psychedelic light shows in a reactive environment, apparatus for automated experiments in animal psychology, etc., etc., etc.,

6. THE LOVE OF THE TURTLE

At M.I.T. we use the name 'Turtle' for small computer controlled vehicles, equipped with various kinds of sense, voice and writing organs. Turtles can be controlled by the same commands used in the previous section to describe Graphics. They can be made to draw or to move about without leaving a visible trace. Procedures to achieve this are exactly like the procedures for CRT Graphics. However sense organs allow another interesting dimension of work. An interesting simple one is a reflectivity sensor held close to the floor. A LOGO operation called 'LIGHT' has an integer value between 0 and 10, depending on the relfectivity of the surface. Suppose we wish to program the turtle to follow the left edge of a black line on a white floor. Using an important heuristic we encourage the child to study himself in the situation, and try to simulate his own behavior. The key idea, of course is to use feed-back according to the following plan:



COLOR	LIGHT	POSITION ERROR	CORRECTION
Mainly Black	small value	Too far right	ROTATELEFT
Equal Black & White	5	O.K.	Nothing
Mainly White	big value	left	ROTATERIGHT.

This leads to the procedure:

```
TO WALK
IF LIGHT < 4          ROTATELEFT
IF LIGHT > 6          ROTATERIGHT
FORWARD 1
WALK
END.
```

Notice that the child can think of the program as a very simple formal model of himself, or, indeed, more justly, of a moth flying to a light. It is rare that children in the traditional context of math-science get a chance to develop a model so simple.

Turtles with touch, interactive behavior with several turtles. Searching mazes, and so on scarcely scratch the surface of what can be done with these beasts.

7. MUSIC

Just as the computer can be instructed to move a point on a TV display or make a turtle move or print a word, it can be instructed to sing a note. The LOGO instruction SING followed by an input to indicate a note (represented by 1 ... 7) or a time. A program can be written thus:

```
TO MARY
SING 3
SING 2
SING 1
SING 2
SING 3
SING 3
END
```

The command

```
MARY
```

will cause the computer to sing the tune.

The program

```
TO CHANTMARY
MARY
CHANTMARY
END
```

Will cause the tune to be played over and over again Similarly programs can be written to change the tune: speedup, Slowdown, transpose etc. on to combine several voices. A child can use this as an instrument to aid composition: he will hear his creation played perfectly according to his instructions. He can make small changes, experimenting, with their effects. He can incorporate music with other programs making the turtle or a picture display move to music and so on.

8. CASE HISTORIES FORM THE MUZZEY Jr. HIGH SCHOOL EXPERIMENT

The following piece is extracted verbatim from a report on the seventh grade teaching experiment performed at Muzzey Jr. High School at Lexington.

8.1 *Problem vs. Project*

The most exciting single aspect of the experiment was that most of the children acquired the ability and motivation to work on projects that extend in time over several days, or even weeks. This is in marked contrast with the usual style of work in mathematics classes, where techniques are taught and then applied to small repetitive exercise problems. It is closer, in ways that are essential to the later argument here, to the work style of some art classes where children work for several weeks on making an object; a soapcarving for example. The similarity has several dimensions. The first is that the duration of the process is long enough for the child to become involved, to try several ideas, to have the experience of putting something of oneself in the final result, to compare one's work with that of other children, to discuss, to criticise and to be criticised on some other basis that 'right or wrong.' The point about criticism is related to a sense of creativity that is important in many ways which we shall talk about later-including, particularly, its role in helping the child develop a healthy self-image as an active intellectual agent.

Let's take an example. A continuing project over the last third of the year was working on various kinds of 'language generating' programs. The children studied a program (given as a model) which generated two word sentences like:

CATS RUN
DOGS SHOUT
CHILDREN BITE
DOGS RUN
CATS RUN
.
.
.

The assignment was to study the model and go on to make more interesting programs. The sample printout that follows brought great joy to its creator who had worked hard on mastering the mathematical concepts needed for the program, on choosing sets of words to create an interesting effect and on converting her exceedingly vague (and unloved) knowledge about grammar into a useful, practical form.

INSANE RETARD MAKES BECAUSE SWEET SNOOPY SCREAMS SEXY WOLF LOVES THATS WHY THE SEXY LADY HATES UGLY MAN LOVES BECAUSE UGLY DOG HATES
MAD WOLF HATES BECAUSE INSANE WOLF SKIPS SEXY RETARD SCREAMS THATS WHY THE SEXY RETARD HATES THIN SNOOPY RUNS BECAUSE FAT WOLF HOPS
SWEET FOGINY SKIPS A FAT LADY RUNS

The next class assignment was to generate mathematical sentences which were later used in 'teaching programs.' For example:

8*BOX ½ 6 = 48
WHAT IS BOX?

Finally, in the last weeks, someone in the class said she wanted to make a French sentence generator... for which she spurned advice and went to work. In the course of time other children liked the idea and followed suit – evoking from the first girl prideful complaints like 'why do they all have to take my idea?' The interesting feature was that although they took her idea, they imprinted it stongly with their own personalities, as shown by the following case studies:

K.M. The girl who initiated the project. Thoughtful, serious about matters that are important to her, often disruptive in class. Her approach to the French project was to begin by writing procedures to conjugate all the regular verbs and some irregular ones. The end of the school year fell before she had made a whole sentence competence at conjugating – e.g. given VOUS and FINIR as inputs it would reply: VOUS FINISSEZ.

M.R. A gay, exuberant girl, who made the 'SEXY COMPUTER' program quoted above. Only half seriously she declared her intention of making the first operational French sentence generator. In a sense she did – but with cavalier disregard for the Academy's rules of spelling and grammar!

J.C. A clear mind with a balanced sense of proportion. Deliberately decided to avoid the trap of getting so involved with conjugation that no sentence would ever be generated.
Too serious to allow his program to make mistakes. Found a compromise: he would make a program that knew only the third person – but was still non-trivial because it did know the difference between singular and plural as well as the genders: thus it would say.

LE BON CHIEN MANGE
but
LES BONNES FILLES MANGENT.

8.2 *A Detail from a Child's Mathematical Research Project*

The fine texture of the work on projects of this sort can only be shown by case studies. The following vignette needs very little reference to LOGO-thus illustrating how the projects are more than programming.

J is the author of the last French program mentioned. A little earlier he is working on generating equations as part of a project to make 'a program to teach 8 th grade algebra.' He has perfected a program to generate equations with co-efficients in the range of 0-9 using a 'random' number generator. His present problem is to obtain larger coefficients.

First Solution: Almost everyone tries this: get bigger numbers by adding smaller ones obtained from the old procedure. Amongst other considerations, this looks like a good technique that has often paid well: use old functions to define new ones.

Consequences: J chooses his equation generator but soon finds some annoying features:

The new coefficients are in the range 0-18, which is unnatural and not very big.
There is a preference for some numbers e.g. 9 comes up ten times as often as 18!

Comment: The first problem can be alleviated by adding more numbers. One can even add a random number of random numbers.
But this aggravates the second problem. J understands this qualitatively but does not see a way out. It is interesting that children and adults often have a resistance to making numbers by 'non-numerical' operations.
In this case the solution is to concatenate the single digit random numbers instead of adding them. LOGO has a simple way to express this and J is quite accustomed to making non-numerical strings by concatenation. In fact this is how he makes the equation! **Nevertheless he resists.**
The problem is discussed in a class meeting and after some prompting everyone suddenly 'discovers' the solution.

New Solution: J changes his program, now making numbers up to 99 by concatenation; he does some crude check of uniformity of distribution and tries his program.

Disaster: For a while it seems to go well. But in the course of playing with the 'teaching program' a user types 5 and is surprised to get a reply like:

> You knucklehead; You took 11 seconds and your answer is wrong. The answer is 05. Here is some advice...etc.

Comment: Poor J will get the sympathy of every mathematician who must at some stage have tried to generalize a result by extending the domain of an innocent looking function only to find that the extended function violates some obscure but essential condition. He is also in the heart of the problem of representation. Is '05' a good representation? Yes, no... have your choice but face the consequences and be consistent. J's problem is that his procedures accept '05' for arithmetic operations but not for the test of identity!

Solution: Change the identity test or peel off the leading zero. J chose the latter. His program worked for a while and was used, in ways that we shall see, to great effect.

New step: Later J was urged to allow negative numbers. He found a good way: use the one digit random number generator to make a binary decision:

> if less than 5, positive; Otherwise, negative.

That Problem Again: J had a program working perfectly with negatives. Then one day decided to make it more symmetrical by using +5 and -5 for positive and negative. This brought him back to the old problems raised by differences between the machine's representation and the human user's. At this point the year ended with J's program not quite as effective as it had been at its peak.

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MATHEMATICAL LEARNING MODELS AS TOOLS FOR COMPUTER ASSISTED INSTRUCTION

Gerrit C. van der Veer

1. INTRODUCTION

In a certain educational situation, a mathematical model can be used to describe a mechanism which could display the same behaviour as a human subject.

My strategy is that the best model for the theory of learning is the model that best describes the actual learning behaviour, including verbal reports from the pupil.

Given a particular situation and the actual history of stimuli and responses of the subject, a mathematical teaching model can give the probability that the pupil is in one of a number of states, for instance, perceptive or non-perceptive. With the help of these probabilities, we can make a decision for the selection of the next item that is optimal according to some criterion.

In general, the various models give different sets of probabilities for the same situation and, in this way, lead to different decisions.

The best model for the efficiency of the teaching situation° is the model that in fact gives the least loss according to the criterion. When we give the computer a model to base its decision upon, we look for this most efficient teaching model.

The teaching situation may differ:

(1) Sometimes it is useful to divide the material into a number of levels, each of which can only be learnt after the foregoing has been mastered. This is the case in some types of problem-solving such as mathematical proofs. In this situation the aim is mostly the end result; the mastering of the highest level.

(2) Another structure can be seen, e.g., in the course of learning to translate from one language into another. Here a number of items are learnt more or less simultaneously. Hardly anybody ever reaches the level of perfect translation of all words from English into Dutch, but the aim of the English lesson in our Dutch school system is to give the pupils the best average probability of correct translation, and, in order to achieve that end, a large number of words and phrases are learnt simultaneously.
Another example of the same structure is learning the style of famous artists. Occasionally one sees a picture made by some particular artist and one learns his name. After some time, one is able to correctly guess the name of the painter when seeing his picture for the first time. We have concepts of the style of a number of artists. For most people this learning process never ends.

When we want to give each kind of situation the optimal treatment, we will have to divide the material into homogeneous parts. We should start with simple homogeneous pieces of teaching material. A special purpose computer terminal has just been finished, with the help of which we will do a lot of experiments. We have already made some interesting comparisons.

2. FIVE MODELS

2.1 *All-or-none model*

The pupil is either in state NL (not learned)
or in state L (learned)
definition of L: p(correct resp.) = 1
NL: p(correct resp.) = g
(from „guess", for instance 1/number of alternatives).
Transition probabilities on every trial:
state before giving new answer:
state after prior trial

L	1	0
NL	θ	1-θ

θ and g can be estimated from the data.

2.2 *Linear model: one parameter*

P_i is the probability of an incorrect response on trial i, $1>P_i>0$.
$P_i + 1 = \alpha \times P_i$, $1>\alpha>0$
where α is the learning parameter.
The probability of an incorrect response decreases on every trial with a constant factor α. From actual data we can estimate P_1 and α.

2.3 *Linear model: two parameters.*

$P_{i+1} = \alpha_1 \times P_i$, if response i was wrong,
$\alpha_2 \times P_i$, if response i was right.
Model two is a special case of model 3, and is simpler to handle.
We prefer model 2, if it is not significantly inferior to model 3.

2.4 *Urn model: one parameter*

P_i is the probability of an incorrect response on trial i.
$P_{i+1} = P_i - \alpha$ $1>\alpha>0$
In this model, the response situation is compared to an urn with black and white balls. One ball is drawn at random from the urn.
If it is a black one, an incorrect response is given. When it is a white one, a correct response is given. After every trial a number n of black balls is replaced by white ones. P is the proportion of black balls, α is the proportion of balls replaced. It is possible to think of the white and black balls in terms of right and wrong memory-traces, or memory-connections, whatever that may be.

2.5 *Urn model, two parameters*

$P_{i+1} = P_i - \alpha_1$, if response i was wrong
$P_i - \alpha_2$, if response i was right.
Both urn models are special cases of the general idea of urn models, with the restriction that the total number of balls in the urn remains constant.

According to common sense we may expect that every kind of learning process has its own model which describes it best, and perhaps gives optimal decisions. So,e.g., problem solving might go on according to the all-or-none model, paired associates according to the urn model. (A red ball is a new good connection; a black ball a false connection for instance). Concept learning seems to be like

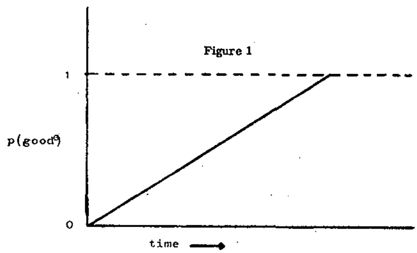

Figure 1

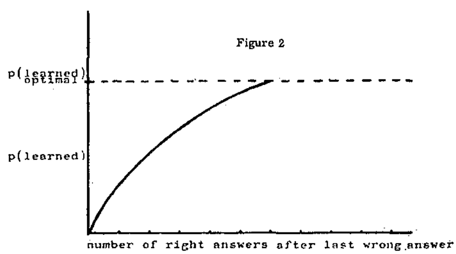

Figure 2

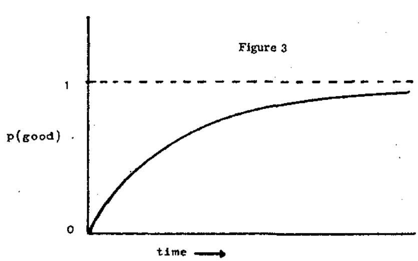

Figure 3

a linear model. Therefore it is necessary to make a separate comparison of the models and the decision rules for each kind of learning process.

3. FIRST EXPERIMENT

Our first experiment uses material that is organized in levels, each of which has to be mastered before the following can be entered. The learning task is a sort of problem solving, and we have done a preliminary study with first-year university students. We plan to continue this experiment with children of about nine years of age; the material used will be mathematics.

3.1 The urn model gives use the opportunity of determining exactly on which trial the subject has mastered the material of one level.

The urn models give the following learning curve: where p_1, α or p_1, α_1 and α_2 are significant to give P (good).

When P (good) becomes 1, the optimal point to go to the next level is arrived at.

In case of models which give no exact determination of the moment the material is learnt, we may sometimes compute the probability of having mastered the level.

3.2 The all-or-none model says in this case: when the answer is wrong, the p (learnt) = 0 otherwise p (learnt) is a function of number of good answers after the last wrong answer.

The strategy the teacher or the computer has to follow is to go to the next level if:
p (perfectly learnt) x cost (useless, superfluous trial)>
p (not learnt) x cost (calling for personal assistance from teacher because the learning process gets stuck)
When somebody (from the Ministry of Education, e.g.) has given actual values to these pay-offs, you can simply find the optimal value of p (perfectly learnt) to switch to the next level.

3.3 In the case of a linear model you can say:

The curve never reaches one, so there never will be a useless item.

In a preliminary study, we compared the all-or-none model and the linear model and we found that the all-or-none model describes the data better than the linear models. We found the all-or-none model to be superior to the linear model with a likelihood ratio of 16 to 1 and 125 to 1 for two levels.

At the third level, everybody answered correctly to the second item. For each model it is necessary to estimate the parameters. That is only possible if we assume these to be equal for a whole population of pupils. Otherwise we would have to teach them the material first in order to estimate the parameters necessary for teaching them optimally. We may make a crude test to see whether learning parameters are actually different between subjects. If every subject has its own set of parameters, it is reasonable to expect that someone who learns quickly at one level, will also learn quickly at another level. We calculated the correlation coefficient between learning speed (= number of items before last incorrect response) at the three levels, and found that the correlation coefficients for 40 individuals were -.31, +.08 and -.07 which suggests that parameters do not vary much over subjects, so that we may use the same parameters for the whole group. We will later duplicate the experiment for the nine-year-old children, and compare the all-or-none model with the urn model strategies.

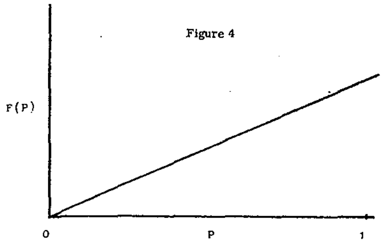

Figure 4

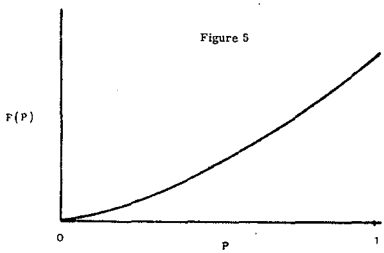

Figure 5

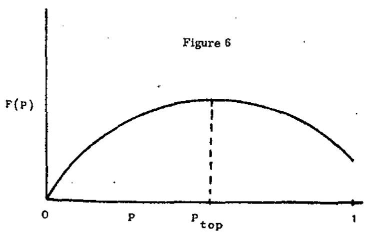

Figure 6

4. SECOND EXPERIMENT

Our second experiment is about a number of parallel learning processes. **Paired associates**: for instance, the learning of a braille alphabet with the strategy that some letter-symbol-combination is presented, then another, then another, then one already presented before, and so on. The learning criterion is that, during the learning-process, we may suddenly interrupt and, at that moment, we want the pupil to have learnt as much as possible: p (good) must be maximal during the course (we behave as if every stimulus occurs with the same frequency in daily life).

Other possible material is **concept formation**: for instance, we take paintings of ten artists and we teach their styles simultaneously. A strategy of this kind was used by Richard D. Walk, Ps. Science, 1968, with this material.

Because we have five models, we divide the material into five groups; the alphabet into 5 x 5 letters. Each group is taught with the optimal teaching strategy according to one of the models. We present one item according to the first model; after that, one item according to the second model and so on. Every item in this way is not repeated before at least four different items are presented. Short-term memory is controlled in this way.

The chosen criterion is that, within each group if items taught with the same model, we present at each turn the item with the highest expected increase in the probability of a correct response.
Let P = probability of a wrong response,
and $F(P)$ = expected mean change $(P_{old} - P_{new})$

a. linear model, 1 parameter, $P_{n+1} = \alpha P_n$.
$F(P) = (1 - \alpha)P$.

The best strategy is to take the item with the highest P, the item that has been learnt the least. In our case this will be the item that was most seldom presented. Hence, the optimal strategy is to give each item the same number of presentations. If the items are numbered 1, 2, 3, 4 and 5, we may give them in any order and, after that, give them all again in any random order and so on.

b. linear model, two parameters,
case 1: $\alpha_1 < \alpha_2$ (one learns most from a wrong answer)
$F(P) = P(P(\alpha_2 - \alpha_1) + (1 - \alpha_2))$.

Optimal strategy: select item with highest value of P. (keep a record of P_i per item i). If two items have equal P, choose one of them at random.
case 2: $\alpha_2 < \alpha_1$

$P_{top} = (\alpha_2 - 1) / (2(\alpha_2 - \alpha_1))$.

If the top of the curve is at the right side of 1 (depends on α_1 and α_2) see case 1, otherwise present item i for which P_i is nearest to P_{top}.
From the material it will be seen which of the possibilities is the fact in model b.

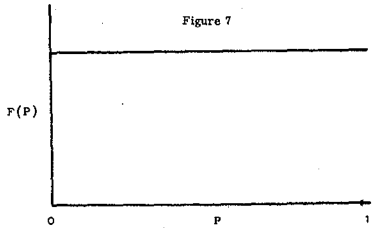

Figure 7

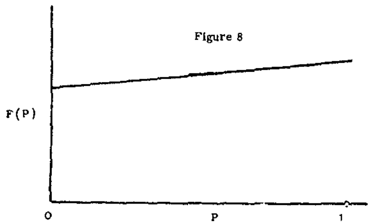

Figure 8

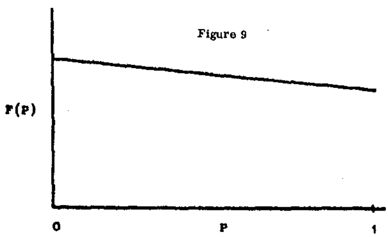

Figure 9

c. Urn model, one parameter. $F(P) = \alpha$

Optimal strategy: take one item at random, but skip item for which P_{n+1} would become >1.

d. Urn model, two parameters: $F(P) = P(\alpha_1 - \alpha_2) + \alpha_2$
case 1: If subjects learn more from wrong response: $(\alpha_1 > \alpha_2)$

Optimal strategy: take item with highest P.
case 2: if subjects learn most from right answer: $(\alpha_2 > \alpha_1)$
Optimal strategy: take item with lowest P.
It depends on preliminary research with the material, whether case 1 or case 2 applies.

e. All-or-none model:
for each item $F(P,n) = \theta\,(1 - \theta)^n$, $0<\theta<1$
where n = number of trials after the last wrong answer, $n = 0, 1, 2, ...$
$F(P,n)$ is max. if n is minimal.
Optimal strategy: Select item with most recent incorrect response.

We compare these five models with the help of samples taken during the learning process, then we stop the experiment suddenly and find which group of items gives the highest proportion of correct responses. At this moment we have finished a series of paired-associates learning tasks with the braille alphabet. We used a small group of 7 subjects (research assistants trained for the task) so that we could make an estimate of their learning-parameters. We changed the combination of braille-symbol-letter at every session, so that we could use these subjects many times. The stimuli in the experiment were visual representations of braille symbols, with at least 2 and at most 4 dots. The subject could give the response (a letter of the alphabet) with the help of a keyboard. After a warning signal, the correct response was shown.

We stopped the experiment before the subject was in the state of perfect learning, for all the 5 stimulus-response-pairs of each of our 5 models (actually this only applies to the urn models, for these are the only ones according to which the learning process ever reaches this state with certainty).

The comparison of test samples at the end of each experiment showed that, for this material, the strategy of the all-or-none model is inferior to that of the urn models and of linear models. This difference is significant at the 5% level, when we take the other models together.

There was no difference between the two versions of the urn model; between the two versions of the linear model, nor between urn and linear models.

We may conclude that, for this kind of material, and for these trained subjects, the learning process is optimal when the teaching strategy is based on a model which describes the learning as a gradual strengthening of the connection, in contrast to the all-or-none model which describes it as a sudden jump to the state in which the connection is formed and held.

COMPUTERS AND THE HUMANITIES

David Pegg

1. INTRODUCTION

The aims of this paper are to examine why a student of the Humanities needs to learn about computers while at school, to suggest a basis for a syllabus, and to discuss certain points of present difficulty and controversy. The word 'Humanities' is used to include all subjects which are not specifically mathematical or scientific. Economics and Business Studies are, for example, covered by the term though they lie rather close to the border-line. The field is so new and broad that a quantitative study and scientific assessment are at present impossible. Much experiment is taking place. but I know of no attempts to synthesize the results. Consequently, the views expressed are subjective and based on eight years of teaching the subject to Arts pupils. But these views are representative of a growing body of opinion amongst teachers in Britain. There is no mention of Computer Assisted Learning, because this lies outside the subject of the paper. But its theme includes the belief that a computer is an educational tool, and this is one of the tenets of Computer Assisted Learning. It seems likely that the teaching of computers as a branch of education and the use of computers to assist in education will soon merge together to form one joint subject.

2. THE REASONS FOR COMPUTER EDUCATION IN SCHOOLS

2.1 *There are two main needs to be met:*

2.1.1 Every future citizen has a right to be taught the basic concepts of computers in order that he or she may not feel excluded from a branch of knowledge which will permeate modern society and revolutionize our way of life.

2.2.2 It is necessary to prepare the future leaders of Government, industry and the professions for their roles in a World increasingly dominated by information processing.

2.2 In amplification of these needs, it is evident that computers can be socially and intellectually divisive. There is grave danger that the ability or inability to understand and use computers will widen the gap that exists between 'brain' workers and manual workers. As machines progressively replace both man's muscles and his mind, so those of lesser intelligence must be educated to form part of the new system rather than be made of feel outcasts. The dichotomy in society, between those who instinctively appreciate what machines can do and those who react against them, exists at all levels from the highest to the lowest. It is evident in most countries that the Civil Service and the leaders of industry are often disinterested in, or even opposed to, machines and particularly computers; where this happens, confusion frequently occurs and progress is slow. In fact, computers can be used to close this gap, for their study forms a valuable bridge between the Arts and Sciences.

2.3 Our purpose in introducing computer studies in schools must be examined in slightly more detail in order to decide what should be taught. At the Western European Symposium held at Heathrow in March 1969 it was agreed that a general knowledge of what computers can and cannot do should form part of a student's general education, that, as the use of computers involves logical abstraction and demands precise communication, it would form a study in its own right, and that computers should be presented as problem-solving tools in a variety of fields, both scientific and non-scientific. This agreed recommendation provides a compromise between those who hold that computer education should form a study separate from other disciplines and those who believe that it should be ancillary to the present subjects in the curriculum. I take the view that computer education should cover a fairly lengthy time span and that at certain stages it should be taught as a subject in its own right and at others the computer should be used as a problem-solving tool to assist other disciplines. This is a fundamental question on which it is dangerous to state categorical views. The emphasis will vary from country to country and from school to school. It is certainly wrong to dismiss either of the methods and retain only one.

2.5 The requirements which have so far been examined lead to the conclusion that there is first of all a need for a general introductory course on computer which should be offered to the large majority of pupils. For more intellectual students – those who will later become the leaders of our society – it is necessary to provide two further lines of study. In the first, the pupil will learn to communicate with a computer in some detail and in particular to solve problems relating to his or her field, e.g. Economics, Geography or a language. In the second, the pupil will examine the applications and implications of the computer in everyday life, with a view to developing its valuable uses and to minimising its dangers.

3. THE RECOMMENDED SYLLABUS.

3.1 *The General Course*

3.1.1 A summary of the main topis for this course is as follows:

What is a computer?

What can it do? A summary of applications

How does it work? – a brief description of its main components.

The computer as an information processor and problem solver.

Simple problem analysis – mathematical and data processing.

Different levels of programming language.
Multi-access and on-line working.
Visit to a computer centre.
Further study of applications and jobs in computers.
The effects of computers on society.
Possible future developments.

3.2.2 Programming has not been included because it is not considered that this is an essential subject. and in many cases no computer may be available and the teacher may have insufficient knowledge. However, the advantages of teaching simple programming are considerable and it should be included wherever possible, as it brings out very clearly the need for logical thought and accurate statement.

3.3.3 The use of visual aids is of vital importance. In the courses that I now give I start with three or four films illustrating the basic elements of a computer and some typical applications. I find that students respond more positively if their imaginations have been fired in the early stages. In particular, it is useful if a package course is provided, as this relieves the teacher from the difficulty of collecting visual aids and providing reading matter. Both teaching notes and pupils books are essential for inexperienced teachers. A good example of this is the teaching package prepared by the National Computing Centre of Great Britain.

3.3.4 For those interested in a more detailed syllabus for the General Course I recommend two publications:

Computer Education for All.	Prepared by a Working Party of the British Computer Society, and published by the Mathematical Association.
Computers in the Schools.	Interim report of a sub-committee of the Consultative Committee on the Curriculum, published by Her Majesty's Stationery Office.

These papers both emphasise that it is not possible to state precisely at what age such a course should be given. It is probable that the starting age should be at about fifteen years, but this is likely to be reduced in the future.

3.3.5 The following points need to be stressed, if a large number of schools are going to be able to give this General Course.

3.3.5.1 As many teachers as possible other than mathematicians need to be trained.

3.3.5.2 The emphasis should be on 'information processing', and the mathematical content should be kept reasonably low.

3.3.5.3 As the course forms part of the main curriculum for all pupils to follow, it is essential to make the presentation as interesting and lively as possible. A boring approach is worse than useless.

3.3.5.4 Some contact with a machine is needed, and this should be made, where possible, by teaching simple programming.

3.3.5.5 The course contents should be educational and not merely vocational training.

4. COMPUTERS AS A TOOL

Mathematicians and scientists will use computers in their particular studies. Students of the Humanities should do the same, but this is difficult to do for a number of reasons. First, high level languages are mainly mathematical in structure as a general rule. Where they are not, as for instance COBOL, they require a great deal of storage for compiling. Secondly, many of the problems in other subjects that can usefully be tackled on a computer are mathematical or at any rate statistical in form. Teachers of the Humanities lack knowledge both of computers and of Mathematics. Consequently, little work is being done in this field, but it is a fruitful one and in need of experiments on a wide basis. Now let us consider the syllabus in more detail.

4.1 The first task is to teach the students some programming.
The language should preferably be conversational – BASIC is a good example of what is required. For Business Studies and Economics a sub-set of COBOL could be used, and for studying languages some form of list-processing is necessary, as for instance in LISP or TRAC. The programming course need not be long as conversational language can be quickly learnt.

4.2 Once the student has a good understanding of a language, the teacher of a specialist subject can use it for problems expressed in quantified terms. At present most applications of computers to such subjects as Geography, History and Languages can only be offered at University level. But I foresee the time in the fairly near future when this can be done by sixteen or seventeen year old students. My experience of mathematical pupils at this age is that they learn quickly and are soon experimenting on their own. There seems to be no reason why this cannot also be done by Arts students also. The first requirement is an experienced and enthusiastic teacher. Once the pupil has gained confidence the teacher can sit back and supervise.

4.3 The subjects of Economics and Business Studies present a number of opportunities. Business Games have been played at some schools with success. In the first instance existing programs will need to be used, and the amount of new programming by students will be small. But, as confidence and experience are gained, more elaborate projects can be undertaken. It will be difficult to offer realistic problems which are also reasonably simple. In practice a computer is not used unless an application is fairly complex, and therefore work needs to be done to provide simple but true-to-life projects at school level. The use of packages of the type offered by the National Computing Centre would be invaluable for this purpose.

4.4 Geography is today becoming more and more dependent on statistics. Methods have been worked out for teaching such topics at University level, and there is no reason why able school pupils should not make use of some of the simpler ones. For instance, the correlation can be calculated between such variables as rainfall and height above sea level, using a large amount of numerical data relating to various parts of a country. Only a computer could effectively reduce such data and give satisfactory conclusions. A combination of a mathematician and a geography teacher can help to get this type of work started.
In general, the use of a computer in the higher levels of the school does demand team work between teachers.

4.5 The use of computers for linguistic research is now well established. There are many ways in which this could be introduced at school level. For instance, counts of words of different length can be made, with a view to analyzing style objectively. There is, admittedly, considerable disagreement in the validity of some conclusions, but the important point in that a student can be encouraged to think objectively and to understand the value of a quantitative approach.

Other types of study might concern the construction of sentences or the problems of translation. Here a list-processing language is essential.

4.6. I have so far not mentioned Data Processing, because I have little experience of it. In Britain there is a certain unwillingness to teach this at school, because it is considered to be vocational and this arouses suspicion in many educationists. My own view is that we should be prepared to include this, particularly in curricula designed for the less intelligent pupils. Provided that it is not limited only to existing techniques which may well be out of date by the time the pupil has left school, and that the emphasis is on organization and processing of information, then there is much to commend it.

5. COURSE ON THE SOCIOLOGICAL IMPLICATIONS OF COMPUTERS

It is now widely agreed that computer education must include some study of what computers can do, what they will probably be able to do in the near future, and what their effects are likely to be. Such a study is only worth doing if the pupils have a sound grasp of the principles of information processing and enough maturity to reach sensible conclusions. It is also best done with a widely mixed group of scientists and non-scientists. In this way the specialist knowledge of individuals can be put into a common pool from which all can derive benefit, and this combined effort will help to narrow the gap mentioned previously. My experience in running such courses leads me to make the following recommendations.

5.1 The first point to be made is that any form of dogmatism is to be avoided. Even within one school pupils vary from year to year and it is necessary to adopt a flexible attitude and to allow feed-back from the pupils to determine the pattern of the course.

5.2 It is best to start with a study of applications. Some will already have been covered in the General Course, and these can be expanded to include recent developments.

5.3 The next stage is to encourage the students to think of the effects that are likely to occur from the use of computers, such as redundancy, increased leisure, invasion of privacy, shift working and many others. I have found that the best way of doing this is to paint an imaginary situation which might occur in real life. For example, the students may study the problem of an industrial firm which is to set up in another part of the country a new factory using an integrated management system based on a central computer. The pupils will assume the roles of the key people concerned, such as the managing director, data-processing manager, the chief Trades Union official and others. They will then debate the problems that are likely to arise, and so in a realistic way social, economic and moral consequences are brought to life.

5.4 Finally the wider social and economic implications can be studied. Students can discuss such questions as 'What will be the consequences of a national computer grid? ' or 'Is a central file of personal records desirable? ' Small groups can be told to study a particular problem and report back to the whole class. Outside speakers may be asked to talk, and recordings of radio broadcasts can be played.

5.5 The main principles by which such a course should be directed are as follows:-

5.5.1. The discussions should be kept informal – the less the teacher speaks the better.

5.5.2. A standard textbook should be used, as this reduces the lecturing and saves time.

5.5.3. Numbers in the class should be reasonably small, fifteen is about the limit.

5.5.4. Although the organization should be flexible, a good deal of preliminary work is necessary, such as arranging speakers and outside visits, and selecting reference books for reports on special subjects.

6. POINTS OF DIFFICULTY AND CONTROVERSY

Proposals of the kind made in this paper will undoubtedly arouse opposition. The fact must be faced that computers produce feelings of fear and antipathy in many people, and teachers are no exeption. We can summarize these emotions as follows:

6.1 **Fear.** There is anxiety lest computers will change our way of life to an unacceptable extent. Massive unemployment will be caused, and this will affect only those who have not the education and intelligence to be 'computer users'. Great power will be placed in the hands of the few who control the machines, and so have access to the centralized records of individuals and have the opportunities for making decisions which cannot be supervised democratically.

6.2 **Dislike.** Many people believe that computers are primarily responsible for the growing dehumanization of life. If everything is governed by figures and the profit motive, the spiritual virtues of love, loyalty, kindness and courtesy will slowly lose their value. Our society is growing to resemble a gigantic broiler-house in which individual liberties count for nothing and efficient production is all important.

6.3. These fears and dislikes may be more emotional than rational, but they contain some truth, and account for much of the unwillingness of teachers of the Humanities to become involved with computers. The very fact that there are great dangers makes it all the more imperative that these teachers should be converted and persuaded to teach the young how to tackle these grave problems. Our aim must be to present the computer as a potential boon to mankind which should be accepted as quite normal and completely lacking in mysterious and irrational powers.

7. TEACHER TRAINING

Until sufficient teachers can be trained, no large-scale introduction of computer education is possible. In most countries the training of teachers in computers started in a haphazard way. This was acceptable when the subject was in a embryo state. But now that it is developing fast, some central direction and control in necessary. It is not my task to examine this in detail, and so I will only make points which are relevant to my main theme:

7.1 All teachers should receive some instruction in computers during their initial training. This should be on the lines of the General Course, with suggestions on how to introduce the concepts of information processing during actual teaching.

Some programming is highly desirable as it gives confidence out of all proportion to the time spent on it.

7.2 In-service training on the same lines as those mentioned above must be given to a considerable number of practising teachers of all subjects. In addition there must be talks, discussions and conferences for the spreading of ideas. At these all teachers with experience should contribute what they can to help those who lack it.

7.3 Regional centres of computer education are needed to give this in-service training. Each centre should be based on a computer used specifically for educational purposes. At this centre also pupils can be given the opportunity to make contact with a machine.

8. HARD-WARE

This is so wide a subject that only a few points relevant to students of the humanities can be made.

8.1 The need for these students to have access to a computer is not as great as for mathematicians or scientists. But if useful problem-solving is to be done, some communications with a machine is necessary. To my mind, this is best done by non-scientists in the conversational mode. Suppose for instance that a student wishes to compare the styles of two passages which have been input into the computer. By means of a conversational language he can ask specific questions such as – 'What is the average number of words in a sentence, or the average number of letters in a word? ' or 'How many connective words like 'and' or 'but' occur in each passage? ' It is not necessary for him to write the programs that will extract this information. If they are not already available he can ask a friend to produce them for him. The important task for him is to use the computer effectively.

8.2 The difficulty of solving non-scientific problems in a language such as ALGOL will discourage the student from even trying to do work of this kind. In any case the use of a batch-processing system would make the task impossibly long-winded. The student might wait for days for his answer. For non-scientists, then, the batch-processing method is not satisfactory, particularly if it is arranged on a postal basis. A on-line system is better, provided that students can use the conversational mode. But if the terminal is at a distance from the computer, telephone costs become too heavy to justify such use, and batch-processing is almost a necessity.

8.3 What then is the best solution? On all but financial grounds a computer in each school is the answer. But this is out of the question except in a few specialized cases. In my view, the ideal compromise is for a small computer of about 16K of storage with a disc file to be linked to 8 – 12 local schools. These schools may have permanently installed terminals, or the terminals themselves may be moved between schools to save capital costs. There is then sufficient power to handle quite large problems in the conversational mode, but the telephone costs will be small. But the main advantage of such a system is that the computer itself need not be remote. Boys and girls can visit the centre where it is installed and gain some experience of running programmes on the spot. The educational value of such a system, especially to students of the Humanities, is far greater than one in which a terminal is linked to an unknown machine hundreds of miles away. It is not difficult to connect the small computer to a larger network, in the same way as local telephone switchboards can be connected to trunk switchboards. I believe that the overall cost of such a system would work out cheaper than one in which individual schools were connected to a country-wide computer grid. This is certainly a field in which considerable research needs to be done.

9 EXAMINATIONS

There are many other questions that raise difficulties and controversies. For instance, should the subject be examinable? The pros and cons are so evenly balanced that it is impossible to give a definite answer.

Examinations do exist for Computer Science, and it is possible that students of the Humanities may be able to take special papers in certain parts of the subject. It is more likely that questions on computers will be set in examinations relating to other subjects. I would urge that extreme care should be taken not to throw away the great integrating value which computer studies will have on the school curriculum as a whole, in order to provide extra qualifications for a few pupils, and so I would keep to a minimum the use of examinations.

10. CONCLUSIONS

The main points made in this paper can be summarized as follows:

10.1 All pupils should be given the opportunity of taking, as part of the main curriculum, a General Course of computer studies. Only by this means can the divisive effects of the computer be eliminated.

10.2 The education of a country's leaders should include the study of computers as problem solving and information processing tools, and should also contain the examination of sociological and economic effects. Special courses should be developed for these purpose.

10.3 The opposition to computers because of their inherent dangers must be overcome, so that they are accepted as normal and unmysterious. It is particularly necessary to convince educationists of this.

10.4 Economical means must be found of providing adequate teacher training and the hard-ware necessary to enable young people to learn to use computers with the greatest possible efficiency and benefit. This applies as much to students of the Humanities as it does to mathematicians and scientists.

COMPUTER EDUCATION; ITS IMPACT ON MEN AND SOCIETY

Trade Union Aspects on Computer Education

Fred Margulies

1. INTRODUCTION

Two decades of applied data processing have turned the computer from an exclusive apparatus for experimentation, used only by some scientists, into an important instrument of modern economy and administration and into a joint tool of all sciences.

Computer application in an ever-increasing number of fields at the same time requires more and more people to familiarise themselves with the processing of information and presents immense problems for those engaged in the organization of computer education.

Undoubtedly, the training of personnel with the highest qualifications for the development, manufacture and operation of data processing equipment, both hardware and software, has top priority. In addition, it will become increasingly necessary to supply potential computer users with the knowledge that will put them in a position to understand and exploit the full potential of the existing installations.

It is not, however, the subject of this paper to deal with those and similar problems. These tasks were and will be handled by more competent persons. It is the objective of this contribution to discuss the training of those whom we might designate as the „third estate" of our computer society: people who are neither software nor hardware specialists, neither programming experts nor operators, people who in their majority are not likely ever to go into those professions either. Yet, they too live in a world which is, to a growing extent, characterized by the computer, a world in which they will be confronted with new problems and where more and more demands will be made on them.

The computer has created a qualitatively new situation which cannot be comprehended by adding up the established installations or multiplying the performance factors. The increasing spread of the use of computers leads to man's developing new ways of behavior and thought for which the present social institutions and our system of education are insufficient. The computer technology of our time may justly be considered part of the 21st century but our society and, particularly, our educational system are still anchored deep in the 19th century. In a lecture delivered in Vienna, Prof. Zemanek expressed this very drastically: „The modern computer permits one million decisions per second, but modern democracy will allow only one decision in 100 million seconds, i.e. at elections once every four years."

This discrepancy between new possibilities of information and man's increasing capacity for decision on the one hand, and the lagging authority to decide on the other, create a dangerous state of tension, to which other factors also contribute, factors such as the growing urge for creative ability, rising level of education and development of the personality for which there is little opportunity within the hierarchy of a modern enterprise. There also exists the necessity of greater professional mobility, a factor for which an inflexible type of vocational training is not exactly conducive; there is the need for continued education – something entirely unprovided for within our present educational system, etc., etc.

For this reason it is one of the most important tasks of computer education to train people not only in the use and utilization of these new tools but – first of all – to enable them to master the new tasks which the computer raises in all fields of life, and to make everyone aware of the hazards and benefits inherent in the computer. A „World Conference on Computer Education" would have to integrate these problems.

2. THE DEVELOPMENT OF PERSONALITY

Life is a struggle with nature; plants and animals are directly confronted with nature and only biological changes, taking thousands of years, alter the manner of that confrontation. Only man was able to change the struggle with nature into a process of work, i.e. due to man's intellectual powers he was able to interpose tools between himself and nature. Along with the development of the working processes, human relations and social structure grew up as a necessary precondition and consequence of human labour. Thus, the pattern of the human struggle with nature does not change according to biological factors but rather along with technological, scientific and social developments, not over periods of thousands of years, but in decades or – in our age – even in years. If production at first served to support life and the satisfaction of material needs, improvements and increases in production at the same time – even though man was hardly aware of it – also serve the development of his personality. The better and easier the material needs can be fulfilled, the more conscious and urgent becomes the human drive for self-fulfilment.

The pre-industrial periods were characterized by the prevailing use of physical (human and animal) labour as the principal factor of production. However, even then every process of production required a mental in addition to a physical effort. In many instances it was the producer himself who planned, prepared, carried out and finished the work; mental and physical work formed an integral whole which required and facilitated a certain development of the personality and a certain creative activity.

The industrial era, which began with the industrial revolution of the 18th and 19th centuries, was characterized by the development of means of production (tools, machines), of non-biological sources of energy (steam engines, later on electricity) whereas other production factors (human labour, materials) remained largely unchanged. In contrast with the small-scale production by artisans, industrial mass production and the application of progressive technology led to an ever more thorough division of labour, to a separation between mental and physical tasks. The worker became an appendage of the machine, in extreme cases his activity was reduced to the dull and spirit-breaking repetition of motions that never changed. The rise in productivity was a gigantic increase on the part of the means of production while at the same time the possibilities for the development of the worker lagged behind. Industrial development freed man from hard physical labour at the price of alienation, chopping up and de-intellectualisation of work. The more mental efforts were separated from production as such, the more the means of production became „materialized science", the less creative effort remained for the man operating the machine.

Only the scientifico-technical revolution of our day is in a position to reverse this process because it brings about a large-scale development of all productive factors. Not only the development of the means of production (automation), the materials (synthetics) and the sources of energy (nuclear energy) are characteristic of this period, but primarily the development of science and thus the basic changes in the process of human labour.

Various developments, particularly in the methods and findings of mathematics and the natural sciences, developments that have their roots back in the late 19th century but which only have taken full effect since the middle of this century, have principally changed the part played by science in the productive process. Theory and practice, research and industry are not strictly separated any longer but enter into ever closer direct relation. Science and research are increasingly being included in the process of production, production becomes increasingly „scientific'; thus, science has become a direct productive force. If during the pre-industrial period production was limited by the available physical labour, and if during the industrial period machines and capital were the limiting factors, in the post-industrial era, at the threshold of which we now stand, the intellectual potential of a country will determine the level of production.

This basic change in the character of science has far-reaching effects on man, his training, his environment, his personality. With the assignment of the monotonous, dull work, to automatic machines man could cease to be the „servant" of the machine, he could be freed for creative work, thus taking one of the steps necessary to overcome alienation.

In this respect computers offer particularly hopeful aspects which – contrary to the views that still prevail frequently – seem predestined to complement man rather than to replace him. The more complex the task, the more complicated an algorithmic solution, the more indispensable man and human intelligence become; this fact is increasingly being acknowledged in control engineering as well as in information science. Developments distinctly tend towards man-machine communication, the direct dialogue and the division of labour between man and computer, with the latter doing the tedious, time-consuming routine calculations which furnish the bases and information for decisions. The decision, however, remains the prerogative of man; yet, man is able to make such decisions with more certainty and more rapidly than ever before when aided by the computer because man's fundamental superiority over the machine consists in his capacity to choose between alternatives, in his ability to process information. Thus man will extend his intellectual performance even further with the aid of the computer, just as earlier tools and machines multiplied man's physical powers.

3. HAZARDS AND BENEFITS FOR THE DEMOCRATIC SOCIETY

Reports have come from the Federal Republic of Germany about plans to equip the seat of every member of the Bundestag (Diet) with a computer terminal and an input-output device with display screen. Thus, direct access to all information stored in a data bank is to be provided. We do not need much imagination to continue this train of thought and to envision, on the one hand, the creation of a world-wide „information network" in which actually the knowledge of the entire world is immediately accessible, and, on the other hand, to regard the installation of such a terminal in every home and for every family as feasible. The theoretical bases for this have already been established, the practical possibilities may be expected to exist in a few years, and the implementation will not take as long as, for example, the electrification of our cities or the establishment of our present telephone network: however, are we – individuals and society – prepared for the technological potentialities which are emerging?

„Knowledge is power" and the knowledge stored in a data bank or even an information network represents a tremendous power factor. Unheard of possibilities for the manipulation of public opinion are open to those able to decide which information is to be stored and which to be forgotten; which knowledge to be made available to the „masses" and which to be only made accessible to the privileged few. Thus, measures to prevent a monopoly on information and knowledge, measures against the abuse of the power inherent in the computer are of the utmost urgency.

On the other hand, the new perspectives opened up by science offer extraordinary chances for a genuine democratisation of our society and its institutions. If all citizens are able to obtain objective and extensive information on any question within a very short time; if they are also in a position to form an opinion that is really their own on that basis; if they are able to express this opinion without any let or hindrance; if they are actually in a position to participate in decision-making, then the concept of democracy will have entered into an entirely new dimension and achieve its proper purpose.

4. JOB PROBLEMS

From our somewhat futurological digression, let us now return to the every-day reality; the „man on the street", when thinking about automation, is mostly concerned and worried about the uncertainty of his own future, what he is most afraid of is the loss of his job.

4.1 *Job redundancy despite full employment*

It is true that a continuing boom and full employment in most industrial countries are frequently cited as proof that technical change does not result in a job redundancy. However, it may easily be demonstrated that full employment and rendundancy are not mutually exclusive factors; under the best of circumstances, i.e. if there is a favourable coincidence of several factors, the visible effects of these two phenomena may temporarily cancel each other out. As long as a sufficient rate of economic growth is maintained, the displacement within the labour force resulting from technological progress is not expressed in the unemployment figures. For example, according to the RKW (Committee on Rationalization of the German Economy) between 1950 and 1966, the over-all economic productivity in the Federal Republic of Germany increased by 157.5%; however, at the same time the number of persons employed rose steadily since production or the net value added by the economy showed a continuous increase. During the recession 1966-67, however, this picture changed. In 1967 the gross national product was only 0.1% lower than in 1966 but employment in 1967 was 5% below that of the previous year. Thus, even though production did not even drop but merely stagnated, about 600,000 jobs were lost.

In reality, therefore, these apparently stable global figures on employment only cover up large-scale structural changes, factors actually justifying the concern and the anxieties felt by many.

4.2 *Who makes the decisions?*

Hardly ever we are faced with just one and evidently best solution to technological and organizational problems. In the large majority of cases we find that alternative possibilities exist; the evaluation of these possibilities will largely depend on who makes the decisions and whose interests are considered foremost. In the main we have three quite different categories of target concepts involved in these decisions. For the individual business man and his operational way of thinking considerations of an economic, time-saving or labour-saving nature are decisive. For example, he will try for:

Minimalization of costs for a production process
Minimalization of time required for a production process
Maximalization of the production resulting from a given input of material, power and labour
Maximalization of the accuracy of results, etc.

The state – as far as over-all economic considerations and actions are considered to be part of its competency – will place considerations of the business cycle, of structural and financial policy into the foreground, as for example:

Maximalization of exports
Optimalization of expenditure for research and development
Promotion of growth industries
Anti-cyclical promotion of investment, etc.

The individual, on the other hand, the white or blue collar employee, wants his desires to be taken into consideration, as, for example:

Minimalization of the monotony of his work
Maximalization of the possibilities of personal development and creative activity
Maximalization of the possibilities for vocational and professional training and improvement in social status
Minimalization of social hardship and adjustment difficulties, etc.

It is apparent that these three categories of target concepts are hardly compatible and in many instances are even mutually exclusive. The objectives of the employees can only be realized if those of the employer are forced into the background and vice versa. The drive of the trade unions for the right to participate in decision-making in economic, technological and organizational matters must be understood in this context.

4.3 *Elementary training with the target of participation in decision-making*

If the hazards of computer use are to be avoided and the chances optimized, employees and their representatives (shop stewards, unions) must be granted an opportunity to exert an influence on decisions and to represent their point of view. Management should be obliged to inform the employees about intended changes and reorganization in time so that, coincidentally with the technical, organizational and financial plans for the introduction or extension of electronic data processing, a social plan of adjustment (personnel plan) could be worked out.

Such a personnel plan is not intended to delay the introduction of technical or organizational changes, nor is it intended to preserve jobs. The period between placing an order for an EDP installation and putting it into operation should rather be used to offer redundant employees a chance for re-training. In this process their inclinations and abilities as well as the jobs that will probably become vacant because of retirement or other reasons should be considered.

Beyond this, however, – as stated in the preceding section – the right to participate in decision-making has, as its purpose, the achievement of the objectives of the employees and of the fulfilment of the economy's requirements, as opposed to the target concepts of the individual business operator.

All this, however, requires employees – or their representatives – to possess at least a basic knowledge of EDP and the problems involved. This may appear as too modest a goal but a thorough training, desirable as it may be, does not appear to be realizable now or in the near future.

The Austrian trade unions have begun to run such elementary courses entitled „Introduction to electronic data processing". During a period of 5 days (30 hours) or six evenings (12 hours) the following topics are at first discussed:

How does a computer work?
What is a program?
The impact of EDP on organizational structures and on occupations (personnel planning)
New methods of EDP (3rd generation computers, teleprocessing, etc.)
Trade union aspects of automation.

Visiting an EDP installation and discussions complete this program for which a surprisingly live interest has been evinced. During the first 6 weeks of this year, 15 courses of this type with about 1,000 participants have been organized. The evaluation, requested by means of a questionnaire, was positive throughout and the wish for continuation on a higher level was strongly expressed. It should be noted that the participants were mainly shop stewards and trade union officials; therefore the interest in advancement on the job or in general information seem to have been secondary motives for attendance.

Further series of lectures entitled „New Developments in Data Processing" are being organized jointly by our

Trade Union with the Vienna University of Technology. They are rather intended to provide an advanced level; first-rate experts act as lecturers and these courses too have met with great interest. We are particularly happy about the excellent support we have received from the University and its staff.

We sofar have no experience with the practical effects of such courses in the interprises themselves, but we can tell something about the expectations of the organizers of these courses.

Through these courses, the trade unions want to qualify shop stewards so that they would be able to demand and exercise the right to participate in decision-making regarding questions of technological and organizational changes. The shop steward cannot and should not become the superexpert for data processing who would do the work of the experts of the computer company or his own organization. It is only his task to effectively complement the considerations of management by the point of view and the demands of the employees; the shop steward is to use his influence so that, in the decision between possible alternatives involving structural changes in employment, upgrading will become the rule and downgrading the exception.

In the long run, however, the elementary knowledge now being supplied will not suffice. Even though experts of the trade unions are at the disposal of the shop stewards, with the increasing complexity of data processing, the training of the shop stewards and finally of all employees will have to reach a higher level. The great interest evinced thus far and the general readiness to accept such training is encouraging. The growing agreement between computer experts and trade unions is also a hopeful sign. The common interest in using the computer for the benefit and advantage of mankind, in spreading knowledge and understanding of modern technology, has caused experts and scientists to agree to hold informational and educational lectures within the scope of trade union courses, to participate in discussions and deliberations – thus rendering valuable assistance. In this connection I should like to mention the symposium „New Methods of Data Processing and the Future of White-collar Employees". organized last year jointly by the Austrian Union of Employees in Private Industry and the University of Technology in Vienna, an event that was widely noticed and received general acclaim.

5. COMPUTER EDUCATION FOR EVERYBODY!

The training of shop stewards and trade union officers for the task of participation in decision-making, however, is only one – though an especially important – aspect of computer education. The principal problem of the near future, however, will consist in offering general computer education, i.e. to make computer education a compulsory course in all secondary schools and institutions of higher learning.

If the present trend of quantitative and qualitative computer development is maintained, today's school children will grow up to live in a computerised world in which not only the vision of a world-wide information network and of „plug-in information" will be realized but also the consequences resulting from these factors for man and society. This means that an adjustment of our present system of education to conform to these future requirements is most urgent. Among other things, the computer now has to become both a subject and a teaching aid. First of all, the system of education should provide a fundamental orientation towards the way of living and thinking based on this future „computerisation" of our world.

The rapid rate development of science and technology which is so frequently cited will be maintained or even speeded up in the future. Those youngsters leaving school now and even more so those now reaching school age have to count on undergoing several changes in the living and working conditions.

The goals of our present school system, characterized by an assumption of finality, are of no use to this generation. Not a completed course of education but orientation towards permanently continued education is required; not acknowledgement of the teacher's authority but understanding for the relativity of knowledge. The essential parts of a general computer education are the recognition of functional interrelationships, the development of our capacity for association and the evolution of cybernetic thinking.

6. CYBERNETIC THINKING – A BASIC REQUIREMENT OF GENERAL COMPUTER EDUCATION

Feed-back as applied in cybernetic systems has not only assumed overwhelming importance in modern technology, but also has major effects on the behaviour of man and the functioning of our social institutions. If we are to master our future, the development of mathematical and cybernetic thinking from earliest childhood is of paramount importance.

Thought is a process of perception, transformation and storage of information. In addition to personal experience and the social rules which largely depend on the views prevailing, our thinking is mainly influenced by the level of our knowledge in the natural sciences. For example, Galilei helped introduce the concept of changing motion into our pattern of thinking and Darwin did the same for the notion of development, thus preparing and generalizing the flowering of the Age of Enlightenment. The mechanistic interpretation of nature at the beginning of the industrial age had, as its pendant, the system of mechanistic thinking. This way of thinking, largely progresses in only one direction from cause to effect, without considering any feed-back of the results achieved; nevertheless it meant progress in its time, compared with the antique concepts of immobile and unchanging substance preserved in the dogmatism of the Middle Ages. Later, however, this mechanistic thinking evolved into inflexible lines and programs because feed-back as an instrument of continuous control and adjustment was lacking.

Today, cybernetics is beginning to change our way of thinking; automatic control and EDP are introducing the idea of interdependency as well as feed-back methods into our everyday life.

However, the influence and effects of traditional patterns of thought as well as many phenomena of our modern technological world, oppose the development of cybernetic thinking. Thus our way of thinking is traditionally static and conservative and we have a tendency to stick with the things we have learned – at least for a while – whereas cybernetic thinking is characterized by methods of continuous adjustment to incessant and rapid change. We have an inclination to try and regard our decisions as permanent but to think cybernetically means to think in alternatives that keep emerging continuously, have to be searched for in permanency and to be examined and adapted according to actual conditions. Only the systematic development and testing of alternatives provides real freedom of choice.

Cybernetic thinking is primarily a way of thinking in extreme abstraction: The search for algorithms, the construction of models, the interpretation of the computer as a „black box" with input and output as the only aspects of interest, etc.

Not only is our mechanistic-concrete tradition in thinking opposed to this but also our present-day life with its flood of material phenomena. Particularly young people who are used to receiving extremely detailed and concrete information from the mass media find it difficult to develop abstract thinking in different fields. As consumers of information, we are tempted to receive the mass of information offered to us in an uncritical manner, examining it only superficially – whereas for information processing the emphasis must be placed on the selection of relevant data and the suppression or even destruction of the irrelevant information.

In their professional work, cybernetic thinking today already forms part of the basic attitudes of engineers and natural scientists. However, it is still lacking in „private domains" of thinking and, primarily, in the social institutions. Electoral systems, party programs, economic management and, last but not least, our educational system have dangerously lagged behind the requirements

We could console ourselves with the idea that cybernetic thinking would succeed spontaneously just as have earlier variants of our pattern of thought. However, such a consolation would underestimate the importance of the opposing forces we mentioned earlier and would deny the existence of the fundamental changes in the factor of time. The rapid technological changes have put extremely narrow limits on the time available for carrying out the necessary adjustments, particularly of our pattern of thought. Today we cannot afford to wait for spontaneous developments because the tensions that would arise would inevitably lead to serious conflicts. The purposive evolution of cybernetic thinking thus must be included in the field of general education – in relation with computer training.

7. TRADE UNIONS AND AUTOMATION

Trade unions too are faced with new tasks induced by the scientific-technical revolution; tasks reaching far beyond the traditional fields of trade union activity. We do not regard modern technology as an „inevitable fate" to which we have to resign ourselves because we are unable to prevent it; quite to the contrary, we regard it as a necessary and desirable objective that we should help promoting (and that needs promotion in Austria), for which we want to work, a development in which we wish to participate actively. We consider the continued occupational training for employees or the supply of information to our shop stewards, officers and members ón new developments in technology and science our task just as much as we are working for greater protection against social hardships or for improvement of the standard of living and working conditions.

We have finally arrived at the conclusion that the trade unions are no „Red Cross Stations" with a scope of activity limited to „accidents" such as unemployment, want and destitution.

Modern trade unions are equally concerned about the lag in science and research, about the outmoded system of general education, about the lack of economic and investment planning and about the development of society as a whole. The trade unions are doing this in their own well-founded interest as well as in the interest of those represented by them – both blue and white collar workers – who would be the first to suffer if the gap between the development of society as such and that of science and technology could not be bridged; this is not an easy task and it requires close collaboration between the major forces within our society, cooperation between science and trade unions, on both the national and international level, especially in the domain of computer-education in the broadest sense of the term. This goal achieved, there will be a better chance to do justice to those who have so far been neglected, i.e. the „third estate" of the computer age.

Our grandfathers combated technological progress and tried in vain to stem the tide. Our fathers passively accepted this progress in the field of technology ... and have had to contend with unemployment. Today's generation is being given the chance to consciously control and regulate technological progress so as to render maximum service to man and society alike – provided the ground is appropriately prepared. In this our generation must not fail.

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THE IMPACT OF COMPUTERS ON SOCIETY AND CONSEQUENTLY ON EDUCATION

1. INTRODUCTION

Each panelist accepted an allocation time of ten minutes with the possibility of a follow-up, having heard the other contributions, immediately prior to the coffee break. Coffee was organised from 10.30 a.m. – 11.30 a.m. The period 11.00 a.m. – 12.00 noon was set aside for discussions on questions collected during the last panel round. The final fifteen minutes was devoted to a summing up by the Chairman.

Four of the panelists, Professor Vollebergh, Mr Bentil, Mr Pegg and Mr Margulies, had specific areas with which they had a natural close association in the concern of the impact of computers on society.
The remaining two panelists, Professor Hebenstreit and Professor Ralston, and the Chairman, were concerned with a somewhat broader field of contact and therefore agreed to choose initially to follow themes which would most effectively provoke discussion and give balance to the panel's depth and breadth of coverage. Subsequently it was arranged that each speaker would react to questions on which he or she felt a particular wish to follow through. This structure led generally to covering the following themes:

(1) The general philosophy.
(2) Practical experience with University students, their reaction, requirements and impact on society and of society on them.
(3) Employment problems in developing countries if education is inadequate or withheld or if the role of the computer is misrepresented or misunderstood.
(4) An alternative view of philosophy (the devil's advocate, to promote discussion and thought).
(5) The position in the school, the role of the computer in the humanities and science and in bridging the gap between the streams.
(6) The role of the Trades Unions in preparing members for the use and abuse of computers.

2. *Summary (prepared by the Chairman: Mrs M.M. Barrit)*

2.1. **Professor Vollebergh**, in setting the general scene, raised several points which clearly emerged during the morning as being a basis on which we should go forward from the Conference, in particular:

a. Preparing programmes for teaching the teachers so that the gap between 'experts', generations and social groups does not widen.
b. To consider the human aspect of automation and in particular, man's relationship with his social and material environment, in addition to the problems of employment and the development of organised systems.
c. The opportunity for balanced study periods during a life time, in order to avoid professional obsolescence and to provide an opportunity for the many to meet the few who are more intensively engaged in the same or related fields. It is suggested that the organisation, management and supervising at the scientific level for such periods of leave, could constitute a substantial task for the Universities but that this would involve more complicated activities and further interest than is normally deployed in organising refresher courses.
d. To emphasise the responsibility which computer experts have, to consider the effects of their research and development and how to take through, in to general strategies, other views which can be adapted to the social interests and requirements of the layman to whom experts will need to be made available.

Finally, Professor Vollebergh wished to emphasise the danger of being concerned with the 'how' and consequently of no longer seeing the 'why' and hence depriving those who have power to make the decision.

2.2 **Professor Ralston** effectively spanned the gap between the philosophy of Professor Vollebergh and the practical vocational necessities highlighted by Mr Bentil; he indicated the role of the Universities and the tasks required for them to fulfil this role (1). Included in this is the study and the control of computer power. A consideration of the systems in use which can cause the gain or loss of identity of individuals, the gain for those who take part and the loss for those who are merely blocks of information in a file processing store (2). The Interaction of power and people is not the cause but brings out latent hostility to the established world order and a wish to start again.

2.3 **Mr Bentil** gave a fairly detailed account of the effect on the economy of a developing country where the installation of computers is incompetently tackled, either by providing inadequate hardware or a combined inadequate hardware/software system and accompanied in all cases, by a neglect to bridge the gap for the employees concerned with using the proposed new computer system as against other previous methods of carrying out the tasks to be done.

Mr. Bentil's contribution emphasised the very grave problem the computer field still has, in the lack of adequately trained consultants who can envisage the effectiveness of a given complete system as against not only the technical or administrative tasks which it is expected to perform, but on in the involvement of the people who will be interfacing with the system. This indicates the need for professional level orientation courses of both depth and breadth and perhaps this is particularly highlighted in developing countries where occurrences are mere isolated, whereas similar problems have already been encountered in the so called 'developed countries', but their impact was less noticeable in that the unfortunate employees who suffered had very little opportunity or means of communicating their difficulties to the rest of the world. By implication, this was also seen in the contribution of Mr Margulies (3).

One may perhaps question whether in addition to tests for programmers, there should be tests for users and tests for intermediaries and third parties who introduce computer systems into a working environment. Professors Vollebergh, Ralston and Hebenstreit's contributions also emphasised the need for complete re-thinking in the form of professional and University courses to provide the right sort of basic education for the intermediaries, the users and the technical staff of tomorrow.
Perhaps we should be working towards a design award for computer systems which is considered from the point of view of the general public and not judged solely as an entity although simplicity and elegance often do mean functional satisfaction.

2.4 **Professor Hebenstreit**, in order to provoke discussion and may be also from some rather deeper motive, undertook the role of devil's advocate and claimed that computers had been in the nature of an evolution rather than a revolution and could therefore anticipate easy adoption by society, which happened in the case of electricity, rather expecting the disruptive changes of, for example, the introduction of nuclear energy. In this view, therefore, the computer, computer systems and other effects, would be assimilated without difficulty.

Professor Hebenstreit also went on to indicate the opportunity which has been obtained by members of society as a result of the computer era. In particular, the on-line interactive facilities available individually via the console, can allow those people who have the skill, to pursue a path of creativity which normally had only been available to those engaged in high-level research and development. This tool, however, does mean that additional stress can unknowingly be placed, for example, on engineers because their work using for example graphics may be designed very quickly, requiring intense mental effort which previously was stretched over many days or even weeks and during which many routine calculations had to be performed before design could proceed. An area of research is thus indicated with exploration in the giving of appreciation courses. Thus the impact which the new tools make in regard to conceptual stress can be made known rather than that these may be found by trial and error, with consequent breakdown of staff. The individual will also need to be educated to know how to plan the right sort of spare time activities to off-set this intense mental activity.

2.5 **Mr Pegg** could, from his own experience of having been originally trained in the Classics and moving to Mathematics, appreciate the problems and potential of computers.
He has chosen the introduction of computer education into his school as a means of linking what are now divergent disciplines and by so doing has tackled one of the most difficult problems now facing the teaching profession. Mr Pegg outlined a course of computer education for the non-mathematician which he is implementing at Bedford School and in this he has become fairly seriously involved in access to computers and in knowledge about fundamental computer design.

2.6 **Mr Margulies** contributed a most interesting paper on the role which Trades Unions can and should be allowed to play in the introduction of computer systems. In the first place, the education of employees to receive such systems and the more important aspect of education and planning for the leisure and the creative opportunities which could either be provided or denied to employees in the future. In one sense, the computer system, by making it possible for those directly associated with it to contribute some creativity assists but it is then by its power, depriving large numbers of people of their individual identities and converting much of their previous work to completely automatic processes. The relationship between proper leisure activities to off-set dull and routine employment, or proper leisure activities to off-set creative employment, emerged very clearly from the Friday morning session as being a problem of today and tomorrow for those designing educational facilities. There was much in depth and understanding in Professor Vollebergh's contribution on how an integrated approach to living might be considered by those responsible for the design and planning of University activities.

2.7 **The Chairman** summed up some main lines of development which emerged as a result of the IFIP week in general and the Friday session in particular, thus:

1) The Conference considers that our actual lack of knowledge about learning processes needs a lot of research to be done in this area (psychology and sociology of cognitive processes) as a basis for implementing education through computers on any large scale. We should keep in mind that our aim is to better cope with the problems linked with the use of computerbased systems in society. Therefore the objective is better education and the introduction of computers into schools should be viewed in this context.

2) The Conference recommends to IFIP to invite trade unions on a national and international level to take part in its work, especially with respect to IFIP-Ljubljana 1971.
3) More emphasis in education should be placed on the computer as an aid to creativity, particularly noting that it makes this possible at a lower level than is normally implicit in scientific and humanistic research activities. In this context, attention should be paid both to the ability of the computer to remove drudgery from many activities and to manipulate abstractions and thereby serve as a human creativity (4).
4) The Conference recommends that Universities and other schools should include into their syllabus of Computer Education lectures on the impact of computers on men and society.

The Chairman's personal contribution and comments to the general underlying themes of the questions would be to accept that we have concentrated on the term computer whereas the human beings such as programmers, system analysts, designers and so on who contribute to the system, make the active impact on society rather than, essentially, the computer hardware. But I suggest, that quite soon nobody will think of computer as meaning just hardware but will automatically think of computer as meaning the total computer system to which the user is subject or has been gifted according to whether such a tool is unfavourable or favourable (5). It is therefore seen and acknowledged that the people concerned with the design and implementation of the total system are in a powerful position and carry a high responsibility to society both in the nature of providing systems which are functionally acceptable and which aid the progress of society, rather than enslaving it. At this stage, their education must, of necessity, be only partly formal and to a considerable extent must rely on continuing spells throughout the employment span.

To formalise too soon or too severely will only increase the gap in knowledge between those who use computer systems and those who design such systems. There is currently an almost complete block in the effectiveness in communicating with the world at large.

It may be helpful to mention specifically where work is known to be taking place on studying the complexity of third and fourth generation computer systems with a view to feed-back not only into the design and management of the implementation of future systems but also into the problem of living with such systems.

In particular, work is in progress under Ted Glazier at the Case Institute, USA and jointly by Professor Tad Pinkerton (of Wisconsin) and myself at the Edinburgh Regional Computing Centre. We are interested in determining the underlying structure of systems which might lead to hierarchical recognition of conceptual levels so that sophistication can be assessed and offered at controlled levels in the next few years. In the case of Edinburgh, this has arisen out of the need for the Centre to master, provide and present to users a variety of computer systems on differing hardware basis at an unnaturally high rate of change during the early development years of the Centre.

In attacking the problems of computer systems of which we have experience, it may be that more light will be shed on the desirable structure of general information systems. There seems scope here for the use of graphics to depict concepts and the probable effect of change as a communications media (6).

Recurring throughout the questions and the conference is the urgent need for control of the power of systems; currently power is rather recognized nor measured.

The Chairman attempted to raise some audience response on the funding of education (7).

The general impression gained is that budgeting is a skill not yet studied and acquired by educationalists other than those accustomed to raising money for research (8) (9).

Future conferences might usefully collate and study terminology to concentrate but not try to solve the problem (10) (11).

Again, in future conferences and in any follow up of this work we might first emphasise the frameworks we have now developed for investigating the things we don't know. The question (12) is very relevant. There is perhaps in general sessions a need for more care by the chairman in introducing such a framework against which research can be discussed. Otherwise there is despair or an apparent lack of relevance. Perhaps educationally and by appreciating the Art of discussing research needs acquiring in the computer field.

NOTES:

As a result of the panel discussions, almost 40 questions were raised from the floor, many of these concerned the same kind of problem-areas.

The most relevant ones are listed here, with reference number to the text of the summary.

(1) What is producing the widespread hostility of students and other young people, toward 'the computer'. Are there possibilities for changing these violent attitudes to more favorable viewpoints or does the hostility have a 'validity', that should be accepted and basic 'causes' removed?

(2) The panel seems to adopt the point of view that computers will have an impact on society and that their job is to consider this impact.
However, are we not agreed that society is sick, perhaps mortally?
Should we not be discussing how computers, education and informatics can be used to create a healthy impact on society?

(3) As we all know, there are economical and educational differences among different countries, they all have different problems.
However, as it seems to me, we are not taking this fact into account. Do the panel agree that it would be very useful to discuss the problems of developing countries and to come out with certain comments and recommendations.

(4) Is there a consensus of opinion on what level of education is needed before a child is exposed to education with the help of a computer? In my opinion one needs a sort of basic education, given slowly, up to a certain point at which computers can be introduced, after which the intake-curve could go up steeper.

(5) Emphasize People, instead of Machines. Drop: 'The computer this..., the computer that...' Use: 'Analyst this..., Programmer that...' Or select a better handle for those who are behind the work, which may use a computer.
Do not let educators succomb to the popularistic trend of emphasizing the slaves and trying to focus on them. Emphasize people, and focus on their responsibility to jobs they accept.

(6) As we hear from J.K. Galbraith and others, we are witnessing the rise of a powerful and independent class of experts, especially programmers. In what ways can education alleviate the dangers this involves?

(7) The idea of national and international data banks frighten the layman. How can we convince him of the security of such records?

(8) One the one hand one can investigate and do experiments in computerized instruction without a lot of money. On the other hand, who is willing to supply a lot of money when only a few reliable results, still very limited, are available? If the panel agrees on this point of view; what to do?

(9) In my opinion, it is the government that pays the investment for education, and it is business/industry who earns the return on this investment. Does the panel agree that this could be one of the main reasons for the rather slow development of education; that a very close cooperation between the government and business/industry in developing a new education strategy will be necessary, and that government must be freed to a certain extent from the colossal financial burden by business/industry?

(10) The congress is concerned, as it seems, with data-structures.
But that is not the magic word, when one does not add the tern logical structure to it. The magic word for me is systemisation. Can the panel agree to this or give directions if not?

(11) How do we improve the image of computer science, or in terms of this conference: how do we educate the public as to the actual impact of computers on society– what computers can and cannot do; what their strengths and what their limitations are?

(12) Although many excellent ideas have emerged from this conference, one characteristic displayed by many speakers is the tendancy to dwell at length upon personal ignorance.
We do not, apparently, know what education is, how to structure information, how people learn, what informatics is, how to write computer programs etc. What we do know is minimal.
Ladies and gentlemen, we, collectively, are the world authority. If we are as ignorant as we claim, is it surprising that a damaging mystique surrounds the subject for the man who is presently digging up the Damrak (one of the main streets in Amsterdam, editor). That same damaging mystique seems to induce us too.

THE CHALLENGE OF COMPUTER EDUCATION:

J.J.A. Vollebergh

Some observations on the social impact of computers on society and, consequently, on education.

Innovation and automation

Automation, like any innovation, can only develop via an open-end strategy in which many are participating.

The final impact of an innovation cannot possibly be foretold, since its relations with the real-life situation are still unknown.
Only after the innovation is generally accepted we are able to see its real importance or its insignificance. Extrapolations as well as analyses of objectives are often too strongly associated with today's situation for the future to be perspicuous to us.
They are often coloured by fear and by the wish to preserve the existing set of values. They only show to their full advantage when associated with choosing and evaluating a line of evolution, and when they are applied for the purpose of making this evolution more explicit and of experiencing it more consciously.
They ought to be part of a strategic plan. Such plans will yield the best results when consisting of:

a) a general view of aims and needs, however vague it may be;
b) a survey of expectations about the future, based upon extrapolation;
c) a conscious choice of nearby and intermediate objectives;
d) a systematic evaluation of the chosen objectives and the underlying aims, needs and expectations; and
e) if necessary, a correction or new formulation of our policy.

Such strategic plans offer possibilities for an open evolution in the long run, in which it is at any time possible to make a more detailed choice.
It is efficient too, if we do not work consecutively on all aspects of a strategy but if different groups tackle all aspects at the same time: some studying, some experimenting, some planning and all of them participating in decisions on policy.

This concept of strategy rests on at the same time vision and pragmatism, a critical attitude towards all existing systems and a genuine engagement. Only a close cooperation of very differently oriented personalities can lead us up to it.

The development of systems

The development of modern systems of organization and communication leads towards an accelerated integration of society. Mentally, we still are not sufficiently prepared for an integrated society.
Such preparation is the most important challenge to our educational system.

The attitude a lot of people are taking versus developments is characterised by reluctancy and opposition. For this there are various reasons.

Integration supposes a synchronisation – which may be difficult to accomplish – of various organizations which have autonomously developed, yet which are often each one of them answering their purpose. E.g. two countries may each have a good and efficient railway network with different track widths. In that case, integration will entail high costs which are only worthwile for somebody who thinks in new dimensions. Such frictions between systems will therefore slow down integration, since on the short term high costs are liable to cause resistance, the more as costs rise and revenues are less obvious. Such frictions may be noted not only between technical systems, but also with regard to e.g. the labour market and in the field of education, where traditional and computer-assisted systems are showing differences in philosophy and attitude.

In all situations integration implies a loss of freedom:
one has to count with highly divergent interests, since the area of influence of modern systems is very large compared to the small living world of the past. This is experienced by a lot of people as the end of individualism and privacy, values which are so essential for many people that the possible loss or reduction of those values a priori causes them to be very reluctant.

Finally, the systems themselves are so unfamiliar to many people that they are experiencing a feeling of insecurity and dependence, which sometimes appears rather explicitly in the medical field (pacemakers, kidney dialysis). The alienation which may be the result may cause a strong aggression against technology.
An unprejudiced and creative attitude towards those problems may be expected to exist only when people have an insight into the developments they are noticing in their environment, and when they have the feeling of being able to participate in controlling those developments. This is the basis of the impact of education on the computer and on a computer-assisted society. Deepening this insight, developing the participation idea as a counterweight for feelings of insecurity and restraining fear, creating structures in which such participation is modeled, as well as promoting an attitude which is communication-oriented, are essential

factors to achieve a real integration and a regulation of discrepancies between sub-systems.

The essential question is whether our educational systems try hard enough, let alone succeed in confronting young people with the social, organizational and technological aspects of integration.
Education should have top-priority, above the solution of ever new technological problems, if we want to realize new ideas about society. In this respect the education of teachers is of paramount importance to prevent a widening of the gap between generations and social groups. What is really done about it, e.g. by teaching teachers, introducing programs in this area into the curriculum of schools etc.?

The human aspect

The human aspect of automation is broader than the problems of employment and the development of organized systems. The basic relationship of man with his social and material environment is also involved.

The employment problem is generally approached primarily from its quantitative aspect: is there enough work for everybody?
Basically, this is correct; however, as our society becomes more affluent, the quality of the work will require more attention.
Our western society has progressed where full employment can be accomplished, and a basic income can be guaranteed even for those who are out of a job. From that moment on, the work will be more and more expected to be attractive and satisfying. At the same time however, the drastic division of labour, which is one of the fundamentals of our prosperity, has taken much of the attractiveness from labour. Again it is chiefly strategy we should give our attention. In this respect, a point of prime importance is the fact that specialization is inevitable, and the forming of teams is one of the most important means for compensating for the disadvantages of specialization; furthermore, that ergonomic research into the interrelation between human skills and the requirements of labour is indispensable.
Another essential point is that specialization is not possible to the extent where all brain work can be concentrated in thinking factories, think-tanks, or whatever they may be called.
An all-round development is based on many people reflecting upon what is happening in the world around us, as well as on a variety of experiments. In this respect, redundancy is very useful in view of the fact that heuristic principles are playing a part.

For that reason we should be promoting the opportunity for getting away from everyday work for longer timespans. During those periods one may fight professional obsolescence through studying, and may especially get into contact with others more intensively, others who are working in the same or related fields. Managing and supervising, on the scientific level, such periods of leave could substitute a substantive task for e.g. our universities.
However, this will involve more complicated activities than just organising refresher-courses. It should be possible for people on leave to participate in research, workshops, individual studies and teamwork. It is an organisational task of the first order to accomplish such a plan. We often prefer, however, forms of organization which are wrongly regarded as highly efficient but in fact, by a too extreme degree of specialization, keep many people from thinking about important issues. A policy which is in many cases detrimental as well for their motivation as for their learning capacity.

Another essential point of strategy in this area is: improving the organization of the human mind itself. Already we are taking up vast quantities of information, but we hardly succeed in reproducing them at the right time and with sufficient accurancy.
Electronic equipment provides only part of a solution, since the selection of the required information is not sufficiently pertinent, but mainly, of course, because the effect of the large output of the machines is limited by the input of our mind. Strange as this may sound, this problem does not, in the first place, seem to be a rational problem of arrangement, but rather an emotional problem associated with openness, receptivity, and the absence of defense mechanisms.

Research in those fields is essential for the purpose of making detailed studies of the relation of man towards his environment and his knowledge of that environment.

We need the results of such research before we can present definite views on the desired form of organization and labour.

The role of specialists

Computer experts have their own responsibility versus further developments in this field. They will have to succeed in converting their views into general strategies which have been sufficiently adapted to social interests, and which they will have to explain to the laymen.

The great danger threatening all specialists is that of their attention being held by the 'how' to an extent where they do no longer see the 'why'. One should be aware of what values can be accomplished in order to be able to make a selection from the possibilities.

Defining those alternatives is the competence of the specialist and, in case the specialist is too busy concentrating on 'how' something is to be done, those who are deciding 'what' is to be done are deprived of the basis for their decisions. Therefore, each specialist will have to spend ample time on a conscious study of the purpose for which his contribution may be applied. There is clear evidence of a growing awareness in this respect.

The basic problem is probably lying less in the specialist being prepared to be socially engaged, than in his capability to accomplish efficient communication. One of the reasons probably is that great stress is put on the necessity of training people – on short notice – who can solve today's problems. For that purpose, courses are short, and efficiently adapted to specialist activities.
Few attention is paid to general education and to the development of personality; therefore, no sound basis is provided for the development of communicative talents in particular.

However, the main thing is that specialists should realize that they are also involved in deciding whether, and if so, how specific values are to be accomplished.

The way computers will be applied in education will have great influence on the attitude which society as a whole will adopt towards computers. The question is not in the first place whether computer experts are aware of this, but whether they will succeed in conveying this awareness onto others, especially including our youths. In this respect, a point of prime importance is that there should be a growing notion that an open-end strategy implies that we are indeed prepared to work towards a specific goal, but that we are not willing to concretely define the society of the future.

We do not just wish to improve man's living conditions, but we also strive to accomplish a structure in which, at any given moment, mankind will be able to decide for itself what does, at that moment, seem to be 'better'.

Precisely in the field of automation, at the head of technological progress, it should be possible to show the significance and value of a dynamic conception of society. Maybe this constitutes the main impact of computers on society.

SOME SOCIAL ISSUES OF COMPUTERS ON SOCIETY

by Anthony Ralston

1. SOME IMPORTANT IMPLICATIONS OF COMPUTING

Let me begin with a few remarks on the societal affects of computing already being felt in the United States. I can perhaps best express these by saying how nice it is to serve on such a panel in Amsterdam knowing that, if any disruptions take place, they will much more likely be at the Dam than here. By contrast, panel sessions on this topic in the United States often become quite unruly and, in fact, one such had to be terminated recently because the disruption got out of hand.

Of those areas in the social implications of computing which particularly concern Americans, I would single out three:

1.1 Military applications of computers. A case in point is some activity last year by a group of computer professionals, of which I was one, against the proposed anti-ballistic missile system on the technical grounds that the software would very likely be impossibly complex and, more importantly, that no program this complex could possibly be adequately tested by simulation, so that it would be bound to fail the first (and only) time it would be needed.

1.2 Public policy. Here the main debate is on the data bank question both with regard to a national data bank and data banks for such purposes as credit information. The probabilities for the national data bank appear to be one of two extremes. Either nothing will happen because of the privacy problem, which is like throwing the baby out with the bath water, or the data bank will be established with virtually none of the safeguards really required to assure privacy.

1.3 Particularly on my mind now is the fact that the Association for Computing Machinery, of which I am Vice President, has two annual conventions scheduled for 1971, a thousand miles apart during precisely the same week! The reason for this is that one of the conventions – that organized by the ACM 'establishment' – is scheduled for Chicago, a city which, because of what happened at one of our national political conventions in 1968, many people, by reason of conscience, just will not visit. More than anything else, I think this episode indicates the depth of feelings of some American computer professionals on social issues.

2. RELATION OF IMPACT OF COMPUTERS TO EDUCATION

Let me now discuss the connections between the impact of computers on society and education. The title of this session is 'The Impact of Computers on Society and Consequently on Education.' It could just as easily be 'The Impact of Computers on Education and Consequently on Society.' Both education and society feed back on one another. Very briefly now I would like to consider the impact of three areas on education and society:

a. Computer applications

b. Computer technology

c. Computer science

ad a. By computer applications, I mean just those areas where computers have clearly had their major impact thus far on both society and education. These are epitomized in education by the use of computers for solving problems by students in many disciplines. It is interesting, therefore, that there has been so little attention to this aspect of computing at this conference. Of course, the reason for this is our relatively good understanding of this area and its lack of glamor. But only at our peril do we neglect the great underutilization of the applications of computers in education. All too often, despite the availability of computers, instructors do not use them because they are unaware of the possibilities or afraid of the unknown. We should not neglect our reponsibility to rectify this situation. Herein, through better educated students, may lie the opportunity for greater if less obvious impact on society than by other means, in the near future at least.

I cannot say anything here about the potentialities for education of computer technology through CAI and time-sharing that has not already been said better at this conference. Let me, therefore, restrict myself to discussing an aspect of education which has been neglected at this conference and a danger of this new technology which we cannot afford to disregard.

ad b. The pace of technology is a problem in all industrialized societies. Men become technically obsolete, unemployable in their 50's, 40's, even 30's. Continuing education, that is, education after the completion of formal schooling, is becoming increasingly important. This is an area in which CAI could play an important role in reaching people outside of major urban centers. The problems are formidable, but I should like to see some of the efforts in computer uses for education oriented in this direction.

The danger I mentioned above is not easily described. Let me use an analogy. Contract teaching is starting to gain a foothold in the United States. This is a plan in which commercial firms contract to take over some aspect, say reading, in a public school system. The theory is that putting an economic motivation behind teaching may improve performance. But performance is usually to be measured by students' scores on standardized tests. The danger is obvious. When test scores are the measure of performance, teaching to enhance performance on tests rather than to achieve real learning may result. The analogy to CAI and related areas is, I think, clear. Within these areas lie the seeds of greater and more subtle dangers than that discussed above. We cannot ignore them.

ad c. I will conclude with just a word about the impact of computer science on education and society. Here I am using computer science in a disciplinary sense, and the impact I refer to is the effect of the discipline on the spectrum of human knowledge and, therefore, on society. At the least this implies that no man can be considered educated without some knowledge of computers; and that, therefore, we must seek ways to introduce such education at appropriate levels of everyone's education. Since a later panelist is going to amplify this theme, I shall conclude my remarks here.

THE IMPACT OF COMPUTERS ON SOCIETY AND CONSEQUENTLY ON EDUCATION; THE GHANAIAN EXPERIENCE

M.A. Bentil

Introduction

I wish to address the message in this brief talk both to top level decision makers who decide to adopt the use of computers, and to equipment suppliers. In my view, it is through the instrumentality of these two classes of people that any impact on the society in terms of computers can be felt. Therefore their education in the right direction need not be over-emphasized.

It is feared in certain quarters that the adoption of computers has the ill effect of displacing labour and thereby generating social problems. In the context of Ghana where I come from the result has been different; with the introduction of machine aided data processing systems starting with punched card systems around 1948 and then computer systems in the mid 1960's, new and additional employment opportunities have been created in the user organizations. On the other hand the equipment suppliers who failed to educate and prepare adequately the users of their equipment soon realized that they were being pushed out of the market. To them it was loss of business and naturally laying off of staff. I shall explain what happened.

Historical Development

At this point it might be useful to give a brief account of the development of nachine aided data-processing in Ghana. The first data processing machines (Power Samas) were installed and put to use in Ghana around 1948. They were used for processing statistical data relating to trade and commercial activities of the Government, and the 1950 population census. Between 1948 and 1963 other applications including financial and accounting systems, tax administration, payroll and weather forecasting, were introduced. During the period in question punched card equipment was in vogue, and there were about half a dozen separate installations.

The successes achieved were impressive and therefore encouraged the Government, the major user of data processing equipment to acquire computers in place of punched card equipment in the hope of achieving yet better results in public management. Therefore by 1964 the first computer system had been established. Since then the growth of computer applications has been relatively rapid; as of now, there are 13 computer installations, consisting of nine IBM machines in the 360 class, one IBM 1130, two IBM 1620 and one ICL 1901 A. Now there are computer applications embracing social security systems, voters registration, preventive equipment maintenance, inventory control, scheduling and planning, municipal rating, general statistical work, financial accounting, payroll and scientific and research work. The installations at the University of Ghana and the University of Science and Technology are also used for teaching purposes.

Impact on Society

As mentioned before, the impact made by the use of punched card equipment was most favourable, to the extent that it encouraged the Government as the major user to take a bold step in acquiring computers. But this favourable reaction has been short-lived because the high hopes that were entertained in bringing in computers have not been realized. In the area of employment, there has been stagnation because beyond the level of machine operators, virtually no indegenous people have been trained as Systems Designers and Equipment Maintenance Engineers to improve and expand computer applications for which there is yet ample room. In most cases the important functions of systems design and equipment maintenance have been the exclusive responsibility of the equipment suppliers who have been employing their own nationals for the work. I may interject by adding that the use of foreign nationals at the inital stages was inevitable, but it is hard to justify the continuance of this practice after machine aided data processing systems have been in use in Ghana for more than ten years.

Another cause for disappointment has been the unbridled acquisition of computers, resulting in a proliferation of installations a number of which duplicate the work of one another. There has been a gross under-utilization of computer capacity, coupled with waste of scarce financial resources. Quite apart from excessive idle machine time, the staff are also grossly under-employed, a situation which is sometimes more frustrating for the persons concerned than if they were not employed. From morale point of view, others who have to work under pressure to create the necessary input with which to feed the computers have complained of exploitation, to the extent of agitating for the scrapping of the computer systems.

Uprooting Anomalies

The advocates of computers seemed to have introduced computers without first ensuring that the users were properly and fully inducted on the use of their machines and systems. The man at the top who decides on the acceptance of the system is invariably not sufficiently educated to appreciate that the first and inescapable step in a computer application is a thorough systems study geared towards optimum utilization of resources. Very often, the decision maker is led to take a narrow or parochial view of comoputer applications, rather than appreciating the need for a global integration of management information systems. In this case what happens is that he goes in for a separate installation which often runs parallel to an existing one. Also, because of the absence of an initial systems study, the computer system was installed to operate parallel with manual systems, or in some cases to produce the proverbial garbage.

At the operating level, as already pointed out, no meaningful steps have been taken to produce a crop of personnel adequately trained and skilled to plan and manage the computer work. Generally, old time punched card machine operators were retrained only in computer programming to take over command of the computers acquired to replace the existing punched card equipment. Although some of these persons proved suitable after their retraining, most of them could not make the grade because of their limited educational background. Thus, the handling of highly sophisticated and expensive machines was entrusted to semi-skilled operatives. Consequently, there have been costly and irritating machine break-downs.
Machine break-downs bring into focus another manpower problem: the lack of trained maintenance engineers. There has been a dearth of competent maintenance engineers with the attendant delays and slip shod work in repairs. This has often created crises which have made computer users as well as those served by computer based out-puts to throw up their arms in despair against the computer and the service it offers. For example, frequent delays in settling retiring awards and death compensations under the computerized social security system have been most frustrating to the beneficiaries in a society where the per capita income is less than $ 200. Sceptics have indeed challenged the justification for computers, and have even claimed that the computer system should be replaced by manual processing.

Solving the Problem

The situation explained can be avoided or at least mitigated only if both the decision maker who takes on the computer and the equipment supplier are educated in the right direction. The decision maker has to learn that two critical conditions should be fulfilled before a computer system is installed and applied:

a) a thorough system study should be undertaken by a competent Systems Engineer;
b) a trained Systems Engineer is always at his disposal to review and update existing systems to ensure optimum utilization of the computer after it has been installed.
c) a qualified computer maintenance engineer is available at short notice on the time to keep the machines running to full capacity.

The equipment suppliers should re-design their selling methods so as to provide adequate training for their salesmen who should learn not only to sell their equipment and systems but also sell up-to-date training methods to their clients. The user often blames the machines and not the men operating them when there is trouble; it is therefore in their paramount interest, that machine manufacturers when exploring new markets, should offer first, systems education as far as they can.

THE SOCIAL IMPACT OF COMPUTER SCIENTISTS

J. Hebenstreit

The lessons of history

As our chairman already stated I am French and therefore I have some difficulties to find the right English words to express what I want to say – I hope that despite the rather poor syntax of my speech the semantics will nevertheless go over due to the wellknown redundancy of natural languages.

Towards the middle of last century when the fundamentals of electricity were discovered and given the previsible impact of this new phenomenon on society in general, I wonder whether people did organize in these days a congress on electricity education. I am quite sure that at such a congress people would have argued about direct current versus sinusoidal current, batteries versus accumulators, accumulators versus alternators and so on. Some people would even have made predictions about the building of big power stations, containing thousands of accumulators which could in a last stage be interconnected in a big international grid which would be called tele-electricity while others would have denied this possibility because it would have been in contradiction with Ohm's law and of course the last session of this congress would have been devoted, I think you have guessed it right now, to the social impact of electricity.

This same scheme would as well apply to the invention of railways, of cars, of electronics, of television and so on.

All these things have deeply modified the way we live and we think but can we really speak of a revolution? Or should we say evolution in a way which was hardly predictable when all these things started. We remember all the speeches made on the wonderful perspectives opened to humanity through the use, should I add the peaceful use of nuclear energy.

I would like to remind that the very first computers have been built for military use and that it is still under the pressure and with the money of the Navy and the Air Force that the most sophisticated computer hardwares, softwares and systems have been designed and implemented. Should I add to this that in many countries the majority of computers in use is owned by the government. Doesn't this give a rather strange picture of the impact of computers on society.

Computers and education

On the other hand we often hear the argument that the man in the street is much more concerned with computers than he is actually aware of. It seems that this way of living is much less affected by in fact his payroll being printed by a computer than by the total amount which is printed at the bottom of this same payroll be it printed by a computer or not.

By the way why should he care that his bank is using a computer or that this newspaper has been printed with the use of a computer or that his income tax has been calculated this way or that his ticket reservation is done through a computer. Is he actually worried about the radar which is used to ensure a safe landing of the plane he is in?

Coming to the very subject of this conference which is computers in education, how much do we really know about the way people learn because this is the very problem we have to solve before beginning to implement instruction through the computer: I am afraid that despite certain brilliant theories we don't know a lot about this and that our approach is terribly empirical as if we tried to go to the moon with a very sophisticated spacecraft without any precise knowledge of the laws of gravitation. But here I am very confident in all our national ministries of education that they are ready to wait until we have found all the mechanisms of learning before giving us the money to get started so that we don't have to be too anxious about this.

All this I think sounds rather dim and perhaps even a little bit more than this because to somebody objecting that after all men will always be able to cut-off the power supply of computers. Norbert Wiener the father of cybernetics answered that the remedy might well be worse than the illness.

Before finishing I want to stress that I myself do not believe too much in all these arguments I have given but one of us had to be what we call in French 'l'avocat du diable' and I agreed to do it with the hope that our succeeding discussions will be more interesting this way.

THE ROLE OF THE TRADE UNIONS

F. Margulies

Men and Society

It seems to me a very remarkable and hopeful development that problems of men and society are gaining more and more weight in conferences like this. At the IFIP Congress 1968 at Edinburgh these problems had yet to be discussed informally since they were not on the agenda. Praise is therefore due to the Programme Committee of our present conference for giving the subject so much attention.

Speaking of society means speaking not only of computer experts, computer professionals and computer users, it means speaking of all human beings and their institutions. For a few years to come there will yet be quite a few people left who are not concerned professionally with computers but who nevertheless form the majority of our society. Let me as a trade unionist say a few words about them.

The so-called 'man on the street' hears about computers or about automation in general, he is mostly concerned and worried about the uncertainty of his own future. What he is most afraid of is the loss of his job. – But let me make this quite clear: loss of his job does not necessarily mean unemployment just as growing unemployment figures are not necessarily the result of an increase in computer (or other automatic) installations.

Given a sufficient rate of economic growth, the demand for labour due to economic expansion might well exceed the number of people laid off due to technical development. Consequently employment figures show a stability which, however, is only correct in a mathematical or statistical sense. In reality extensive structural changes are taking place continuously and at an increasing rate – affecting something like 50% of the labour force within a period of 10 years and causing considerable material, social and psychological difficulties.

Aspects of employment

Taking these facts into consideration it ought to be our concern not only to strive for an adequate economic policy in order to ensure full employment but at the same time make certain that these inevitable structural changes within the labour force do not lead to any material disadvantages or social downgrading affecting the individual. This is why trade unions in Austria aim at compelling employers to give full information to their employees about all intended technical or organisational change well in advance of their implementation. The period between placing an order for an EDP installation and putting it into operation should be used to work out a plan of social adjustment along with the technical, organisational and financial planning.

This is where computer experts come in. Their unbiased opinion might bring home to management that a computer – in order to work properly – not only needs air conditioning, but also 'human conditioning'. Employees and their representatives should be granted the opportunity to take part in all planning bodies right from the beginning, to put forward their point of view and to exert an influence on decisions.

For this purpose employees or their representatives obviously have to possess at least a basic knowledge of EDP and the problems involved. That is why Austrian Trade Unions have begun to run short elementary courses for shop stewards and trade union officers. These are not meant to turn them into experts but merely to provide them with the knowledge necessary for negotiations on personnel planning in connection with EDP installations.

A first series of such courses was organised at the beginning of this year and met with excellent response. More than 1000 people attended the lectures given by outstanding experts from universities, secondary schools and firms. A new series is now in preparation and will for the first time include one course on a slightly higher level as a sort of 'advanced training'.

Job enrichment

Job security, however, is only one side of our concern, job enrichment seems to me equally important. I believe the experience is the same everywhere: the more man's material needs can be satisfied, the more deliberate, the more urgent becomes his drive for self-fulfillment; neglecting this element spells frustration and despair – especially for young people.

Taking this into account means that new motivations for work have to be found. Work in our industrial society, with its extreme division of labour, its separation between the thinking few and the toiling mass, with its utter alienation between man and his work can offer only one satisfaction: money. The time has come to look for more human motives.

In 1968, Frederick Herzberg, professor of psychology at a USA university published an article on 'How Do You Motivate Employees? ' There he put forward some principles of 'scientific job enrichment'. His idea was to change existing jobs so as to allow for greater responsibility, more decision making etc., thus giving more scope to personal achievement and its recognition. These principles have since been checked by studies carried out in several British firms over periods lasting between six months and one year. These studies confirmed in every case that job enrichment quite remarkably improved both task efficiency and human satisfaction.

In Austria the installation of a computer for process control of four interdependent power stations was combined with a similar experiment: the whole installation was laid out to make the man-machine system optimal not with respect to the machine but to the people working with it. Here too the result was better than predicted.

The scientific and technical revolution of our time is obviously presenting a great chance to man: reversing the alienation process of the industrial revolution. By assigning the monotonous, dull work to automatic machines, men could cease to be the servant of the machine, he could be freed for creative work, thus taking one of the steps necessary to overcome alienation.

Looking into the future

In this respect computers offer particularly hopeful aspects. Contrary to the views that still prevail, they seem predestined to complement man rather then to replace him. The more complex the task, the more complicated an algorithmic solution, the more indispensable man's intelligence becomes; this fact is increasingly being acknowledged in control engineering as well as in information science. Developments distinctly tend towards man-machine communication, the direct dialogue and the division of labour between man and computer, with the latter doing the tedious, time-consuming routine calculations which furnish the bases and information for decisions. The decision, however, remains the prerogative of man; yet, man is able to make such decisions with more certainty and more rapidly than ever before when aided by the computer because man's fundamental superiority over the machine consists in his capacity to choose between alternatives, in his ability to creatively process information. Thus man could expand his intellectual performance with the aid of the computer just as earlier tools and machines multiplied man's physical powers.

Shall we be able to make use of this chance? How can we make sure that among the different possibilities of solving technical or organisational problems, the one is chosen that offers optimal conditions not in terms of the machine or profit but in terms of man? In my opinion there are two prerequisite conditions for this:

1) that trade-unions obtain the right to participate in decision-making pertaining to all economic, technological and organisational matters to ensure that human demands as opposed to the employers' target concepts are enforced.

2) that scientists, computer experts and computer teachers give this new aspect of technical development their unreserved support, for example by including lectures on the impact of computers on men and society in their respective syllabus.

Summing up I think we all agree, that somehow we have arrived at a turning point of our society. Certainly there were other turning points in the course of history, but what happened in former times by no means induces us to let matters drift as was the case in the past. Automation and especially computers bring about huge difficulties and risks; on the other hand, automation shows the way into a promising future where man might live to find and develop and fulfill his individual personality. It is up to us to avoid the risks and pave the way to creativity.

Much will depend on how far we succeed in bringing these points forward within general education also, not just in computer education. Trade Unions as representatives of manual and non-manual workers will have to bear great responsibility as to the future developments and they are quite willing to do so. At the same time we trust that scientists and experts all over the world will give attention to the problems of non-computer people also and will help us in making the computer a tool for gaining a better world.

THE CERI PROGRAMME ON COMPUTER-BASED LEARNING SYSTEMS

A.G. Khan

Statement prepared by Dr. Abdul G. Khan on behalf of Mr. J. R. Gass, Director of the Centre for Educational Research and Innovation.

1. COMPUTER-BASED LEARNING

The introduction of computer-based learning systems (a) represents qualitative changes in the educational process, and (b) calls for the mobilisation of large resources in terms of money, equipment and skills. The problem is therefore a major concern of public policy in education. This realisation has led the O.E.C.D. 's Centre for Educational Research and Innovation to take on a number of activities concerning the use of computers in education as part of its overall programme on Curriculum Development and Educational Technology.

The Centre's promotional and disseminational effort in the field of computer-based learning systems falls into two broad areas:

1.1.field experiments in the use of computers in higher education

1.2.development and introduction of computer science concepts and practice in secondary education.

These two activities are consistent with the Centre's purpose of developing policies, structures and methods for promoting educational innovations. Experience gained from these activities may lead to certain broad policy recommendations on the use of computers in education which will serve as guidelines for O.E.C.D. Member countries.

2. FIELD EXPERIMENTS IN THE USE OF COMPUTERS IN HIGHER EDUCATION

In order that international co-operation should have a major impact, the Centre has directed its attention to certain selected points for experimental work. Five countries are co-operating with us in our experimental work on computer-based learning systems. A list of these experiments is provided in the table below, and a resumé of each is given in the Annex.

CERI-sponsored Field Experiments in the Use of Computers in Higher Education

Country	Location	Resource Person
United Kingdom	Cambridge University Dept. of Applied Mathematics and Theoretical Physics	Prof. G K. Batchelor
Belgium	University of Louvain General Physics Laboratory	Prof. N. Jones
France	University of Paris Faculty of Sciences Dept. of Physics	Prof. Le Corre
Japan	University of Osaka Faculty of Arts Dept. of Psychology	Prof. S. Tanaka
Netherlands	University of Leiden Pedagogical Institute	Prof. Dr. L. de Klerk

In addition to these activities, the Centre convened an international meeting of experts from 19th to 21st March in Paris. The purpose of the meeting was to have first-hand reports on the application of the computer for educational purposes in institutions for higher education. In describing the experiments carried out in their own countries, the experts presented the current situations and the difficulties encountered. The meeting enabled the participants to extend the debate to fruitful areas of international co-operation. For this purpose, an international working party has been organised.

3. DEVELOPMENT AND INTRODUCTION OF COMPUTER SCIENCE CONCEPTS AND PRACTICE IN SECONDARY SCHOOLS

The Centre convened an international seminar on Computer Science in Secondary Education from 9th to 14th March at Sèvres, near Paris. The broad conclusion to be drawn from this seminar is that the introduction of computer science in secondary schools in the Member countries has become a practical issue of considerable importance and has already reached the point where a number of specific experimental and development projects need to be launched. There is also widespread agreement that this development work could be most effectively and economically accomplished through international co-operation to achieve an effective sharing of development tasks and results.

A working group has been set up to examine three areas of computer science curriculum development for secondary education:

(i) it will conduct a critical analysis of existing curricula, one aim being to propose guidelines for an initiation course which could be introduced in the Member countries;

(ii) it will set up a group of experts to review the available technical means for introducing computer science in secondary schools, and to make proposals to Member countries concerning policies to develop and use such technical means, including relationships with the industrial sector.

(iii) it will develop a training course, or courses, for teachers which could be widely used in Member countries.

The group is expected to arrive at international recommendations covering the content, media and teacher-training requirements in this field. The first meeting of this group is scheduled for 24th September, 1970.

ANNEX

Resumé of CERI sponsored Field Experiments on The Use of Computers in Higher Educations

I UNITED KINGDOM
(Cambridge University – Department of Applied Mathematics and Theoretical Physics)

1. In contrast with its customary use as a research aid and as a basis for training computer users, the computer in this project is conceived as an aid in teaching mathematics-based subjects in which numerical or diagrammatic information is at least part of the end product.

2. Under the present project it is proposed to use a computer in two main ways: as an aid in the delivery of lectures, corresponding to a demonstration in the course of a science lecture and as a means of allowing practical work by students corresponding to the planned laboratory work of a science student.

3. The arrangements for collective use would be as follows:–

– a lecture theatre would be equipped with a display screen (a large cathode-ray tube) and a control box linked to a hybrid computer elsewhere in the building. The display screen is part of a closed-circuit television system, with the camera recording the output screen of the computer. The lecturer's control box contains a number of push-buttons, each of which can initiate a separate task, and knobs with variable settings, each of which allows the lecturer to change the value of a parameter involved in the computational problem, thus illustrating certain physical laws and their mathematical formulation. If full use is to be made of the computer, it is essential for lecturers to analyse their teaching so as to determine the areas of knowledge most suited to such an approach.

4. The great value of the system, however, is that it gives individual students (or small groups of students) practice **in the techniques of numerical work** and in **understanding the mathematical structure and physical significance of the problems chosen for that purpose** – these being precisely the goals of 'practical work' in teaching. Since the computer, unlike a textbook, can record the approach of each student to a given problem and compare it with the 'models' stored, it offers both students and teachers a means of **continuously checking knowledge**. It goes without saying, moreover, that only computers can familiarise students with the **simulation and solution of problems**, which are fundamental approaches in physics teaching.

5. Unlike many projects using 'big' multiple terminal machines – usally connected to typewriters – the system set up at Cambridge for this experiment features small computers hooked up to complex terminals. The nucleus of the system is constituted by two small computers:

– a digital PDP8 computer for all calculations involving numerical quantities; and
– an analogue computer (TAG) for converting numerical inputs into curves.

Within the overall system, these two computers are governed by a 'controller', which in this case is another small digital computer.

Communication between students and computer is through terminals equipped with:
(a) a teletype;
(b) a cathode-ray display; and
(c) a control box.

These three items of auxiliary equipment are, of course, connected with one another, and inputs to the computer pass through either (a) or (c), whilst outputs (to the student) pass through either (a) or (b).

6. The sponsors of the project envisage the following time-table for operations:

– during the **first phase**, starting in October 1969, the system will be set up and used in third-year classes (100 students), mainly for individual work. In the early stages, the emphasis would be on practical classes, and a collection of suitable exercises with detailed instruction sheets would gradually be built up. The objective at the end of the trial period would be a programme of teaching applied mathematics to third-year students in which the use of a computer was fully integrated with the conventional aids and methods;
– in the **second phase**, the experiment would be extended to second and third-year students (numbering 215 and 280 respectively), and the sponsors envisage the installation of a group display system. At this date (early 1971), first overall evaluation of the experiment and its results, will be made.

Plans call for the gradual installation of a dozen or so terminals in the course of the experiment. In addition, closed-circuit television will be added to the system for both group and individual use.

II BELGIUM (University of Louvain – General Physics Laboratory)

1. The experiment is part of a general physics course (1) and is designed:
(a) to allow each student, after following a series of lectures, to check the knowledge he has acquired. This check is based on one of the major axioms of programmed learning: correction or immediate repetition;
(b) to analyse learning behaviour.

2. Analysis of learning behaviour, which is indispensable not only in itself but also in achieving the first goal (knowledge testing) involves the following steps:

– breaking the subject down into items;
– defining a strategy, i.e. examining how the subject may be adapted to each student, what path should be followed and what techniques should be used in passing from one item to another;
– analysing learning mechanisms, i.e. the behaviour of the learner, wrong answers, the paths followed and mental blocks reacting on the subject;
– improving techniques for transmitting information;
– constructing a model for measuring results by checking:
  the acquisition of knowledge, using conventional types of examination;
  creativity, using a new type of examination (currently under study in conjunction with Professor A.

Kaufmann of Grenoble);

reasoning power, by setting catch questions.

The techniques used in this study are computerised recapitulation and 'audio-tutoring'.

3. The scale on which these operations will be carried out depends on the resources available. For the first year (1969), only a limited version has been adopted. Subsequent plans call for both large-scale and limited versions (1970 and 1971), but intermediate versions are, of course, conceivable and it is always possible to switch over from one version to another.

The large-scale version places more emphasis on research, dealing with the problems of simulating experiments

4. The table shows, for each version, the goals which the sponsors of the project hope to achieve in the nect few years.

5. The set up is relatively simple, especially in the limited version. A number of terminals, four in this case, constituted by MS33 teletype machines installed at the university of Louvain are linked part time to the GE235 computer at the University of Brussels, using a Datanet 30. Provision is made for additional terminals to be installed at Louvain or elsewhere should the necessary funds be available.

6. During the second phase of the project, the sponsors contemplate the use of audio-visual terminals.

III. FRANCE

(University of Paris – Faculty of Sciences, Department of Physics)

In the context of the teaching of electricity at University level, which is divided into three parts (lectures, tutorials, practical work), it is essential that each student's knowledge should be checked between the time when he is following lectures and the periods in tutorials where these lectures are to be applied. Taking into account the large number of students in this branch of education (at present several hundred), the organisation of series of oral tests is practically impossible and at an appreciably lower cost a computer can carry out almost the same task.

The objective of this experiment is twofold:–

- to interest those students who know their work, while checking on their knowledge;
- to give the others the opportunity of filling in gaps in their knowledge on fundamental points.

The computer is used to present students with a series of questions on a given subject, and the questionnaire itself contains one of the subsidiary questions corresponding with various possible mistakes analysed by the machine. The 'explanation circuits' relating to the error committed make it possible for the computer to assess the student's ability, the main criteria being:–

- the number of departures from the main sequence;
- the time the students take to reach the question where the request for assessment is made.

Taking into account the result obtained the computer decides automatically (by reason of the program compiled by the teaching staff which has been fed into it):

- to continue as before;
- to switch the student to a simpler questionnaire;
- to call the assistant supervising the class, if the machine is unable to take a decision concerning the student being questioned.

Obviously, a student in difficulties can at any time ask for explanations, first by typing 'help' on his keyboard, which connects him immediately to a simpler questionnaire; this will in the last resort put him in touch with the assistant in charge of supervision.

In actual fact, the project described above has already been the subject of preliminary trials. As from 1967 the Ministry of Education and the General Delegation for Scientific and Technological Research have made the necessary funds available for launching experiments in this field. Since November 1968, 150 students have been regularly tested every week and more than 30 questionnaires have been prepared, part of the responsibility for the preparation being given to about 30 of the older students under the guidance of one of the teaching team.

In addition, since 1966 the team in charge has prepared several sets of programs some for the purpose of controlling all the student-terminals on a 'time-sharing' basis, others for analysing the student replies by succesively comparing them with the various programmed answers and finally, the remainder for servicing the system (print-out of questionnaires, preparation of charts, etc.....).

A language suitable for the preparation of questionnaires has been developed (Minitran II of SYMPLE) which makes it possible to introduce, among other things, the students to programming techniques.

The present set-up consists of:–

- an I.B.M. 360/30 computer with a central store of 16 K octets; the small capacity of this store makes it necessary for questionnaires to be divided into several parts which are successively called from the central store;
- usual peripheral material (1403 Printer, 1442 reader and punch, 2311 disc deck);
- twenty 1052 terminals (typewriters) connected to the central unit by means of a 2701 control unit and a 3965 terminals concentrator. It should be noted that these typewriters are equipped with a 'golf-ball' on which the characters are those used in the teaching of physics.

The limitations imposed by the low capacity of the system have so far made it impossible for the team in charge to develop some of the projects which germinated from the initial program. This is the case for:–

- the analysis of free answers given by the students, although the results the team in charge obtained show considerable progress over the first attempts;
- the extension of the experiment to various other areas of scientific teaching. Tests already made for Mathematics and Biology have shown that there too the diversity of possible algorithms soon leads to saturation of the system;
- the study of the method of resolving the exercises and problems. This point seems of capital importance for the progress of the teaching of scientific disciplines, because if such a system could be developed it would be an exceptional tool for determining learning processes.

In these circumstances, and at the risk of seeing these very detailed and rewarding experiments lose some of their meaning, it seems essential to boost the capacity of the system.

But prior to any amplification of the store and to any modification in the existing configuration, it is important:–

- to prepare and test the programs for operating a 64k system;
- to develop the question-and-answer unit control

system and to improve the analysis of the students' free answers;
- to design and develop a 'mathematical golf-ball' for the student terminals.

The work undertaken by the team under Professor Le Corre is being done in close collaboration with other laboratories or bodies in universities and elsewhere and both at national and international level. This applies to the questionnaires themselves, which are discussed both as to content and form with the team led by Professor Jones (Belgium) whose experiment is linked with the Joint Project. The same collaboration exists with the United Kingdom and the United States.

While the achievement of the objectives listed above will be a matter of a few monts, the team concerned has, of course, promised the Centre its active co-operation in the Joint Project for the whole of the latter's duration, and for the same purposes (producing reports, making studies, taking part in meetings, exchanging information, etc.).

IV. JAPAN

(University of Osaka – Faculty of Arts, Department of Psychology)

At the level of the final years of secondary education and the first part of the university course, the compilers of the project intend to develop a teaching method for Statistics which would be checked by computer. This check would make it possible amongst other things to compare different forms of data presentation:–

- a **'linear'** technique which would comprise a single teaching method, the same items of information being presented in a single strictly defined order, the students, having to solve identical problems;
- a **'branch or fork'** technique, in which the direction taken by each of the students following the questionnaire would depend on the answers given in 'multiple decision' situations;
- a **'jump'** technique where on a linear progression the questionnaire is programmed to provide 'loops' – revision in cases of knowledge gaps, acceleration in cases where the student shows an above average level of knowledge.

This experiment would make it possible to compare different teaching approaches as regards their effects in terms of developing creativity, the use of a computer facilitating the rapid processing of such essential data as the level of knowledge, the intellectual aptitudes, age, sex, etc.....

The data processing system already set up at the beginning of 1969 by those responsible for the project consists of:–

- one HTAC-10 computer with a central store of 8k words;
- peripheral equipment: disc deck control unit, etc.....;
- 4 teletype machines connected to video and C.R.T. recorders.

V. THE NETHERLANDS

(University of Leiden – Pedagogical Institute)

1. One of the two main objectives of this Project is to study **the role and nature of switching during a programme** as part of computer-assisted education. One of the advantages of the computer in this kind of application is its adaptability to various types of pupil behaviour as evidenced in his replies to questions asked during the course. Theoretically, there is, of course, an endless number of possible replies to a question, however specific it may be. Yet, only some point to any significant type of behaviour, and it is in terms of these responses that the programme should be patterned. One objective of this experiment is, therefore, to study the nature of these replies and how programmes can be organised accordingly.

2. The question of languages is equally important. In this type of application language is defined as 'an organised set of codes used to instruct the machine in the various tasks it is desired to perform'.

In the context of computer-assisted education, the function of languages is to make it easier to set up the course (the introduction of information and questions into the machine by the teacher, the analysis of replies, and the overall management of subject matter and curricula from both the students' and teachers' standpoint). What should the structure of the languages be as determined by educational functions required from these languages so that all the information contained in the student's reply will be taken into account and the conversational aspect of such a use thus turned to best advantage? This problem, which seems to be a particular feature of computer-assisted education, is the second theme of research underlying the experiment described in this document.

3. A third aspect, at the frontier of research and development, concerns the type of terminal equipment. In most current experimentation the peripherals used are teleprinters. Although this sort of device is a simple one, its capacity for communication is admittedly limited since it is unable to transmit information of a graphical kind and still less to receive replies in this form from the student. Moreover, development trends in computer technology show that such visual peripheral equipment as cathode display units, light pens, etc., are a future answer to these communication problems (which do not only arise in connection with computer-assisted education). For this reason it is important to define the advantages and costs of such a solution. Research into such 'interface' considerations is the third theme of the Project.

4. Finally, it is important that the soundness of computer-assisted education be invariably tested in an actual teaching context. The authors, therefore, intend to take advantage of the experiment by devising a set of statistical programmes for students of the human sciences, the teaching of computer science and cybernetics, etc.

5. For purposes of the Project in question, two computers will be used: –

(a) an I.B.M. 360/50 (model M) with a central store of 512k, to which will be added three auxiliary magnetic stores (M.2400), a disk unit (M.2314) and at least five 1050 terminals. This system will be used to meet objectives (1), (2) and (3);

(b) a P.D.P.-8 with a central store of 8 to 32k and an audio-visual terminal to meet objective (4).

(1) Based on the Manual of Physics drawn up at the University of Berkeley, the same textbook is also being used in the experiment conducted in Paris by Professor Le Corre.

Targets	1970	Limited version 1971	1972	1973	Large-scale version 1971	1972	1973
Number of students	250	250	250	250	1,000	1,000	1,000
1. **Physics** Drafting mechanics test question sheets	XX	XX	X	+	XX	X	+
Adapting electricity question sheets	XX	XX	X	+	XX	X	+
Adapting thermodynamics question sheets			X	X	(X)	XX	+
Stimulating creativity (testing of students)	(X)	X	XX	X	XX	XX	XX
Simulating experiments			(X)	X	(X)	X	XX
Decisions regarding equipment (computer, terminals)			(X)	X	(X)	X	
Combination with audio-tutoring scheme				X		(X)	XX
Combination with theoretical and practical exercises						(X)	XX
Computerised checking of knowledge (learning, creativity, reasoning power)				X			X
2. **Psychology and Education** Correcting question sheets	X	XX	X	+	XX	X	+
Learner behaviour (analysis)	(X)	X	X	XX	XX	X	+
Reasoning followed by student	(X)	X	XX	XX	XX	XX	X
Linguistic analysis of student-computer communications					(X)	X	XX
Comparison of various teaching methods				(X)		(X)	XX
Active group learning							X
3. **Information science** Graphic structuring of items				(X)		XX	X
Optimum-path method				(X)		X	XX
Psychological and educational teaching models				(X)			XX

(X) = Preliminary study.
X = One-man research.
XX = Intensive group research
\+ = Completed.

Note: In this table, the entries 'adaptation of electricity question sheets' and 'adaptation of thermodynamics question sheets' refer to the task of transposing, for use on our equipment, the question sheets drawn up by Professor Y. Le Corre and his team at the Faculty of Sciences in Paris.

CLOSING ADDRESS

BY

DOV CHEVION

vice-president of IFIP

Mr. Chairman, dear conference participants,

One might have wondered why it was necessary to devote a special international conference to computer education. It is customary to organise conferences devoted to a profession but it is not quite so to focus a conference on the education of that profession. I hope that now, at the conclusion of the conference, it became really superfluous to answer that question.

The entrance of computers into society brought with it fundamental changes which by far exceed the changes in various different professions in the past. Their growth in number in the last decade, their great impact on all spheres of life and on all strata of the population, the deep involvement in scientific and administrative matters had caused the computer and education for the use of the computer to become more and more the object of interest not only to people professionally connected with the computer world, but also to the many millions who in their day to day life depend in the execution of their professions on the utilisation and knowledge of computers. This seems to be first and the most fundamental reason why computer education had become of such wide interest, surpassing by far the interest in the education of other professions. fundamental reason why computer education has become of such wide interest, computer training is the constant development of its technology, its sophistication, its scale and consequently the demand for more and more skilled manpower, thus we are faced with a paradoxical situation: while on the one hand the computer hads contributed to the solution of many problems of manpower shortage, it has created on the other hand a severe problem of manpower shortage of its own: of course the manpower relieved by the computer and the manpower required by the computer is not one and the same, neither in quality nor in quantity.
Generally we may say that we have effected a trade-off of quantity against quality and I hope that in the long run it will be a quite 'profitable business' for society as a whole.

Even though our gain in quantity is quite substantial, nevertheless we have to face that world-wide it is necessary to speak of the education of hundreds of thousands of professionals at various levels and of many millions of persons to whom general knowledge about computers, their true value, their advantages and disadvantages, their perils and the price we have to pay in order to get the advantages materialised and the perils neutralised is essential.

Computer technology has also brought about another peculiar situation: the development of technology is much faster than the possibility to create a new breed of manpower. We cannot of course bring this development to a standstill and wait until the next and new generation of professionals is ready.
We have thus to face an extremely difficult task, from the social and didactical point of view, namely, the retraining and the adaption of persons already trained in other professions to computer professionals, to persons able to be involved in computer applications. This time it is not only education, which is as such very complicated, but re-education which in some ways is even more complicated than education itself.

The awareness of computer education has become more and more general. It was not so ten or five years ago, but it is now quite clear that computer education has to begin in secondary school and maybe earlier. Computer education has to be included as an independent subject in higher institutions of education and to be widely included in various educational institutes on a post-secondary and vocational level or para-university education level. Although, as we have heard here, in nearly all countries where the use of computers has reached a medium to high level, computer education is being organised at the various levels and although we have already a fair amount of experience in quite a number of countries, we can hardly state that a standard curriculum for the various grades of education has emerged.

The difficulty in computer education originates from various sources. We do not face a problem as long as we include in this curriculum subjects which were taught witherto within a different discipline. We can list a substabtial number of courses in mathematics , engineering and logic which are of course relatively easy to organise as these already existed before and the only problem is to shape them within another organisational structure.

The difficulty arises when we start to define the specific topics which have to be included in computer education at various professional levels. This is especially a cardinal problem in all those cases in which the new and characteristic computer-education topic has not yet reached the required degree of uniformity and specific crystallization. Let us take as an example the education of system analysts and teaching them information processing system theory.

The difficulties which we encounter here are not so much inherent in computer education as such but in the still not yet fully developed teaching of this new subject as applied to any living organism and to society systems specifaically. So what to teach in the various levels is really a very difficult problem.

In many cases in fact it is a collection of various topics brought together under the heading 'computer education' which were taught before, under another classification, in different professions. The new and additional subjects have still not yet emerged clearly enough and did not boil down to fully established analytical disciplines. The teaching by experience, exercise and by 'training on the job' is thus a real must. We have here another trade-off: shortcomings in theoretical knowledge have bartered, so to speak, against experience and 'training on the job', where the proper solution can only be provided by experience and intuition. Dependency on such a barter is not peculiar only to computer education, although it is quite characteristic of it. The curricula for the education of computer professionals have thus in the majority of cases to solve a problem of how to transfer to the student, along with well-delineated theoretical studies, experience which can be gained only after a period of a number of years, within a much shorter period. This means that the practical training of the student should be so well prepared, so well supervised and so well selected that everyone who passes this training will be nearly as proficient as those who have usually to rely on experience gained in a random way during a much longer period. In other words, we face the need to include in computer education, at the various levels, and especially on the vocational one, along theoretical subjects also 'on the job practical work' for half a year to a year at least: such a year should be equivalent to four to five years of random experience gained otherwise. With the ever growing need for professional manpower such a: 'squeeze' of experience is of the utmost importance in facing the real problem of computer education curricula. The extent to which this will be achieved will determine the degree of success in creating many new professionals in the most efficient and fastest way!

Computer education should by all means not be restricted to the education of a skill only. Secondary education might be here a good example. It is, I assume, generally felt to be improper, as a rule, to link computer education with mathematical education only. The role of computers and their impact have to be included in the teachings of history, sociology and even languages and arts in general. Has not computer science contributed quite a number of new points of view and new didactical methods which are of importance to the education of a modern man? More than that, are they not a must in such an education? How about the philosophy of the flowchart? The search for an algorithm behind the human decision process? How about the philosophy of debugging and the way of thinking behind it? How about the notion of feedback and interaction between the human intellect and the computer?

We encounter, as already mentioned, quite substantial difficulties in devising curricula about computers and their utilization; however, we are still less successful in including the so-called computer philosophy in education as such. More research into this area seems to be of substantial importance.

It is not astonishing – in view of everything that has already been said about computer education – that the role of governments and of national planning in this field is of invaluable importance. The reason for the special role played by the government and by national planning is the necessity to solve the problem of manpower, in great numbers in the shortest time possible, especially in applications areas as well as in research; otherwise we might face a gap which could be detrimental to the development of society.
The only way to avert a crisis is to plan carefully, on a large scale, and not leave matters to develop by themselves.
For such a course of events the problem is too large, it will take too much time, it will cost too much money and the solution will be too inefficient.

So it is not suprising if the aspect of government planning, of national planning, has been dealt with quite substantially at this conference. Problems of professional selection, professional tests, professional certificates, professional classification and the organisation of 'on the job training' being complementary to the theoretical education at the various institutes – all that has to be regulated on a national scale.
It is perhaps at the moment pitiful that although higher education is a requirement for all senior computer professionals, it cannot be left to the universities alone to solve the problem. While the universities focus their interest on some aspects and the various vocational institutions on others, an integrated planning effort, by a central body in each country, is essential to solve the problems of computer education.

Computer education is not only the interest of developed countries. It is becoming more and more of interest to developing countries which now still stand behind. It is by no means an established rule that development has to take the same time in each stage of development in each country in the world. In this world of fast communication and constant interaction it is quite possible to utilize the developments in the field of computer education, which are so decisive for developed countries, also to developing ones after a suitable adaptation. This international gathering might more than any other contribute to the development of all countries in the world. It may be impossible to skip phases of development but it is certainly correct to say that one could accelerate and pass some stages in a smoother way, if planned well. This applies fully and totally also to computer education.

Quite a numer of ideas have been voiced here about computer education and the use of computers for education. However, we have touched only lightly on a third problem, namely: the contribution of computers and their philosophy to education. This is a most difficult topic and probably most important. It is to be hoped that in our future conferences more attention will be paid to it.

We may now sum up.

Computer education has become a major focus and a pre-condition in the smooth development of society.

Computer education must face the difficult problem of re-education.

Computer education has to build into its curriculum the proper 'barter' of long and random experience into much shorter and well devised 'on the job training'.

Computer education has to be planned on a **national** basis and, finally,

Computer education is a prominent tool for development all over the world and in developing countries particularly.

These major conclusions should be accompanied by an earnest effort to strengthen research in the main field of the contribution of computers and computer philosophy to education as a whole.

It seems to have been quite justifiable on the part of the IFIP Technical Committee on Education and the IFIP Administrative Data Processing Group to organise this important conference. It coincides well with the growing need for international worldwide action on behalf of the United Nations organisations on the use of computers and computer technology for development.

I am sure we all greatly appreciate the immense work done by the Steering Committee headed by its Chairman, Mr. Duyverman, by the Programme Committee Chairman, Professor Wolbers, the Chairman of TC3, Professor Buckingham, and the Secretary General, Mr Veenhuis, who has done so much work under very difficult conditions.

Furthermore, we should like to express our appreciation to the chairmen of the various sessions, to the lecturers and to the many collaborators who have made the conference the success it is.

Sincere thanks are extended to the Centre for Educational Research and Innovation, CERI, the Organisation for Economic Cooperation and Development, OECD, the Intergovernmental Bureau for Informatics, IBI, and the various Dutch and Belgian organisations and institutes for their cooperation and assistance.

Last but not least may I express our heartiest gratitude and thanks to His Royal Highness the Prince of the Netherlands for his patronage of the conference and for the extremely warm hospitality characteristic of the Dutch people enjoyed by the participants from all over the world.
Participants from 42 countries took part in the conference. Let us hope that following the call from this conference we shall use the benefits of computer technology, through well devised computer education, for the benefit of all nations in the world!

GENERAL REPORT

Bob Scheepmaker and Karl L. Zinn

1. INTRODUCTION

The Technical Programme of the World Conference on Computer Education consisted out of 20 sessions, five plenary sessions as well as 15 working-sessions organized in parallel. In the five days of the conference, more than 125 papers were presented by the authors and discussed. The main subject of Computers and Education was treated in so many ways, and such a number of ideas and suggestions were presented, the editors were asked to summarize and present a selection of relevant issues at the start of the final plenary session on recommendations. The conclusions drafted by the Recommendation Committee then were discussed by the participants. The final version of these recommendations are printed after this chapter.

The general report presented during the Conference is the basis for this chapter. It is intended to provide the reader with a framework for entering into the invited and contributed papers, and to enable him better to "evaluate" the Conference by focussing on the most relevant opinions accepted by the majority of the participants, as well as on those ideas and subjects which were disputed, sometimes quite strongly. The ideas mentioned in this report are primarily those of "the participants" of the Conference; it was derived from reports prepared following each session. Each chairman was assisted by a secretary and a rapporteur who were responsible for reporting the discussions and for phrasing the conclusions and/or recommendations. The authors of this general report are, however, responsible for the structure of it and therefore for the corresponding impressions obtained from it by the reader.

2. IMPORTANCE OF EXISTING AND FUTURE SITUATIONS

At the opening session Prof. Zemanek reminded the Conference participants about several levels of education and a variety of kinds of knowledge. Computer education programs must provide computer professionals who produce devices or programs and run them, professional computer users who in their daily work depend on computer support, and routine users who want maximum use of the computer without paying attention to it, that is, with minimum knowledge of the inner processes. The kind of knowledge may be characterized by the training obtained: advanced degrees specializing in research and development; graduates in informatics who will work as engineers preparing device structures or information processing programs; graduates in mathematics, physics, electronics, economics and many other fields; graduates in any field applying a knowledge of computing; technical trainees seeking a career in computing and other users of the computer as a tool, perhaps receiving only short courses and seminars.
The highly stratified complex of problems gives rise to misunderstandings. Also: hardware, software, service, operation, applications, implications.

Using simple computations based on the number of computer specialists at various levels required on the average for each computer installation, and the expected concentration of computers in developed countries, Zemanek derived the truely overwhelming numbers required for a country, or continent, or the world, in the near future. It shall be a tremendous task to meet this challenge of training and education for computer developments and uses.

Zemanek pointed out that the growth of a new field such as informatics (or computer science) depends on the influx of good people. Some of these will be specialists, researchers, engineers and teachers, but others will be users, and casual users can be as important as those for whom computing is essential to their main profession. Only an excellent education can attract and yield all those persons necessary to advance the field of computing and information sciences.

The availability of well-prepared teachers, effective learning materials and realistic computing resources are essential to sound programs. Assembling these components of an effective educational program may be especially difficult in developing countries, and failure to aid countries needing rapid growth to establish a place in rapidly changing world will only increase the technological and economic gap.

In a fast developing science such as informatics, the presentations for students still have the rough language of the discoverer and researcher while often explaining obvious details and jumping over crucial steps of explanation. Informatics, specifically, is still burdened with unnecessary details, with classical parts of mathematics and electronics which could easily be dropped.

Concerning the uses of informatics in teaching and learning activities, Zemanek remarked that too many optimists have raised expectations which the computer will not be able to fulfill in the near future. Although applications have been successful in certain narrow situations, the real hope is that the next generation growing up with computers and information processing, will handle these problems much better than we can today.

3. AREAS OF CONCERN

Anyone who reflects on the rapid developments which are expected, should be highly concerned about the ways to train people in the field of automation to come, and to educate all people for the future. In this respect questions concerning the following areas are of relevance:

3.1 **WHY** are computers important? The existing and potential roles for computers, computer-technology and computer-science in the area of education, training and learning.

3.2 **WHAT** is to be taught? Important aspects regarding the development of computing and computer-science:
– What knowledge about the principles or fundamentals of the computer logic and functioning is required, especially regarding education and learning?
– What use of the computer and the related principles of informatics should be applied in the area of teaching and learning in the different fields or disciplines?

3.3 **HOW** is teaching to be done? The best approaches to teaching and learning **about** and **with** computers, the area of learning **with** computers including:
– The results of the learning process itself;
– The interaction of the learner with the particular process or program.

3.4 **WHO** are the teachers and the learners? All parties involved, on the teaching side as initiators, teachers, tutors, and on the learning side as final users.

As Mr. Grosheide pointed out, it is no longer possible to work without computers, and continuing rapid developments will have considerable influence on society. Computer education for all has become nearly a necessity.

The problems of education are such that changes are needed and new resources have to be applied. It is no longer a question of whether computers will help, but one of how and when. The exchange of information and the conduct of studies at an international level will be stimulating and fruitful, and countries without special resources to invest in research and development and large field trials for computers in the schools can profit from the experience of the countries which are prepared to make those investments in the future for computers in education.

Major changes may be expected in education with computers, at least as significant as those resulting from the introduction of computing into business and industry. Institutions will change, in order to more effectively bring learning resources together with students of all ages at appropriate times and in suitable situations. The classroom teacher is more likely to find a useful place working within the class than standing in front of it.

Prof. Langefors set out a dilemma. Because informatics is still in its infancy, the present problems and methods are likely to become obsolete quickly, except for a small set of fundamental parts. Nevertheless, the subject of informatics needs quickly to be taught in schools in order to prepare the general citizen for the computerized society of the future, including computer-aided leisure as well as work, and to accomplish in all special fields of knowledge the understanding of the place of informatics and the changes introduced because of it.

He also pointed out exciting aspects of the technology and applications of the future, for example:

The future will include terminals in homes and public service centers; these will be convenient user stations, with functional keyboards supplemented by pointers, images and voice communication. Programming languages, though they will no longer be called that, will be convenient to needs and goals, and function well in interaction or according to sets of stored directives. Man-machine dialogue will be used for the solution of problems in a flexible and responsive working environment; a new perspective on methodology must be developed and taught.

Applications programming with general-purpose procedural languages will be replaced by a combination of information systems precedence analysis, decision tables and stored process programs. Already a shift is evident from small to large data bases, from data terms to data structures, and from data processing to information systems.

And the future lies not in using computers to replace judgement, but to support judgement. This view applies equally to the design of large computing and information systems and the contribution of computers to the instructional process.

Langefors indicated dramatic changes in the teaching and testing of knowledge in all fields. Some of this is brought on by contributions of information systems to the work of all professionals and most citizens, that is, they will have large data banks and processing capabilty at hand as needed for solving problems and answering questions which members of an earlier generation tried to carry about "pre-solved" in their heads.

Other changes will follow from the application of informatics to the systems and process of education. For example, large data bases and information management techniques tremendously increase possibilities for integrating learning materials and activities as they have previously in management: bringing together distinct subjects as appropriate for the individual goals and needs for each learner.

In planning for the future of informatics and education, Langefors reminds us to be realistic and open-minded about the possibilities. "It is of the utmost importance to understand that realistic planning does not mean conservative planning."

It is well to remember that the initial uses of the telephone services were primarily commercial, and the motive was one of profit through speed of communication and perhaps an edge on the competition. Increasingly the telephone was used for convenience, and for personal as well as business purposes, until some families find two telephones in a household to be "a necessity".

The same transition from commercial to personal may be expected of the demand and uses for video signals and display in connection with voice communication. Although initially a luxury, Picturephone (by Bell Telephone in the U.S.A.) will become a necessity for shopping by phone, planning a trip, and perhaps a call to the grandparents.

The purchase of television receivers was originally for public gathering places and private clubs, and similar to the phone, the convenience spread into homes. Computers, at least the associated information retrieval and processing, will also move into the home, to provide entertainment as well as economic advantage and personal convenience. Information systems will provide a base for continuing education for all members of the family. The opportunities for young children are particularly exciting.

Self-education can be arranged through selective receipt of information, automatically and on demand, and also the use of automatic procedures for individual reorganization of information. In other words, the student in school, or the school failure, or the adult changing jobs, will have acces to considerable power for learning and self-determination, and should be prepared by educational experiences today to make effective use of it.

From the opening sessions it was clear that IFIP and other organizations of international scope should take initiative to establish conferences and working sessions on a regular basis to deal with problems and potentials of computers, informatics and education. In addition to facilitating face-to-face exchange through international meetings, such organizations should also review the existing journals and other media for exchange to more countries and persons, and to open new channels for communication as they appear to be necessary and/or desirable.

All these areas were treated in the Conference, but category 3.3 (on approaches) received the least attention. This was primarily due to the fact that, until recently, communication and coordination has been sadly lacking between the scholars working in the theoretical and experimental areas of education and practicing teachers and educators. The integration of educational and didactical aspects has also been rather poor. As a consequence, the requirements of terminals for use in educational processes cannot yet be well defined by those involved; the equipment available is considered by many not adequate nor reliable but on the other hand, rather costly because of the lack of standardization and limited use.

4. TERMINOLOGY AND CONCEPTS

A variety of ideas were expressed on matters of terminology and conceptual frames of reference. For example, in the description of courses in systems analyses, information systems, etc., for different levels of students and different types of educational institutions, the intention could be:

- Identification of aspects of or topics in the course, and/or
- Indication of the sequence and segments of the curriculum, and/or
- Explicit listing of the process and activities of teaching or learning.

From several separate discussions the suggestion was passed forward, to recommend clear and detailed descriptions of course purpose, objectives, materials, sequence and procedures.

In the area of terminology, the mayor areas of confusion concern:

Teaching versus education. In one paper teaching is described as the control of a learning process, whereas in another one, education is phrased as: supervised learning.

Computer science versus computing science. Computer science is most often described by little more than the study of computing machines (actual or potential). Increasing numbers, however, appear to be shifting the emphasis by adding to techniques and concepts dealing directly with computers and their programs, a concern for all its applications to intellectual endeavors generally. This broader domain is implied by "computing science," i.e., the knowledge dealing with applying the computer.

Computer Science versus informatics. Although "computer science" was the most used label during the Conference, a number of persons stressed that the concept of "informatics" is more comprehensive and encompasses the software and application elements of computers as well as the technological.

As was stated by Mr. J. Arsac. "Informatics deals with information processing in the sense that information consists of a string of symbols. It is fundamental to this definition, that the processing of information is not the processing of knowledge. There is a clear distinction between information processing by humans, which is a semantic process, and information processing in the informatics sense, which is a syntactic process."

The notion of Informatics should be taken from the original French definition: "Science du traitement rationnel, notamment par machines automatiques, de l'information considéré comme le support des connaissances humaines et des communications, dans les domaines technique, économique et social."

This was translated by the members of the Recommendations Committee in the following way: 'The science of the systematic and effective treatment, especially by automatic machines, of information seen as the medium for human knowledge and for communication in the technical, economic and social contexts.'

5. THE LEARNING PROCESS

5.1 A significant portion of the formal plenary sessions (invited papers) was devoted to aspects of learning and the learning process, particularly by the papers of Mr. S. Papert on 'Teaching Thinking' and by Mr. G. Pask titled: 'Fundamental aspects of educational Technology Illustrated by the Principles of Conversational Systems.' To characterize both approaches in the same framework: Pask dealt primarily with the systematic and modelbuilding aspects of the learning process from the inside out, whereas Papert emphasized more the teaching process and learning optimization from a pupiloriented point of view, i.e., the learning process looked upon from the outside in.

Discussion showed agreement on the fact that better control of the learning process is required, and may be accomplished in various ways, for example:

. Humanization of the learning process, enabling the pupil to interact directly with the subject to be learned, and in a conversational mode.

. Application of the elements and concepts of 'instruction in computer use', to 'computer use in instruction'. In other words, the logic of the functioning of the computer hardware and operating systems can be and should be applied to design of procedures for teaching with the aid computers;

. The integration of some elements of the systems-concept into the learning process. The most relevant notions are:
  - process;
  - feed-forward (problem posing) and feed-back (problem solving);
  - planning and the subsequent moduling of a project, as well as subroutines (or macro's) related to the model-approach; and
  - debugging successive approximations to the desired procedure.

Furthermore, the application of computer hardware itself is less relevant than the underlying principles of its internal functioning and of the systems-oriented aspects just mentioned. On the other hand, hardware was recognized as very useful in the learning process, but more for its high potential output-oriented capacity than for its relative costs or the possibilities for problem-solving, simulation etc.

Papert, Pask and other speakers were concerned about the dangers of translating existing poor learning processes into CAI programs, whereas the use of computers in instruction should be perceived as the opportunity for a complete review of existing curricula and concepts, and the possibility for introducing computer logic-principles, model-approach, etc.

5.2 From the session on individual learning (Papert), it is worthwhile to stress the following ideas:

The need of reforming the methods of teaching mathematics is generally recognized. Althoug much has been done through conventional methods, using set theory and formal logic most recently, a computer approach to mathematics for teaching children should prove much more appropriate when it is developed beyond the experimental stage. Computer scientists and related professionals in computer science and technology appear to have neglected this task; a much greater contribution could be expected from them.

The learning of mathematics using active and applied situations and methods is a promising way to get the right "state of mind" in a child. The conventional approach to inductive teaching of algebra and geometry neglects the desirable "discovering" of the underlying principles in mathematics by the child himself.

Research and development in instructional use of computers should not proceed on the assumption that children have empty slates – virgin minds – upon which the tutorial procedure will write. Children have theories about many things including their own thinking, and this natural concept-forming can be guided creatively by cybernetic methods. Children have open minds toward their own perception and thinking, and one should be less concerned whether a thought-structure is correct in the conventionally accepted pattern of "right or wrong". Taking this approach, a healthy activity of "feedback and debugging" will develop.

While mastering pleasant games children can learn essential routines and logical procedures – if properly presented and explained – which teach them to recognise parameters, variables, subroutines, etc. These can later be applied as a general method or approach to analytical recognition and problem solving – "real adult-life"– in all situations and tasks.

The potential danger inherent in experimenting with children lies in the problem of emotional re-adjustment after returning to the "normal" school and other environment.

5.3 Many psychologists working in the field of learning, as Mr. Papert commented during one of the discussions, tend to observe the strategies applied by the learner in a concrete learning process and help to promote them. In addition someone should assist teachers to become good at learning, which may require patterns different from the existing ones. In this respect, the research performed by Mr. Pask showed that:

- individuals use a variety of skills in learning relatively simple tasks;
- learning is based on a tutorial relationship between pupil and problem, through a process of problem-posing and goal-oriented problem-solving by reduction of uncertainty;
- taking into account, both aspects mentioned in order to optimize the interaction between pupil and problem, pupils should be given a repertoire of problem-solving procedures, rather than a single strategy;
- a teaching system or model should allow the addition of new strategies; it should give feed-back at the level of the strategy.

6. HUMANIZING THE LEARNING PROCESS

6.1 Computers already have contributed to the learning process through factors like:

- tutorial and testing exercises with features for special editing, phonetic encoding, approximate comparisons and the like, also by:
- branching and more complicated decision logics, including error rate and response latency as parameters.

These kinds of developments are helpful in establishing better conversational learning processes, but they are not sufficient. More basic analysis of the interactions between the pupil and the problem, and the role of the human tutor involved, is required in order to obtain a better understanding of what is meant by 'human learning' and 'cognition'.

Some important areas in which work is suggested are:

- languages and processors with special attention to translatability and documentation, as well as the publication of programs using these languages;
- means of student access to computing resources, including input- and output-devices, and communication facilities;
- means for the exchange of technical information, including libraries, incidental publications, reports on meetings, etc;
- computing as a contributor to learning environments for young children;
- simulation concepts and models.

This list is by no means exhaustive. Particularly the need

for a better exchange of material, publications and results of research was stressed in all sessions.
In more than one session critical remarks were expressed about the contents and quality of material normally published. It was stressed that more papers should show actual results, rather than just talk around the problem and conceal what the authors may really have done.
On the side of education about computers, improvements in the distribution of material were suggested by the use of television. It was considered desirable for production standards of television computer education material to be aimed as high as those adopted by national broadcasting undertakings, weherever possible. This implies a high degree of professionalism among design staff and studio staff;

Two classes of subjects were distinguished in televised education:
a) courses intended for continuous use with general audiences;
b) courses embodying much expertise, and intended for smaller groups.
The courses from class b) call, in particular, for institutional cooperation. A major problem with regard to international cooperation concerns the teaching language. Any televised courses intended for non-university audiences will be presented in the native language of the viewer. Only for courses used primarily within universities will English as a common language be adequate. In instances where several language versions of a particular course are required, television production-techniques should evolve to meet this need.

6.2 There was expressed a great need for widespread communication of the implications of using computers for education to the public at large.
Both the reasonable concern and the unreasonable mis-conceptions about computers in general, and the use of computers in education in particular, need to be clarified to prepare people to make more intelligent decisions about the relevant issues that will be forthcoming.

Mrs. S. Charp, in her presentation on: "Computer Technology in Education – How to make it viable", mentioned some major obstacles to the rapid growth of the use of computers in education:

- The development of software, including courses, is very difficult for two reasons. First of all it is very costly: one hour CAI in for example biology or arithmetic requires between 100 and 200 hours of analysis, programming, etc. Secondly, authors try too hard to second-guess in advance the errors and unexpected responses of the student.
- The necessity to change the teacher's role and the school's structure. The classical role of the teacher has to be changed into one of an organizer, diagnostician, and prescriber.
- The equipment is at the present still unreliable and costly; at least no one configuration can answer to all needs. The specification of these needs is however a problem. Educational technology provides, it should be recognized, only a contributing tool for education; and help for the teacher (Computer-assisted Management of Instruction) is becoming more important.

6.3 Much attention was given by conferees to the aspects of training teachers, particularly by the members of Working Group 3.1. (Secondary Schools) of IFIP's Technical Committee on Education. This group proposed the following suggestions to the participants of the Conference:

- that IFIP should bring to the notice of governments and education authorities the urgent need for more attention and finance to be devoted to the training of teachers in general and in particular in computer studies;
- that IFIP should call attention to the needs of developing countries and that international cooperation in the training of teachers – necessary in all fields – is vital in computer education;
- that the applicability of data processing to all fields should be more broadly emphasized;
- that the recommendations of the seminar on computer education held at Sèvres on March 9-14 1970 (on secondary school computer education) should be endorsed.

Furthermore the working group recommended that the document, Computer Education in Secondary Schools: An outline guide for teachers, should be published as widely as possible. This brochure of 28 pages, has been printed by IFIP in the meantime and is available now.
After an introduction, which explains the purpose of the guide, the following chapters are listed:

- information processing and the nature of a digital computer;
- the organization of information for machine processing;
- programming languages;
- applications – computers in industry and commerce
- impact of computers in school subjects, and impact of computers on school subjects;
- conclusions, resources and bibliography.

The most relevant underlying ideas are: There should be an introductory course in computer studies in the early stages of secondary education. Applications of computers should be the aim of these studies (instead of the hardware characteristics only), in order to make clear the significance of the computer in society. The change of economic, social and political factors, particularly the labour market-structure, as well as the impact of new methods of political relevance make a profound knowledge of the possibilities and limitations of computer-applications required for all individuals involved. For example, computer-aided planning and decision-making will be deciding professions, and automated administration may be invading individual privacy. The group expressed a preference that the introduction to applications of computers should be developed in the framework of the specific disciplines in which they arise. This will demand closely coordinated teams of teachers of these different disciplines.

Discussions of the provision of computer hardware to the students, tended to stress convenient on-line access, preferably through typewriters and document readers. This point was considered a 'must' for the optimisation of the effect of computer courses in secondary school curricula.
As was remarked in one session:

- each student should have on-line experience for a minimum of ½ hr/month;

- in order to provide additional experience for each child, there should be either:
  a) a remote batch terminal with rapid printing capability;
  b) an optical scanner or card reader, perhaps used in conjunction with a typewriter terminal

Several participants drew attention to the situation in developing countries, where the avaible equipment may preclude on-line possibilities. Therefore it was suggested, that in such circumstances school-courses in computer studies should nevertheless be supported with whatever equipment can be made available. Otherwise the "gap" between the developing and developed countries is widening even more.
One speaker stressed the possibility of schools sharing computer facilities and with commercial users by arranging access during the evening and/or night-shifts (on the assumption of peak-use by the commercial user during the day shift).

Concerning the problem of "teaching the teacher" on computer use in education: it was proposed that for those already in service, a training course should be provided equivalent at least to one month, full-time, but preferably spread over a longer period, for example a year.
The need for a systematic follow-up was emphasized as an important component of in service education.

6.4 Concerning the aspects of costs, the discussions were concentrated around two different concepts, namely:
- an approach oriented to cost-effectiveness, although the measurement of the effects of the use of computers are still to be developed (and may not be possible at all);
- the concept that results are more important than costs, between certain tolerancies.

The second approach is based on the notion that the effectiveness of the use of computers in educational processes is very difficult to measure adequately; therefore a rather small success is considered to be relevant enough to apply computers on a broader scale. The second approach more or less ignores the costs; the comparison of the small effects against the high costs should in most case be unfavorable for a rational decision. A participant noted that computers are not being put forward to replace something that exists in education. It is invalid therefore to draw cost per hours parallels. New ways are needed to measure how people learn and what good teaching is, and new goals for education will evolve.

An illustration of the confusion on the topic of effectiveness is the subject of learning program. The idea that it is impossible to **teach** programming was more or less generally accepted. On the other hand, participants at one session concluded that the use of computers and programming as a framework for teaching can help enormously to humanize the teaching of mathematics, language and science.

The problems involved here can best be illustrated by the following rather pessimistic suggestions made by one group:
- There exists a great need for research concerning computers and education. Much of the past work has been done in an **ad hoc**, unscientific way, without serious concern about educational and psychological assumptions, implications or even possibilities.
  Two particular areas where work is needed are:
  a) using computers for studying how students solve problems and perform tasks; and
  b) investigating principles for designing new kinds of teaching tools, programs, languages and systems, expressly for use in teaching, as distinct from the widely used 'hand-me-downs' from business and industry.
- The scholars who will be required to further extend these developments will not generally be interested in doing so until they see plausible evidence that computers can indeed make an exceptional intellectual contribution to the theory and practice of education. This evidence will probably need to come more from computer scientists with serious concern about specific educational issues and interests, than from educators using ready-made systems given them by technologists or by technologists recruited for the purpose from the ranks of applications engineers.

6.5 The sessions on the more technical areas of simulation and languages where somewhat disappointing for their failure to better relate to the aspects of humanizing the learning process.
In the language sessions, no general agreement was reached on the choice of the best structure for these languages, or a specific language at all. Neverthless, some examples were presented that have shown to be applicable and functioning in real situations. Regarding simulation, the results were propositions stated in a general way:
- simulation must be integrated into daily routines of the learning process, rather than be produced 'like a rabbit out of a hat'. Children still see computer activities as different and separate from normal classroom routine;
- the difficult problem is careful measurement of outside, real situations to ensure that they conform to the model;
- there is a need for an 'author language' with which teachers can generate their own simulations. Such a language should be simple for construction of models as well as conversations;
- hardware and software facilities need to be made conveniently available to teachers as are water and electricity in a science laboratory) or they simply won't be used.

7. EDUCATION AND TRAINING CONCERNING INFORMATICS

7.1 Mr. Arsac suggested that Informatics should be taught at three different levels:

a) **Informatics for all**: one should recognise, as was stressed by him, that it is not important to teach about the computer **per se**, but about Informatics methodology, i.e. the organization, representation and processing of information.

b) **Applied Informatics**: stressing the application of

Informatics to other disciplines, to be taught to those who must use Informatics in their discipline. Wherever possible, this instruction should be given by the teacher of the discipline;

c) **Fundamental Informatics**; to be taught for the purpose of building a group of people who will develop the science.

This division into levels of teaching suggests for many the distinction between education (level c and b) and training (level b and a).
In some countries the responsibility for both education and training is distributed among different institutions such as schools, professional training institutes and universities. The teaching of fundamental aspects of Informatics requires more time than training people in the field of the so-called Applied Informatics. Universities are generally more concerned with long-term objectives of education, and a more fundamental orientation.
More or less independant organizations and control of different levels is therefore understandable.
In light of the rapidly changing society and the increasing speed and impact of technological change, training should be oriented more towards the creation of human flexibility to adjust to change, instead of passive adjustment to it. This goal can be approached by considering training as a continuous activity during the entire life-time; better coordination and some integration of the non-university training and university education is desirable.
Cooperation in the development and use of facilities as well as curricula and teaching methods is possible.

7.2 Concerning the national schemes for computer education and government responsibilities, the following conclusions were recorded from the discussions:

- In the developed countries the personnel output of present computer education and training resources is, and will continue to be, insufficient to meet the requirements of expanding computer usage.
  A simular situation prevails in developing countries, as was stressed very clearly in the panel session on the social implications of computers by the participant from Ghana;
- The consequent world shortage of suitable trained and educated computer personnel will inhibit more effective and economic use of available equipment;
- Government-supported organisations have developed in some countries national schemes for computer education and training at school, high school, technical college, and to a lesser degree at university levels. In other countries plans are being formulated on the inititative of professional organisations. National programmes cannot be effective without the active support of government, both central and local. At the implementation level, computer users and education and training institutions and organisations need to be involved on a co-operative basis;
- Packages of training material developed in some countries could help meet the requirements in developing countries if modified and adapted to local conditions;
- Common structural features have been observed in existing national schemes and supporting material; major benefits may be gained from a co-operative curriculum research and development at an international level.
  In other discussions, a 'modular' structuring the curricula to facilitate wider use of these packages in a way similar to standard software packages provided in modules by computer manufacturers for production-control, etc.
  Computer education in the developing countries should be accentuated at the managerial level of all sectors of business, industry and administration to enable these countries to become self-sufficient in regard to general computer education and wide spread applications.

7.3 The existing management training in data processing may be questioned regarding its effectiveness. It was felt that the structure and focus of the courses were oriented excessively towards the use of computers as a **tool** of management, instead of at least equally to the use of computers as an **object** of management. This position was confirmed by the remarks in another session regarding informatics as a separate discipline rather than part of mathematics.
To achieve this balance in management training it was believed necessary to improve the knowledge of the basic assumptions and objectives underlying the need for and structure of management training in Informatics. Therefore, the publication and wider distribution of existing material was recommended, including detailed literature references defining what is behind the various headings in the curricula-subjects.

7.4 The presentations and discussions on the problems of professional training included some striking points on need:
- a realistic estimate of the need for well trained personnel in the field of automation indicates that by 1975 the USA will need 450.000 operators and 1,5 miljoen programmers; the estimates for the UK for 65000 programmers by 1975.
  This figures made it clear that efforts in training people in these areas should be raised by establishing informatic-schools at non-university level. It was pointed out that the danger is real that users will not accept graduates from regular school systems (non-university level) but prefer to train within the company or by choosing evening courses or arrangements which do not require interruption in the work of the employee. It was therefore recommended that in designing curricula and in organizing computer education, schools should work in close cooperation with users;
- the education and training schemes for computer professional should be made such that:
  a) selection points are included at different places in the program;
  b) tests are based not only on knowledge, but also on aptitudes.
  Selecting during the educational and training processes seemed to be better than selecting before and/or after the program by means of a final examination;
- it became apparent that training schemes for professionals differ significantly in duration (from 4 weeks to a year). A clearer description of the various functions of informatics in data processing is needed.

7.5 A major point in the discussions on the subject of Higher Education centered around the need felt by user-representatives to increase the relevance of university programs in computer science and informatics to the practical situations of today. As was remarked by one: "After they leave the university, we first have to retrain them before we can use them". The university representatives recognized this point, but argued that industry has not been able yet to define its wishes very precisely. Although the existing 'tuning' between universities and users may be insufficient, 'translating' the existing needs of the users of today into university programs increases the danger of creating curricula that are very quickly obsolete, because requirements defined by the users may change rather rapidly. This for example was illustrated by the discussions of the necessity to distinguish apart from the accepted function of the systems designer, new specialists in multi - programming, the optimization of programs, and an information analist to define the information-needs of management. Others expressed concern about the communication problems resulting from the separation of related functions.

Some other relevant points in the discussions were the following:

- Students should be taught to become better problem solvers through emphasis on the theory of systems and the theory of applications methodologies (for example, as outlined in the ACM curriculum '68);

- As the computing service centres in universities have become more efficient and better managed, they have at the same time come to fulfill only part of the specific needs of computer science departments. The increased flexibility of digital equipment, (e.g. mini-computers) and the resulting growth in the range of digital computer techniques is so important that facilities for developing new techniques and training, should now be a part of the computer department. However, little attention appears to be given to these points in university planning;

- Therefore, because laboratory facilities are important in the operation of computer science departments, it was recommended that the interested parties should turn their attention to providing facilities for: analog–digital interfacing, interactive graphics, high performance data collection, monitoring of experiments and other similar requirements;

- Team projects have been shown to have considerable advantages, particularly when projects have been drawn from industry and when sufficient time is available for their completion. Such extensions of the educaional environment should be stimulated.

8. SUMMARY

Conflicts appear between the existing needs of today and the expected ones of tomorrow. Investigations more oriented to the future are required in order to define better the operational objective. Progress requires inproving knowledge about learning processes, a better coordination between user and educational institutions, the cooperation of all parties involved in personnel matters, and the personal consequences of enlarging the role of computers in the areas of education, training and learning. The addition to the pupils and teachers, the trade-unions, professionals and researchers of different kinds (psychologists, paedologists, computer scientists, engineers, etc.) must participate.

More emphasis should be placed in education on the computer as an aid to creativity, particularly by recognizing the contribution at younger ages than is normally assumed for scientific and humanistic research activities. The impact of computers on society, in and outside the field of education, indicates that control over developments is uncertain, and passive adaption and fear by those involved may result. The view of future developments and requirements must be improved and translated into curricula for training and education.

Computers and their use will become a real danger if too little is known by too few concerning the "why", "what" "how" and "who" questions, and particularly the answers to these questions.

IFIP WORLD CONFERENCE ON COMPUTER EDUCATION

AMSTERDAM, 24 – 28 AUGUST 1970

The following recommendations, drafted by the Recommendations Committee were reviewed and approved by the plenary meeting at the end of the Conference, 28 August 1970.

TO EDUCATION AUTHORITIES, that they provide an early introduction to informatics *) as an integral part of general education in secondary schools and primary schools.
In view of the profound social and political implications of the widespread use of computers, authorities should provide general education in informatics for **all**. This informatics education is distinct from that appropriate for those who will apply informatics to other disciplines, and for those who will contribute to fundamental development in informatics. From another report: '....it is our belief that introductory courses in information processing should, for pedagogical reasons, include some practical work which will involve the running of pupils' programs on a machine'.**)

2. **TO GOVERNMENTS AND NATIONAL AUTHORITIES**, that they provide, or actively support endeavours to provide, informatics education for all students.
3. **TO NATIONAL AUTHORITIES**, that they promote and support the development of information centres for Informatics Education in concert with local efforts. These centres should facilitate the effective use of national resources by collecting, annotating and exchanging information.
4. **TO UNESCO and OECD**, that they encourage the developments of national and international centres for information on Informatics Education and that they co-ordinate these efforts in co-operation with an IFIP committee of experts. Particular attention should be given to the needs of developing countries.
5. **TO IFIP**, that it establish an interdisciplinary working party to review and effectively disseminate knowledge about computer contributions to learning and teaching in all subjects and at all levels. Subgroups should be charged with specific tasks in this broad area. The composition of the working party should provide expertise from different disciplines and liaison with professional associations concerned.
6. **TO TEACHERS, TEACHERS OF TEACHERS AND THOSE RESPONSIBLE FOR CURRICULA**, that they draw upon the experience of others in informatics and education as it becomes available. In particular they can consider the document 'Computer Education in Secondary Schools: An Outline Guide for Teachers' prepared by the Working Group on Secondary Education of the IFIP Technical Committee on Education.
7. **TO TEACHERS, TEACHERS OF TEACHERS AND THOSE RESPONSIBLE FOR CURRICULA**, that they use computer-aided activities such as simulation, gaming, modelling and design excercises in all subject contexts in which this will be fruitful. This should create active learning situations for both student and teacher.
8. **TO IAG***)**, that its facilities be used for publication of curricula for informatics courses for all levels of management. Publication should include detailed references defining what is implied by the various headings.
9. **TO IFIP**, that it organise on a regular basis conferences on Informatics and Education which will include, as participants, teachers and students in many disciplines as well as in Informatics and also employers, representatives of trade unions, administrators and others who may be served by education and training involving informatics.

Notes:

*) 'Informatics' is used here to indicate a subject field without implying a recommendation that this be the universally accepted term. Conference discussions included also 'computer science', 'information processing', 'computer studies', etc.

**) From the recommendations of the OECD-CERI Seminar on Computer Science in Secondary Schools held in Sèvres, Paris, 9-14 March 1970. Full text of the recommendations is printed in Part I of the Conference Edition of the papers of the World Conference, pages 85-87.

***) The IFIP special interest group on Administrative Data Processing.

SOME TERMS AND DEFINITIONS

L'informatique
'Science du traitement rationnel, notamment par machines automatiques, de l'information considérée comme le support des connaissances humaines et des communications, dans les domaines technique, économique et social'. Académie Française, April 1966.

Informatics
The science of the systematic and effective treatment, especially by automatic machines, of information seen as the medium for human knowledge and for communication in technical, economic and social contexts (translation from the French).

Computer science
The study of computing machines (actual or potential). The art and science of representing and processing information.

Information processing
'The sorting ordering, retrieving, or sifting of character strings without reference to the meaning of these strings during the machine processing stage'. WG 3.1 Guide for Teachers.

Information science
(deals with).... 'the body of knowledge that relates to the structure origination, transmission and transformation of information – in both naturally existing and artifical systems'.

RECOMMENDATIONS OF THE WESTERN EUROPEAN IFIP SYMPOSIUM ON COMPUTER EDUCATION

Computer Science teaching in Universities

1. Whilst some countries now have established computer science courses at Universities, it was recommended that every country should make an effort to establish such courses at a large number of Universities (including technical and business schools).
2. Courses had been developed largely independent of each other. There was already a large and a growing need for an interchange of information on the details of subject matter taught, on the text books available for teaching, and on the experience gained.
   The group recommends the establishment of a clearing house to be administered by the IFIP administrative data processing group for such an interchange of information. The clearing house would receive lists of courses and bibliographies and would circulate these lists to all interested parties. The material itself could be obtained by any enquirer from the Institutions responsible for the material.

Computer Science Teaching at Schools of Economics and Business Studies

1. A number of schools had recently started, or were intending to start, University courses suitable for information analysts, systems designers, and computer users in administrative or business organisations.
   There was a need to share the experience gained by these new courses. The group recommends an interchange of information using the 'IAG Communications' for this purpose. All Universities or Business Schools teaching the subject are asked to publish details of their courses and the text books used, together with reports on experience to date, in the 'IAG Communications'.
2. The group recommends that a section at the World Conference on Computer Education (Amsterdam) in 1970 should be reserved for further discussions on teaching and curricula in these Institutions for information analysts and systems designers.

Computer Science in General Secondary Schools

1. It is now important that computer studies should be available as at least an optional subject in all secondary schools.
2. As soon as possible, computer studies should be included in the general education of all students.
3. In planning the future growth of computer facilities, provision should be made for the necessary computer access for secondary school students.
4. In addition, television and telerecorded teaching programmes might be helpful to assist teaching in the interval of time until sufficient teachers are available with the ability to teach computer studies in secondary schools.

Vocational Training in Computer Science

1. Effective usage of data processing services depends on a proper approach, which must come from management.
2. Top management requires 1-2 day courses to assist in evaluating:
   a) capabilities of computer systems for information processing;
   b) relative costs of hardware and software means of solving problems.
   Topics would be developed on subsequent courses.
   In conjunction with the computer manufacturers, these might be based on government departments and universities since, ideally, those presenting courses should have intimate knowledge of several installations and configurations and working knowledge of many user systems.
3. Middle management and other specialists require 4-6 week courses (not necessarily provided consecutively), based on problems common to many fields – conventional management training will require to be augmented by training in computer systems and techniques relative to management functions, and in the associated human problems caused by change.
4. Special modules of training in both management and computer requirements and methods will be required for 'information analysis' consultants.
5. Recommendation for additional middle management training.
   For the forseeable future (perhaps 10-15 years), middle managers on completion of conventional management training are likely to require additional understanding of computer techniques relative to their management functions. This understanding must have international application, and be co-ordinated under an international organisation. Computer Assisted Instruction might be an acceptable basis for this form of training.
6. It is desirable that all employers of computer professionals should allow for their continued training. This could help to show a career path within the organisation.
7. It is desirable that there should be national provision made for the award of certificates at appropriate stages in the training programme. These should be awarded by public examination under the control of appropriate examining bodies or government agencies. Such public examinations would be taken several times a year and candidates should be examined in written and/or oral fashion as a result of relevant theoretical study and practical work.
8. The question of certification of teachers and approval for examiners must also be considered and national systems should be set up to cater for this problem. The

relationship between the 'single subjects' certificates and the qualifications of national professional bodies in the computer field must be taken account of.
Single subjects could, for example, give exemption from portions of professional qualification examinations.
9. International agreement should be reached as to the equivalence of levels of qualification in the computer field; IFIP is recommended to look into this matter.

Special Secondary Schools/Colleges of Further Education (Professional)

1. It is recommended that Computer Studies should be taught as a subject in Technical and Commercial Secondary Schools and, where appropriate, in College of further education which cater for students not proceeding to University.

Computer Education for Teacher Training

1. Informatics (studies closely associated with computers and their uses) is not limited to a subset of Mathematics (no definition attempted). Therefore, children should not be allowed to get, or their teachers to retain, the impression that it is such a subset.
2. Generalised criticisms of teachers trained in mathematics, when considered as potential teachers of informatics, arose from the importance of closely relating the work to practical applications. In fact, regardless of the background of the teacher, this problem needs special attention. Some suggestions for helping teachers to present the practical side of informatics and to remain up-to-date were:
   - short courses in vacations or term time (these same courses might also form part of a longer vocational training for trainees in other fields).
   - exchanges of problem examples between groups of teachers on a national or international basis.
   - co-operation between schools and local industrial or commercial users of computers.
   - attachment of teachers for short periods of work in an industrial or commercial data processing department.
3. A basic computer appreciation course should be included in the initial teacher training of all school teachers, regardless of subject speciality.
4. The magnitude of the problem posed under point 3 alone suggests that urgent consideration be given by IFIP to the ways in which international co-operation can help to make available information about practical results of efforts in the fields of:
   4.1 program instruction text books;
   4.2 audio visual aids;
   4.3 computer-assisted instruction;
   4.4 computer-controlled instruction;

Training technology and especially Computer-Assisted-Instruction (C.A.I.)

1. It is unanimously recommended that all teachers should receive information techniques useful in C.A.I. and the effect which it will have on teaching techniques in the classroom. This instruction should be built in to form an integral part of normal teacher training.
2. C.A.I. systems should be developed by teachers and computer specialists together both at the systems design stage and the preparation of material stage. The importance of releasing teachers on a full-time basis for one or two years to write the teaching material was especially stressed. The group did not consider it satisfactory for teachers to be released to do this work on a part-time basis.
3. The group felt that the design of terminals could be improved significantly from the ergonomic aspect and as well as with a view to making the terminal a more interesting device for the student to operate. It was pointed out that existing terminals which relied on only one medium for presentation of information to students tended to invoke restlessness in the student unless the response time was extremely fast.
4. It was also recommended that a great deal of research still remained to be done in the whole area of C.A.I., but in particular on the relationships and interaction of teacher, student and computer.
5. Discussion centred around the role which computers can play in providing specific assistance for the teaching of business and scientific subjects mainly at the university level. It was generally agreed that if teaching could be divided into a conceptual part with a high semantic content and an arithmetic part, then computers can be used effectively to re-inforce the teaching of the arithmetic part. Examples given were the use of business games and linear programming studies in operations research. It was also emphasised that by taking the necessity for doing routine calculation away from the student, he would have more time to experiment and evaluate appropriate methods and procedures. One effect of this is to give students more time to think creatively and on a higher level and it was generally agreed within the Group that at the moment students were not being equipped to do this. Consequently, it was recommended that more emphasis should be placed, especially at university level, on how to approach and identify problems rather than emphasis the training in methods and techniques of solving problems that are already clearly identified and specified for the student.
6. Fellowships should be made available to educators for practical experience in association with large scale projects, now operational in other countries, to study the teaching methods and the content of the courses assessing suitability for their own country.
7. It was recommended that IFIP – possibly on co-operation with other international bodies – start a study on:
   - the possibility and feasibility of constructing structures in which courses can be written, to be used with modern teaching aids especially C.A.I. in the field of informatics (i.e. the art of science of information processing), on an international basis;
   - manpower necessary to effect such a project and an estimate of the cost involved, against the results (not necessarily financial results) to be realistically expected;
   - the entities where the finance for this could or should come for.

Examinations Standards

1. The recommendations are primarily related to the area of post 16 year old students outside the non technological universities. It is assumed that 16 to 18 year old school leavers in Western Europe are broadly comparatable.
2. The functions of examinations can be:

2.1 Course oriented: (a) to measure achievement
(b) to be predictive

2.2 Job oriented: to provide a qualifying test.

3. The areas to be examined:
   3.1 Professional standards: these are externally imposed.
   3.2 Specific vocational groups (e.g.: programming, operating).
   3.3 General educational field (degrees, diplomas, school examinations).
4. The design of the examinations:

Evaluate Educational and industrial needs

Determine kind of courses required and their outcomes	Determine structure and standard of examinations
Determine relevance to a) What student is doing (esp. part-time courses) b) what he will do in future	Provide meaningful information about separate components: a) aspects of theory b) practical skills.

5. Presentation and use of results:
   5.1 Profiles of performance – users must decide on the combination of result measurements (grades or % etc.) required for specific purposes (e.g. employment in a particular job).
   5.2 In using results predictively, there should be great flexibility at the present time, and the minimum application of barriers to subsequent courses of study.
   5.3 No examination structure will be of full value unless the content and standard of the examinations are understood and accepted by all users, especially employers.
6. Standards should be:
   6.1 Based on sampling of full range of subject syllabus.
   6.2 Such that majority of students achieve a 'pass' grading.
   6.3 Consistently applied from year to year (or examination to examination) until the examining authority gives public notice of a change.
   6.4 Not varied with size of entry to regulate flow of those qualifying i.e. examinations should not be competitive.
   6.5 Taking account of the developing situation in computer studies.

Computer Appreciation in Universities

1. It is recommended that the IFIP Technical Committee for Medical Data Processing should be approached to organise an international seminar to inform senior members of the medical profession on the current and future use which may be made of computers. It is intended that a formulation of problems appropriate to these developments be made.
2. There should be an opportunity for all undergraduate students to learn a programming language and to gain experience in problem solving.
3. In certain disciplines students should be encouraged to use the computer as a tool.
4. It is desirable to have courses oriented to specific fields such as Law, Medicine, Social Science and the Arts.
5. The Computer Science Department should exercise responsibility in maintaining quality and content of all courses associated with Computer Education.

RECOMMENDATIONS OECD – CERI SEMINAR ON COMPUTER SCIENCES IN SECONDARY SCHOOLS

The Centre for Educational Research and Innovation of OECD in Paris organized a Seminar for invited delegates from its member countries in Sèvres, Paris, from 9th – 14 th March 1970.
The text of the final recommendations adopted during the last plenary meeting of the Seminar is as follows:

Recommendations from group no.1.
Significance and objectives of computer sciences in secondary schools

1. The advent of the computer has serious scientific, cultural, social and economic consequences. Already the first three of these consequences make the introduction of computer studies at the secondary school level necessary. The fact that for several Member countries a sizeable and growing proportion of their Gross National Product can be related to computers and their applications, only adds strength to this.
2. In the first place there should be an introductory course in computer studies in the early stages of secondary education. This could be used to advantage in other subjects of from a basis for specialised education.
3. In general education computer studies should be a means not an end in themselves. They will help the pupils better to understand the world in which they will live. They should therefore contain such applications as to make clear the true significance of the computer in society.
4. The school curriculum in all studies is already overcrowded. An introduction of computer studies either as a separate field of study of within another subject will require careful reconsideration of the curriculum as a whole. In this connection a very important property of computer studies is its ability to create in the pupils an organisational algorithmic and operational attitude which is desirable for many lines of study.
5. The advent of the computer influences many academic subjects. Application of the computer to other disciplines where relevant should preferably be developed in the framework of those disciplines. Contact between the teachers concerned and those with competence in the field of computing should be promoted.
6. A basic course should take into consideration that the algorithmic approach to problem solving tasks is a basic aspect of computer science. Examples presented to pupils should be taken not only from mathematics but also from other fields according to the interests of the pupils. It is important that during this initiation period pupils have access to the computer. Substantial agreement was reached that high-level programming languages should preferably be used but that with this limitation the choice of language is of secondary importance. At the same time the programming details should not be allowed to dominate the course.
7. The Committee considers the contents of the course in the light of documents tabled at the Seminar. They are impressed by the measure of agreement between the various courses outlined but recognised that there were some differences of emphasis. The Committee appreciates that the syllabus will not be static and must be progressively modified in the light of experience and technological development.
8. The Seminar recognised the urgent need for other courses in secondary schools intended to give an education of a more specialised nature in the use of computers. However, the structure of such courses is considered to be outside the scope of this present Seminar because they depend too much upon the structure of secondary education and upon local conditions in each country.
9. A critical need in the implementation and development of such courses is the establishment of an international centre for the dissemination of information concerning syllabus content, working experience, hardware, configuration and costs, and course material. The Committee believes that this process will be greatly facilitated by the publication of an international magazine devoted to computer education.

Recommendations from working group no. 2
Methods and means

1. The details of education in information processing will depend upon the national education systems and the aims of the specific courses. This Working Party has concentrated on providing for introductory courses in the belief that these will be common to all types of information processing course in secondary schools. Introductory courses are therefore of the highest priority and will involve large numbers of pupils.
2. In particular it is our belief that introductory courses in information processing should, for pedagogical reasons, include some practical work which will involve the running of pupils' programs on a machine.
3. A very wide range of provisions for running pupils' programs and for returning the output of these runs is presented in the annotated list associated with this working party. This list is offered in the hope that it may be helpful in considering what systems will be best suited to solving a particular local problem.
4. However, experience in some countries indicates that during the early stages of establishing introductory courses in information processing the cost of each presentation of a pupil's program (e.g. of 25 lines of high level coding) might be expected to be in the range

of 1-4 French francs.

5. To facilitate the choice of systems which, on pedagogical and economical grounds, seem the most appopriate to particular situations, this working party proposes:
   5.1 That a factual investigation be made of the alternative means by which a computer may be made available to pupils. This study together with the results of relevant experience gained should be made available on an international basis through OECD.
   5.2 Some members of the working party also felt that a similar factual study of programmable calculators would be valuable.
6. The working party recommends strongly that every opportunity should be taken by educational authorities to make use of existing computing facilities in particular, arrangements can be made for pupils' programs to be run on machines belonging to universities, government offices, private industries and businesses and also computer service bureaux. However, two points must be stressed:
   6.1 To make effective use of computing facilities, staff must be specially appointed to see that the needs of the schools are met.
   6.2 Any arrangements for pupils' programs to be run should be on a contractual basis to ensure that a satisfactory service is in fact provided.
7. The working party further recommends that the use of Government and industrial computer installations should be regarded not merely as an expedient since:
   7.1 This may make available for education more modern and powerful machines and more fully informed staff than would otherwise be the case.
   7.2 Pupils can be given experience of installations which are more representative of applications in the world at large. This method therefore has intrinsic value for education.
8. There is a great deal of potentially useful visual aid material in the form of film, TV programmes, etc., and also a large number of teaching aids in existence. There is, however, an urgent need to exchange information on these and to make the material itself more suitable for school use and more accessible to teachers. The working party therefore proposes:
   8.1 That an international centre for educational information and development on information processing be set up.
   8.2 Within this centre a teaching aids project should be established to evaluate existing material.
   8.3 Another project should be the development of further teaching aids which would facilitate teaching in information processing, e.g. new films and TV programmes, and the use of teaching machines and CAI.
9. One of the most important applications of computers is in data processing, and this provides a major justification for introducing information processing at secondary school level. For this purpose educational programming languages are needed which provide such facilities as table look-up, file manipulation and sorting. The working party draws attention to the need for such a language.
10. The working party is aware of the fact that a long term policy should be established with respect to financial considerations and, especially, technical staffing problems. However, such a policy cannot be defined until the technical studies referred to above are available. However, none of the recommendations for immediate action are such as would inhibit progress at a later stage.
11. Computers have precipated changes which are proceeding at a very fast rate which shows no sign of diminishing. It should be a function of the international centre to monitor current practice in information processing education and to ensure that adjustments are initiated as soon as the need for them is detected. In particular there is already a need to study the social impact of computers and to make available suitable teaching material in this field.

Recommendations from group no. 3
Teacher training

The present situation of computer education in secondary schools is critical. About the nature and urgency of the problems facing us there is no doubt.

People realize that the world is changing and many teachers will have to face up to the fact that their younger pupils will emerge in to a world significantly different from that of today, with a widely changed spectrum of jobs in which numeracy and flexibility of mind will be paramount and will involve universal computer literacy.

Of all the facts contributing to this situation, teacher training is the most vital. So few teachers are themselves educated in computer apprecation and computer science that we cannot even find sufficient of them to train the other teachers.

The following points are emphasised:

1. Just as courses for children may be general or specialist, so courses for teachers will have to be provided at more than one level:
   a. training for those who will teach computer appreciation;
   b. more specialised training (of various types) for those more closely concerned with the computer and its applications, (e.g. mathematics, economics, business studies, etc.);
   c. computer literacy has relevance for teachers of all subjects and should be available where desired.
2. Courses for secondary school teachers who will be responsible for the introduction of computer studies in their school (1a, 1b above) need to include:
   - setting up problems for computer solution;
   - programming the solution of:
     a. some numerical problems;
     b. some non-numerical ones;
     c. simplified but typical data processing example(s).
   - running these programs on a computer;
   - acquiring some insight of the mechanisms involved in simulation, game preparation, programmed instruction;
   - influence of computers on industry, commerce and private life;
   - applications of computers to other sciences taught in school.

As soon as possible the above content should be included in preservice courses as part of the teachers' general training.

For teachers already in service, a training course should be provided equivalent to one month fulltime at least, but preferably spread over a longer period, say a year.

Follow up help will be essential.

For those who will teach more specialised courses in schools (1b above), it is essential that their training should be extended to include considerably more.

Teachers who have had a course of training should be ready to help train their colleagues (1c above).

3. International efforts should be co-ordinated perhaps by CERI/OECD, IFIP, UNESCO, towards the establishment of a centre or a network for the following functions in cooperation with national authorities:
   a. to mediate in the training of teachers where desired;
   b. to make a synthesis of training courses already in use in some countries so that other countries may be able to adapt it it for their own use;
   c. to sift, annotate and exchange information between the various countries concerning computer education in schools;
   d. to encourage and help individual countries to establish computer education at school level;
   e. to initiate projects to produce films, videotapes, etc..., which would have commentaries in various languages and could be used by any country.