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ABSTRACT

An overview of the current status of new information technologies (NIT) in teaching, training, research, and administration of higher education internationally includes 25 papers: "The Impact of NITS of Higher Education" (C. Calude and M. Malitza); "Educational Implications of Artificial Intelligence" (M.A. Boden); "On Theory of Knowledge" (L. Iliev); "Computer Technology and Education" (L. P. Steier); "New Information Technologies: The Role of Artificial Intelligence" (G. S. Pospelov); and "The Challenges of Cognitive Science and Information Technology to Human Rights and Values in University Life" (M. Pellery); "Computers at Stanford: An Overview" (P. Suppes); "The Use of the Personal Computer in Education at the University of Buckingham" (J. E. Galletly); "End User Computing--A Challenge for University Organization" (P. Baumgartner and S. Payr); "The Influence of Informatics and the Use of Computers in the Content and Methodology of Higher Education" (H. Mohler); and "Informatics in Higher Education in Switzerland" (excerpt from a report on informatics issued by the Federal Ministry for Education and Science); "Searching for Patterns of Knowledge in Science Education" (A. Kornhauser); "Medical Educational Computing" (D. Ingram); "Patient Simulation by Computer--C.A.S.E.S., Software for the Construction of Computer Patients" (H. A. Verbeek); "Microcomputers in Statistical Education: the Buckingham Experience" (E. Shoesmith); "Courses in Computer Graphics in Faculties of Mechanical Engineering in Czechoslovakia" (J. Novak); "On the Way to Chaos--An Analysis of a Family of Logistic Models" (T. Kinnunen); "Educational Technology and the New Technologies" (P. W. Verhagen and T. Plomp); "A Knowledge-Base for Instructional Design" (F. C. Roberts); "Facilities Concerning the Infrastructure for Development of CAI in Advanced, Further, and Higher Vocational Education in the Netherlands" (R. van Asselt); "Some Thoughts on Structures, Objectives, and Management of Centres for Computation Sciences and Software Technology" (D. Bjorner); and "The Social Impact of Technology: An Issue for Engineering Education" (A. Bitzer and R. Sell); and "The Emergence of Institutional Research and the Use of Microcomputers: New Roles for Institutional Researchers in Western Europe Higher Education Institutions" (E. Frackmann); "The Student Information System of the University of Helsinki" (A. Heiskanen); "The Impact of Information Technologies on University Administration" (R. Bouchet); and "An International Centre for Computers and Informatics (ICCI) to Promote Third World Development" (

UNESCO

NEW INFORMATION TECHNOLOGIES IN HIGHER EDUCATION

STUDIES ON THE INTRODUCTION OF NEW INFORMATION TECHNOLOGIES IN HIGHER EDUCATION IN THE EUROPE REGION

EDITED BY
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PUBLISHED BY
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NEW INFORMATION TECHNOLOGIES IN HIGHER EDUCATION

Studies on the introduction of new information technologies in higher education in the Europe Region

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FOREWORD

The large-scale introduction of new information technologies (NIT's) in practically all spheres of intellectual activity is unanimously recognized as that singular development which already affects and will continue to affect higher education for many years to come. With regard to NIT's higher education institutions are not simply called upon to make use of them in their teaching and research programmes and to adapt these programmes so as to assure the training of high-level expertise in their utilization; they are also expected to maintain a leading role in research and development for the further advancement of NIT's and for their application in various branches of the economy and in society as a whole.

A European symposium on "Higher Education, Research and Human Problems", organized by CEPES in Hamburg, in 1985, singled out the introduction of NIT's in higher education as a priority area for the future activities of the Centre. The recommendation to that effect adopted by the participants referred to the elaboration of a *study of the use of data-bases and various other computer-based information systems in European higher education*. Since the scope of such uses is extremely wide, defying any attempt at providing an exhaustive review, CEPES was advised to begin by preparing a collection of short state-of-the-art articles on key aspects of this vast topic.

The present volume, direct outcome of the endeavour to implement the recommendation of the Hamburg symposium, presents experiences of universities of various sizes and degrees of development in making use of NIT's. They cover three main areas: the use of NIT's for (a) backing research in universities, (b) teaching at the higher education level, and (c) the computerized management of higher education institutions.

CEPES is very grateful to Professor Mircea Malitza of the University of Bucharest and to his younger colleague, Dr. Cristian Calude, for having agreed to assist in the challenging work of elaborating this publication. Professor Malitza, a former minister of education of Romania, is the author of a large number of books, studies, and articles, including a recent volume on "Fundamentals of Artificial Intelligence"

(Bucharest, 1987). He has also published extensively on issues related to present-day education and science. He is one of the authors of the Club of Rome Report "No Limits to Learning" (1979).

My colleague, Professor Dumitru Chiţoran, has coordinated the planning and elaboration of the volume on behalf of CEPES. His broad contacts in the world of European higher education and his background in the humanities have been instrumental in securing the co-operation of various international organizations in the project and in assuring a balance both between the disciplines and the countries represented in the volume.

We are aware of the inherent shortcomings of the book. As a "state-of-the-art" survey of relevant practices and experiences in the introduction of NIT's in higher education, it is not, nor can it aim to be, exhaustive either in the geographical sense (there certainly are interesting experiences in many countries of the Region, which could not be included, mainly because of lack of space), or in the thematic sense (there are certainly many fields of research and many disciplines of higher education, in which NIT's have made significant inroads which are not reflected in the book). More importantly, it is extremely difficult for a book of this kind, about a field which is in constant and rapid development, to be up-to-date. By the time requested contributions arrived at CEPES, new developments had occurred, which would have indicated new directions and new trends. In a few cases, it was possible for CEPES to obtain contributions reflecting such changes, but there was the obvious danger of expanding the book to unmanageable proportions, and of delaying its production indefinitely. The present content of the book is, accordingly, the result of a decision made by CEPES and by the editors of the book to limit it to the contributions available. A possible updating of the publication, in the not too distant future, may be envisaged.

There are many institutions, organizations and individuals to whom CEPES is indebted for assistance in the elaboration of this volume. The outline of the study was discussed with colleagues in various divisions and units of Unesco and in the Secretariat of the Standing Conference of Rectors, Presidents and Vice-Chancellors of European Universities (CRE). They made useful suggestions for its contents and for the identification of authors. The Division for Higher Education and Research of the Council of Europe, and the OECD Centre for Educational Research and Innovation (CERI), through its Programme on Institutional Management in Higher Education (IMHE), placed at the disposal of CEPES relevant documents and other material related to this topic. In fact, two studies, one by M. Pellerey and the other by R. Bouchet, are included in this volume with the permission of the Council of Europe and of IMHE, respectively.

FOREWORD

Special thanks are due to the European Association for Research and Development in Higher Education (EARDHE) for having agreed to allow CEPES, to publish, with the permission of their authors, a number of papers presented at its 5th Congress (Utrecht, April 1987), which was devoted to "Higher Education and New Technologies").

Although the publication is meant to reflect European experiences and is thus aimed primarily at a European audience, we felt it to be our obligation in keeping with the universal mission of Unesco, to consider the implications of NIT's for the developing countries as well. We are therefore indebted to the Third World Academy of Sciences and to Dr. Mohan Munasinghe for the special contribution on this topic, prepared for the volume.

Thanks are also due to Mr. Leland Barrows of the CEPES staff and to Miss Angela Clark of the University of London for assistance in the linguistic editing of the text.

CEPES plans to pursue further its activities related to the introduction of NIT's in higher education. Thus, a regional symposium on "The Advent of Artificial Intelligence in Higher Education" is planned for the autumn of 1989. The Centre will be most grateful to scholars and researchers, and also to administrators and to students, who will send us their comments and suggestions for the further improvement of the CEPES programme in this field.

Carin Berg
Director of CEPES

Motto :

"People progress according to what they're ready for".

Shirley Mac Laine

THE IMPACT OF NIT'S ON HIGHER EDUCATION

Cristian CALUDE and *Mircea MALITZA*
University of Bucharest, Romania

Rhetoric is not responsible for the present fascination exerted by the new technologies in every field of human endeavour. Indeed, they are being accepted universally and adopted on the basis of their demonstrated and proven effectiveness. In the views of A. Toynbee, technologies are first in getting across the border areas bewteen cultures, whereas ideas are the last to be disseminated. Paraphrasing Toynbee's principle, one could say that what emerges naturally from the contact between two universities is an exchange of experiences in educational technology. Controversies arise the moment a pedagogical doctrine is thrown open for discussion. Nothing circulates more freely than technologies, the only fly in the ointment being that it is by no means easy to come by them.

Once it has been applied (and sometimes — although rarely — even before it has been tested), a new technology splits the scientific world into enthusiasts, detractors, and neutrals. Every institution of higher education in Europe has introduced — on a larger or a smaller scale — the slide projector, the film projector, closed-circuit TV, the tape recorder, the cassette recorder, the video recorder, and the computer. Each innovation was expected to be a breakthrough.

Sceptics have been critical of the new technologies on various counts, two of which merit attention :

a) an increase in student passivity (which recalls the criticism levelled at the effects of television upon children) ;

b) the close relationship between the educational processes involved in the new technologies and the various psychological theories of conditioning and of mechanical association.

Such justified criticism has prevented information technologies from acquiring a high status in education. They are regarded as useful, but not indispensable, ancillaries in the instructional process.

In this family of technologies, the *computer* has emerged as a top-notcher, winning universal acclaim through its ability to become an interactive medium. The computer was introduced into higher education even before it had reached the threshold of interaction. The 1960's saw the creation of university-based computer centres. At the start, the computers, frail and expensive as they were, were housed in specially designed rooms; later, with the improvement of paralleled processing, computer terminals found their way into libraries, research laboratories and the lecture halls. In the 1970's, the following became a familiar sight: a professor would write a mechanical formula on the chalk board, pick up the telephone receiver, and get through to a computer centre (whether based in the same university or another institution); then he would type the formula on the keyboard on his desk and, within minutes, would be in possession of the results of a sophisticated calculation. The computer was then adopted in university management where it has proved invaluable in information systems, and accountancy.

No one has played down the computer *as* a computer given its unparalleled capacity to manipulate symbols rapidly and accurately. At this stage, the computer was widely used as an instrument of simulation and representation of quantitative and structural models. With the influx of mathematical models in economics, sociology, linguistics, biology, etc., the use of computers for teaching and doing research in academic science became widespread. The only prerequisite for computer use was knowledge of *programming languages* (BASIC, PASCAL, FORTRAN, etc.), which was a constraint on the large-scale utilization of computers for modelling and simulation. To make this task easier, simulation languages were devised. And even if the computer had not gone beyond this stage, it would still be an indispensable instrument for use in universities.

The Use of Computers in Teaching and Training

The first interaction barrier was eliminated with the advent of programs making communication possible between users and computers. This advance opened up a new prospect for the use of computers in education. In addition to giving instruction, the computer could also be used to test the knowledge of students, to signal correct and incorrect answers, to make requests for repeated answers, and to evaluate results. Its application, first restricted to the teaching of writing and arithmetic to children, was gradually extended to the teaching of foreign languages, the imparting of certain skills, and the teaching of more advanced subjects. Thus Computer-Assisted Instruction (CAI) came into being. In time, CAI was extended from school to business and industry.

Many written courses of lectures were tailored to suit CAI. The computer-based educational program, commonly called *courseware*, appeared in various disciplines: mathematics, physics, technical subjects, medicine, biology, law, and foreign languages. One widely used CAI system is PLATO (Programmed Logic for Automatic Teaching Operations); it was started in 1976 at the University of Illinois and was then operated by Control Data Corporation. PLATO IV is a computer-based educational delivery system which includes CAI activities such as tutorials, drill and practice, inquiries and games. In 1981 about 8,000 PLATO terminals were in operation worldwide and more than 7,000 hours of instruction were available in over 150 subject areas (including special terminals for handicapped people or children who cannot key in responses).

To facilitate courseware production, *author languages* were devised, which played a part analogous to simulation languages on models. The procedure is as follows : the instructor (i.e. the professor) writes the course with the aid of an author program (which often bears a suggestive title like COURSEWRITER, TUTOR, etc.). Thus he incorporates his own specialist knowledge, a questionnaire, drills and evaluations (i.e. the marks). The end-product is a computer-based instructional program (i.e. courseware). In spite of the fact that this proces presupposes previous knowledge by the instructor/author of a programming language, CAI has proliferated, being used in a wide spectrum of subjects, particularly at the undergraduate level. A fault one may find with such automated systems of instruction is that the program's set of questions and answers is pre-established by the programmer. Programs accordingly suffer from a marked absence of flexibility which proves to be a disadvantage when compared with the flexible dialogue which takes place between the human instructor and the student. Indeed, the computer/student interaction and dialogue are rigid and limited.

The Personal Computer

The computer has been characterized as a machine which "every 2 years doubles its performances while reducing by half its cost" (David Mumford, as quoted by Jackson (1988)). The process of miniaturization of the components reduced the size of the computer to today's desk-top or portable machine.

Many teachers take great satisfaction in writing their courses and their papers on computers with word-processing facilities New possibilities for the editing of scientific texts are constantly emerging.

The personal computer opens up the possibility of rapid and accurate documentation, of keeping records of data, facts, bibliographies. To the extent to which the libraries of higher education institutions are also computerized, the data available are easily accessible to each computer linked to them. The creation of data banks has increased the possibility of rapid and complete information and has augmented the efficiency of scientific work.

The number of programs available for personal computers, which facilitate text editing and the automatic programming of the creation of new programs, is continuously increasing. In education, the step the teacher must take is that of moving ... editing of his course on the computer to the elaboration of ... m which represents the course in the computer.

The opinion often held that intelligent programs are the attribute of 5th generation computers only (which are presently being implemented) or that they require supercomputers is false. In fact, a large number of intelligent programs are available for use with personal computers. Indeed such programs can be created by means of personal computers.

Artificial Intelligence

The next step in the human/computer interaction was made with the advent of *artificial intelligence* (AI), the immediate effect of which was the consolidation of the status of computers in higher education.

Like any new discipline, artificial intelligence is not easy to define. According to a commonly accepted view, it exists when the computer does things which would have been labelled "intelligent" if they had been done by a human. Thus, artificial intelligence avoids the necessity of defining intelligence, leaving this unenviable task to psychology. Indeed, psychologists are still at variance as to the definition of human intelligence. Recently, in the Reid Column of FACS-FACTS (British Computer Society), the following anti-definition of AI appeared: "If machines could be designated to write novels, compose music, print pictures, and play chess as well as humans can, then these activities would no longer be regarded as signs of intelligence".

A widely held view is that vision, along with speech production and recognition and reasoning are human activities requiring intelligence. Their performance by the computer is the province of AI. Despite the label "intelligent machine", intelligence proper is an attribute of the programs used and is thus part of software. True, recent improvements in hardware manufacture, great rapidity, a vast memory, have proved to be essential for the running of intelligent programs. Another key branch of AI, robotics, does not concern us at the moment as it is not directly linked to education. But the automatic demonstration of theorems, together with automatic problem solving, both of which belong to AI, are central to the instructional process.

ELIZA and BACON

In 1966, Joseph Weizenbaum from MIT designed a program which he named ELIZA and which was able to simulate a possible discussion, in English, between a patient and a psychoanalyst of the Carl Rogers School. Here is a widely quoted example of the way in which the program works (Weizenbaum, 1966):

Patient : Men are all alike.
Doctor : In what way ?

Patient : They're always bugging us about something or other.
Doctor : Can you think of a scientific example ?

Patient : Well, my boyfriend made me come here.
Doctor : What would it mean to you if you got some help ?

Patient : Perhaps I could learn to get along with my mother.
Doctor : Tell me about your family.

Patient : My father is afraid of everybody.
Doctor : What else comes to mind when you think of your father ?

Patient : Bullies.
Doctor : Does that have anything to do with the fact that your boyfriend made you come here ?

It is obvious that the above-mentioned passage makes a strong impression on the reader. ELIZA is undoubtedly an "intelligent" program. And yet, its range is extremely limited, as we shall further see when we examine how it operates.

The program has a script. It has ready-made answers, intelligently devised patterns (so as to convey the impression of being involved in the discussion). For instance, the program reacts to the mentioning of relatives (mother, father, etc.) by *tell me more about your family*. When statements involving universal quantifiers like "for all", "always" occur, the program immediately requires an example. The spectacular recipe *does that have anything to do with ?...* is applied whenever the discussion turns to areas that have not been included in the patterns of the program. So far ELIZA belongs to the AI programs generation of the 1970's which can be regarded as a definite succes so far as the ad-hoc programming tricks are concerned, but lacks the support of strong theoretical models of human intelligence. The author used the apparent authenticity of the program to disclose the claim of AI to simulate human thinking.

Starting with 1980, Gary Bradshaw, Pat Langley, Herbert Simon, and Jan Zytkow designed and later developed a program named BACON ([illegible]d after the philosopher Francis Bacon, the promoter of inductive logic), for detecting laws in data and extracting them in mathematical forms (i.e. by equations that fit the data). It is worth mentioning that BACON does not just fit curves to points on a graph, but it generates hypotheses (according to sets of heuristics), tests the hypotheses against data and, if necessary, generates new terms to formulate laws in mathematical forms. The program has been tested on a great variety of examples, including Ohm's law, the ideal gas law, Snell's law of refraction, Kepler's third law of planetary motion, and Joseph Black's law of temperature equilibrium mixtures. In the authorized language of the authors "...we confront the program with discovery problems that scientists have encountered, and we observe whether (it) can make the discovery, starting from the same point the scientist did" (Bradshaw, Langley, Simon, 1983).

One can contrast general AI development tendencies starting with ELIZA and BACON, with profit. To begin with, one notes a fundamental difference between the designers of the two programs in the way in which they analyze their own creations: while Weizenbaum is appalled by the possibility that persons using his program may imagine that they are talking to a real person, Bradshaw, Langley, and Simon defend the hypothesis according to which, researchers like Black, Snell, or Kepler produced science according to the same thought processes used by BACON.

Secondly, ELIZA and BACON hold different places from the point of view of their "intelligence", although they belong to the same research field, AI. A somewhat exaggerated optimism, which is however necessary even to other undertakings in AI and which has been dominant for quite some time now, namely the idea that there is a simple, general procedure for problem solving, has been now amended by results of recent research, which concentrate on programs limited to specific fields (like diagnostic infectious diseases), programs mainly based on incorporating large and very large amounts of systematized human knowledge: *the expert systems*. Due to their great importance, expert systems will be analysed in a further section.

Artificial Intelligence and Education

The connection between AI and education can also be examined from a different angle, that of the amalgamation of classical subjects like psychology (especially the psychology of learning), philosophy (in particular epistemology), mathematics (chiefly symbolic logic), computer science (languages and programs), brain physiology, and the technological sciences (microelectronics and automation). Such combinations of disciplines are aimed at a common goal, the computer modelling of cognitive processes. Learning is thus perceived as a cognitive process. By making "knowledge" a basic concept, AI becomes a new landmark of cybernetics, which was centred on "information".

As is well known, the interdisciplinary approach has been a focus of attention in universities. AI adds a new dimension to it. The consequences for education of such an approach are incalculable. With each step forward made by AI in the area of computer-modelled knowledge, some fresh light is cast on the processes of acquiring, processing, and assimilating knowledge. This whole process is of vital interest to education. To take only one example of what may happen: if concepts are formed around certain typical cases offered as examples (i.e. prototypes) — a hypothesis favoured by cognitive psychology and AI — the learning process will diverge from the general to the particular, a time-honoured formula praised for its economy, elegance, and formal consistency, and thus become increasingly inductive. Such a change would entail the rewriting of most textbooks and teaching materials in use in higher education institutions, as well as the changing of the ratio between lectures and seminars, and between seminars and practical work.

As all sciences are branches of human knowledge, universities may be defined as institutions of knowledge. It is to be expected that AI, as a cognitive subject, will, for a long time to come, remain a fertile subject of study, due to its affinities with and applications to higher education.

The present debates concerning AI are not something new. They began two decades ago when people began asking themselves if the computer-assisted modelling of cognitive processes were possible, and worth attempting, and whether it would have positive or negative effects, etc. The arguments, of a philosophical nature, were then concerned with the limits of formalization (Gödel's theorem, which will be taken up again later in this study), and with the implications of considering the human mind as a process analogous to a formalized system. The resulting debates divided the participants into supporters and opponents of AI, the latter being inclined to view AI as a modern version of dehumanization. Today debates tend to focus mainly on the results of certain intelligent programs. One question, for instance, is whether or not such a software as BACON simulates (or fails to simulate) the process of scientific discovery. In case it fails to do so (as BACON's creators claim), the next task is to pinpoint the hallmark of human discovery and invention. For example, in Margaret A. Boden's recent book (Boden, 1987) the author describes computational work in vision, language processing, reasoning and learning always addressing the question: "How can we decide which programs are acceptable as psychological theories, and which merely mimic behaviour in a psychologically uninteresting way?"

In the coming years, the progress of AI will underlie the most fruitful debates, universities being particularly interested in the following:

1. the progress of AI in the modelling of cognitive processes;
2. the implications of advances in AI for a better understanding of learning processes and for devising computer-assisted learning strategies;
3. the applications of AI in various fields of knowledge;
4. AI and the man-machine relationship;
5. AI and the creative work processes.

Expert Systems

The success which confirmed the progress achieved by AI came at the same time as the emergence of *expert systems*. These are programs which, in addition to knowledge taken from various books and articles, also incorporate knowledge stored in the expert's mind, the result of long experience. Such an expert system has been devised, for example, for oil prospection. It does everything that an expert is required to do. Basing itself on data (geographical, geological, petrographical, etc.) and on the results of test pits, it forms an opinion as to the chances of striking oil. This knowledge and experience, in one word, the expertise of various specialists, are incorporated into programs. Another expert system, for example, in the field of medicine, simulates a real medical doctor. It examines a patient, analyses the symptoms, and identifies the disease from which the patient is suffering, at the same time making recommendations about the medication to be followed.

The first expert systems required some 50 man-years of work to complete. In other words, they could be elaborated by a team of 10 experts working for 5 years (about as much time as one needs to become an expert). Then, following the steady improvement techniques for the writing of expert programs, the time needed for their elaboration has been considerably reduced.

There are two major trends in artificial intelligence. The first starts from the assumption that the human mind uses a single procedure for problem-solving, irrespective of the domain from which the problems are taken. The second assumes that each problem requires a solution which is specific for the respective domain. Expert systems have favoured the second assumption. The experts themselves are thus looking for knowledge models dependent on the field of knowledge.

Once we have clearly understood what an expert system is, we will be able to move on to a new generation of *courseware*. Even if expert systems do not have a direct impact on instructional programs, they will become, alongside simulation models, a valuable asset for higher education, for the application of all the sciences, for the elaboration of case studies in each field of knowledge, and for student training with a view to real-life problems. An illustration of the state-of-the-art in the field of courseware can be obtained from Hegamen and Gardy (1986), who designed an anatomy course called CATS (Computerized Anatomical Teaching System) to teach anatomy.

An expert system consists of a knowledge base, a host program, and relevant data. The host program interprets the data by means of the knowledge it possesses in order to reach decisions. In the case of clinical expert systems, the data are the symptoms which are interpreted by means of the medical knowledge making up the knowledge base.

Is there in fact any novelty in a medical expert system as compared to a computerized management model ? The latter, like the former, is built on probabilistic elements. It draws conclusions (i.e. the disease, treatment) on the basis of data (i.e. symptoms). An important difference is that, in expert systems, all knowledge is explicit. Another difference is that such a system represents an attempt to change human thought, with an emphasis on qualitative reasoning. A third difference, the most important from the educational point of view, is that the program permits questioning (how the respective conclusion was reached, why another hypothesis was not accepted); briefly, it reproduces the line of inferences. There no longer is a fixed set of queries and answers. With each problem, subproblem, and issue, the system reproduces for the user the line of reasoning and the way the knowledge is applied. The expert system is flexible: it recognizes an error and corrects it.

Essentially, the construction of an expert system requires the drawing forth of knowledge from some subject experts. Usually, the skills of most experts reside more in performing subject tasks than in explaining to others the ways they do it. Consequently, the attention is frequently focussed on the *automatic induction* of rules from sets of examples. The writing of expert programs, the most recent concern of AI, has been greatly facilitated by existing programs which permit experts to introduce their knowledge into a base, without knowing any artificial intelligence language.

A New Generation of Intelligent Systems

Expert systems have demonstrated that intelligen tprograms have passed the second and most important obstacle of the student-courseware interface, namely the possibility of conducting dialogue with programs and obtaining from them not only knowledge but also clarifications and explanations. In the CAI system, the interface was programmed. The instructor (invisible) was present in the program through the single route that the student was to follow. But at this new stage, the interface is generated by a separate base of rules which act on the knowledge base. The increased freedom of initiative for the student shifts emphasis from instruction to "learning".

Now we know that a computer-assisted courseware is an organized, intelligent, inquiry system of knowledge. The role that the expert played in the expert systems is now played by the teacher for the *new generation of intelligent computer-assisted instruction* (ICAI) *and learning* (ICAL) *systems*. The queries are not identical with the ones put to expert systems (i.e. wherefrom this conclusion ?). It contains more "what's ?" and "why's ?". This characteristic is greatly facilitated by the fact that communication takes place in a simplified natural language.

The first programmed courseware was modelled after the expert systems used in application-oriented disciplines (i.e. for medical or legal cases, etc.). At present, the courseware belonging to the intelligent, knowledge-based generation covers a wide range of university disciplines including anatomy, organic chemistry, plant biology, linguistics, etc. The great potential of ICAI and ICAL rests therefore with the knowledge-based approach to AI in expert systems which can work out explanations and advice. Progress achieved in this field is already remarkable. There are, however, many problems and difficulties which await solutions. Thus, although various proposals have been put forward, no consensus has been reached with regard to *knowledge representation*, to *interpreting* users' questions and to *constructing coherent explanations* which are more than mere sequences of rules.

The writing of such courseware requires considerable effort. The time needed for the creation of a 1 hour-long programmed courseware is estimated at 50—200 hours. One of the difficulties is similar to that pertaining to expert systems : the expert has the knowledge, but he does not know the language into which this knowledge is to be programmed. How can a teacher, who does not know programming languages, write courseware ?

The solution to the problem of author languages in ICAI was derived and perfected by so-called *authoring systems*. These are high-level interfaces which permit authors to create courseware without having to learn or to use programming languages. This accomplishment has increased the accessibility to the teaching community of computer-based instruction and learning. At the same time, it has reduced the cost of creating courseware. Many teachers are willing to participate in the production of courseware, but they expect to be exempted from having to learn programming languages.

There are three approaches to the advanced form of automatic programming : the teacher is offered a number of high-level commands which are immediately translated into a program ; the teacher fills in a form ; the teacher is questioned by the computer about the kind of knowledge which must go into the knowledge base and about the kind of information required for the elaboration of the program.

We do not need to bring forth too many arguments in order to see the consequences of courseware proliferation :

a) an increase in the quality of education through access to the best courseware ;

b) an easing of the existing pressure in the student-teacher ratio ;

c) the possibility offered to students of initiating independent learning processes at any time and in any place ;

d) the continuous improvement and updating of courseware through the addition of new knowledge and new rules ;

e) the computer processing of a large number of routine tasks leaving the human resource of intelligence free to tackle innovatory and research-oriented tasks.

Modular Curricula

Modularizing curricula is one way of making them flexible. Modular curricula appeared before AI and independently of it. The method consists in organizing curricula in independent sections which can enter into various course combinations. The matrix algebra is a part of algebra which is compulsory for games theory, for graph theory, for linear programming, etc. Sections which require less than a semester and more than one course-hour can be considered to be modules. According to a modular conception, they require 1 to 2 months of study. With the increased involvement of universities in lifelong education, it has become obvious that postgraduate and specialized training programmes will be made up of modules rather than of whole courses. In addition to the possibility of flexible combination into large units, the modular system has the advantage of permitting easier updating. In the traditional system, there is a considerable degree of redundancy (the same material is taught several times in separate courses). At the same time, there are obvious blanks (i.e. sections in a course, which are important for the profession, are missing). The modular system corrects these deficiencies. An education system structured according to modules facilitates the design of special paths for groups of students pursuing a specific qualification or specialization. The same goal is sought, with less satisfactory results, by means of optional courses. Why was the modular system not applied on a large scale some years ago, given that the idea was put forth in the 1960's? The answer is simple: it involves the close co-operation of many university departments, chairs, and disciplines and of many teachers. Or, anyone who has spent some time in a university knows how difficult it is to overcome barriers between chairs, departments and other university structures.

The transition to computer-based curricula will facilitate the taking up of this initiative once again. It is urgent that a modular approach to co-operation among disciplines be adopted in the development of courseware. Thus it will be possible to achieve two objectives with a single effort. The use of computer programs is expected to facilitate the identification and the constitution of modules, that is, their automatic organization.

From the point of view of the qualification to which a given student is aiming, the computer will be able to show him/her the sequence of modules he/she must take in the form of an individualized study plan.

The Use of NIT's in Distance Higher Education

Distance education is one area in which NIT's have and will undoubtedly make an important contribution, particularly at the higher level of such education. The unqualified success of the 'open' universities such as the British Open University are indicative of the great opportunities existing in this respect. By their very nature, new information technologies seem if be ideally suited to the of distance higher edocation, particularly when its organization is envisaged on an international scale.

It is significant to point out that we have been witnessing of late the emergence of international schemes and undertakings meant to increase the international dimension of open universities, precisely by making use of the great opportunities offered by the NIT's. Thus, the recently created *European Association of Distance Teaching Universities* with headquarters in Heerlen, the Netherlands, made up of eleven non-profit institutions of higher distance education from Belgium, Denmark, the Federal Republic of Germany, Ireland, Italy, the Netherlands, Norway, Portugal, Spain, and the United Kingdom, specifically set among its primary objectives "the development of new methods and techniques for higher distance education, including new technologies and media". Similarly, the *Asian Association of Open Universities*, established in Bangkok in November 1987, is conceived of as an educational establishment based on the massive use of new information technologies, aimed at facilitating close co-operation among open universities in Asia and in other regions.

More recently, at the 4th Conference of Ministers of Education of the Countries of the Europe Region (MINEDEUROPE IV) convened by Unesco in Paris, in September 1988, the idea was put forward of setting up a University of the Peoples of Europe as "an international academic and scientific institution concentrating on studies and instruction relating to the major problems concerning the whole of Europe, its history, languages, culture, ecology, and the future development of the peoples of the region". The functioning of the University is to be based on the large-scale use of NIT's and of the media.

An *International Study on Distance Education* produced recently by Fern Universität (the Distance Teaching University of the Federal Republic of Germany) and the Zentrales Institut für Fernstudienforschung (the Institute for Research into Distance Education) (Graff and Holmberg, 1988) which examines, by means of questionnaires, the teaching media used in several hundred distance institutions of higher education in all the regions of the world, reached the conclusion that radio, TV, films, slides, video, and audiotapes, the PC and other systems of electronic data processing account together for some 70% of all the teaching media they use.

The PC in particular is bound to play a major role in distance higher education. One of the merits of the open universities resides in the fact that they offer "personalized programmes" to their students, through the study guides and books they prepare for them, through the radio and TV programmes they recommend and through the telephone communications that can be arranged between students and teachers. All these means of contact will be greatly facilitated (or replaced) by the PC, which can now function as an individual workstation in a distance education network.

At a recent consultation of university leaders on Unesco's mission and future activities (Bologna-Venice, 18—20 September 1988), emphasizing Unesco's role in fostering mutual understanding between cultures and peoples, the participants brought to the fore the major part which could be played by modern technologies, including television link-ups. The interactive television hook-ups already existing between universities in North America, Western Europe, and the USSR were given as an example of the prospects lying ahead in this field.

In the realms of *educational satellites,* the prospects are indeed vast, provided there is be good will for co-operation on an international scale. The same Bologna-Venice consultation mentioned above, pointed out that "only three satellites would be needed to cover the world if, for example, the United Sates, the Soviet Union and Japan could come to an agreement on putting these satellites into place".

Computers and Research

All higher education institutions include among their educational objectives the imparting of the skills of scientific investigation to students and their introduction to research problems and techniques. While the computer asserts itself as an instrument for learning, is it to the same extent a research instrument ? The answer given by today's scientific practice is definitely positive.

The solution in 1976, after more than one hundred years of attempts, of the "four-colour conjecture" (see next section) by means of the computer was a widely reported success. But mathematics is not the only science in which computer assisted research can be applied. In the design of new machines and new constructions, the drafting board has been replaced by a computer having a CAD (computer assisted design) program. The computer makes the computations for all possible variants. In economics, the computer provides alternatives for forecasting or the optimum strategies for attaining an objective. In chemistry, the computer helps determine chemical structures on the basis of physical and chemical data. How could a problem in astrophysics be solved without a computer when such problems may require the solution of equations involving the determination of 5 variables in a network of 25,000 points, in 10,000 steps, with a total of 1.25 billion numbers ? The computer is an instrument for the mastery of complexity.

The significance of the computer for the experimental sciences will increase with the development of programs which on the basis of induction or analogy determine the regularities (the laws) from a body of (experimental) data. (A recent, much discussed example, was the BACON program presented above.)

If the assertion that "we shall think with the computer just as we are writing with the fountain pen" seems exaggerated to some people, there are few who doubt that "research will be carried out with the computer at hand".

A Personal Experience

Starting with the May/June 1988 volume, the journal *Notices of the American Mathematical Society* has inaugurated a new column entitled "Computers and Mathematics". Professor Jon Barwise, from Stanford University, an outstanding specialist in Mathematical Logic, agreed to try get the column going. It is very instructive to quote Barwise's confession, in his open column. "As a mathematician, I have found my professional life profoundly influenced by computers. As a researcher, I have seen my own interest gradually shift from model theory as inspired by pure mathematics to model theory as developed for the more concrete needs of computational linguistics and information processing. As a writer, I have completly switched over from writing mathematics papers in longhand and having them typed, to using LATEX, a version of Knuth's mathematical text processing, I discover that the bulk of my mail is in the form of electronic messages — known as email. And as a teacher of mathematical logic, I have worked with a colleague, John Etchemendy, to develop two computer programs, *Tarski's World* having to do with the semantics of first-order logic, and *Turing's World* having to do with *Turing Machines*. With this courseware, I have seen a dramatic change in our ability to teach abstract material to beginners. I can imagine a time when these sort of programs will completely alter the way we teach logic".

A Case Study : Mathematics

A first use the computer finds in applied mathematics is the solving of approximate calculi for problems requiring explicit solutions of a kind which theory can either not provide at all or not provide in a reasonable amount of time. Such examples occur frequently, from the building of a viaduct, to weather forecasts or the launching of satellites. In this case the theoretical method *coexists* with the computational one : they are but independent facets of one and the same phenomenon. The difficulty resides in the correlation of the two methods so that the results of the mechanical calculus is as close as possible to the one anticipated theoretically.

Another use of the computer is that of producing and studying a large quantity of data, with the aim of discovering a particular theorem. Such possibilities occur frequently in the theory of numbers, for instance in the study of prime number distribution, thus giving birth to a hypothesis — a conjecture. The more data are analyzed and the respective hypothesis verified, the more confident one becomes in the validity of the hypothesis. Nevertheless, the hypothesis becomes a certainty only when it can be demonstrated theoretically.

Like in the first case, the role of mechanical calculus does not influence the mathematical corpus whatsoever ; it only brings to the fore an experimental method offering numerous advantages, but restricting itself to the position of substitute or heuristic aid.

An advanced step in the relationship between mathematics and computers is reached, when purely theoretial results can be demonstrated with the help of "intelligent" programs. A start was made with some logical theorems written in the vein of *Principia Mathematica*, to be then followed by elementary algebra theorems, and to culminate with impure demonstrations, the most spectacular example being that of the four colour theorem (any map requires no more than four colours, so that any two neighbouring countries, the borders of which are not reduced to a point — as in the case of the American states of Utah, Colorado, Arizona, and New Mexico — should be coloured differently). For more than a century the problem of the four colours was a challenge to mathematicians, whereas Appel anad Haken's demonstration — which makes use mainly of the computer — extends far beyond the boundaries of mathematics and philosophy. This demonstration has greatly influenced both the knowledge corpus, and the inner mechanism of mathematics, for its computational component can be neither replaced nor verified "by hand" by a reader, however competent and perseverent he may be (at least at the present time). The confidence in such a demonstration should be divided between that placed in the mathematical argument and that placed in the machine-made calculi. Even the most famous mathematicians have made errors. The most sophisticated computers can likewise make mistakes, sometimes in "obscure" ways; their errors are extremely rare but not out of the question. Experience has shown that errors made by mathematicians are ultimately detected by the mathematicians themselves. But how can errors made by computers be detected, when calculations take tens and even hundreds of hours, and even partial results fill thousands of pages (Mathematicians estimate that the classification of finite simple groups — Fischer's monster, a group of the order 8×10^{53} is such an example — an important problem in algebra which is almost solved with the help of a computer will be contained in a volume of almost 5000 pages)? What guarantees of accuracy are offered by "experimental" methods, the change of the machine or of the program? Only recently have we started giving serious thought to such problems.

A recent scientific event stresses the role of AI not only in the process of development in the field of mathematics, but also, and more particularly so, in understanding brain mechanisms.

Science in the 20th century evinces a characteristic that is both interesting and new: awareness of its own limitations. The best known example probably belongs to quantum mechanics, where Heisenberg's uncertainty principle forces restrictions upon the notion of measure as such. In the field of mathematics, K. Gödel demonstrated in 1930 the famous incompleteness theorem by means of which he constructed several true propositions which, however, cannot be demonstrated within the range of axiomatic systems with certain properties; an example of an undecidable propostition is the assertion regarding the lack of contradiction of elementary arithmetic. For a long time, Gödel's propositions (which lead to the emergence of a new branch of mathematical logic, the theory of undecidability) have been considered as exceptional singularities, which cannot be found in "genuine mathematics". They could well be disregarded, just as continuous curves without derivatives "did not exist" for physicists. However, in both cases such ignorance did not last long: today fractals curves have invaded natural sciences, while undecidable propositions, as has been recently demonstrated, occur in various branches of mathematics (theoretical computer science, theory of formal languages, geometry, etc.). A problem of constant topicality concerns the explicit devising of undecidable propositions, and in this direction Gregory J. Chaitin, from the IBM Thomas J. Whatson Research Centre has made a decisive break, though its significance is still under analysis.

Chaitin's starting point is represented by the computation of the probability, that a universal algorithm (or equivalently, a universal computer) stops the execution on a random program (entry). An algorithm is a list of instructions written in a formalized language. As an entry, the algorithm receives a piece of information (e.g. a word) and then sets out to the execution proper; the computation can stop after a finite number of steps (in which case a result is produced) or can continue indefinitely. A famous result obtained by A. M. Turing states the existence of a universal algorithm, capable of working like any other individual algorithm. In order to explain the notion of "random program" we must first deal with some rudiments of the algorithmic theory of information. The information unit is the "bit", which contains the information necessary to provide an answer to a dichotomic question. A message containing n "bits" of information can decide between 2^n possibilities equally possible. For instance, the message "it is raining" contains 1 bit of information, while the message "today is Monday" contains log_2 7 bits of information. The messages may be codified by means of binary words; among the binary words of length n, some are "compressible" in the sense that they may be codified in a simpler form, others are not. For example, the word 10 10 10... 10 the length of which is one million, may be written more simply as "half a million of series 10", a phrase which in turn may be codified binary by means of a word of a length no greater than 300. As early as 1965, A. N. Kolmogorov, R. Solomonoff and G. Chaitin, in different but essentially equivalent ways, started to study the algorithmic quantity of information of binary words, by way of *complexity* (for technical details see Chaitin (1987 a), and Calude (1988)). The complexity of a statement is the length of the shortest program necessary to a universal algorithm to produce the respective statement. As already mentioned, there are "uncompressible words" (in disorder, to use a notion from thermodynamics) for which complexity is as great as the length of the word itself. Paradoxically, the majority of words are "uncompressible"; as P. Martin-Löf has demonstrated, these words display a "random behaviour", in a technical sense which exceeds the level of this presentation.

It is interesting to analyse the way in which G. Chaitin used the above mentioned facts. At an early stage, dating back to 1974 (Chaitin, 1987 b) includes both strictly mathematical articles and applications in the fields of biology and physics) the author demonstrated that, to any given formal system corresponds a natural constant c, so that any theorem to be demonstrated within the system has a complexity inferior to the sum between c and m = the complexity of the axioms of the system.

This leads to a spectacular extension of Gödel's theorem, because all the true statements which can be formalized in the system and the complexity of which are superior to $c + m$ are undecidable. At a second stage Chaitin shows that the number Ω is a random number, in the sense that writing it in base two and taking its fractionary part, there results an infinite sequence, any initial word of which is random. In the last stage, to the number Ω one associates an exponential diophantine equation (an algebraic equation in which only integer numbers, sums, products and exponentations occur) with approximately 17,000 variables and 900,000 symbols (which fill over 200 pages of listing). The equation has a parameter k, just a Fermat's equation $x^k + y^k = z^k$ has three variables, x, y, z and a parameter k. The outstanding quality of Chaitin's equation is the following : the equation with the parameter k has an infinity of solutions if the k—th position of the binary sequence given by Ω is 1, and the equation has a finite number of solutions when position k is taken by o. Chaitin's equation is so complex, that the answers to the question "has the equation with k parameter an infinity of solutions ?" for $k = 0, 1, 2... n$ corresponds to random words and given the case in which n takes all natural values they make up a complex of data which can be described by *no* finite system of axioms.

Chaitin's equation was in its turn devised in several stages combining mathematical ingenuity with programming ability. Briefly, the procedure was the following : drawing upon a method of encoding developed by J. P. Jones and Y. V. Matjasevič, Chaitin defined an abstract, machine-type, programming language and a translator capable of transforming any program of this language into an exponential diophantine equation. Then, a simplified variant of the LISP language was defined and a program allowing this dialect of LISP to be used was written. The final step was the writing of a LISP program which was *not* meant to be executed, but translated into an exponential diophantine equation, via the abstract language.

Chaitin's equation, in the elaboration of which theoretical and practical aspects are inseparable, shows that our intuition concerning the deductive structure of natural numbers is far from being clear and accurate. Even in the approximative forms depicted by the study of mathematics, randomness is present, not only in quantum mechanics or nonlinear dynamics, but even in the oldest branch of mathematics, arithmetic. The result is only apparently pessimistic ; it does not upset the balance inherent to mathematics, but signals the simple, but undeniable existence of new types of laws arithmetic is governed by : statistical laws. Just as physics is not capable of foreseeing the exact moment in which a particular atom undergoes radioactive decay, mathematics is unable to answer certain particular questions even in the domain of arithmetic.

In addition to the vast study area being pioneered, the brief but instructive experience accumulated over the past decade leads to several general recommendations :

1. The correct choice of the data corpus as well as their representation is decisive.
2. The area of impure demonstrations needs to be broadened by means of theoretical and computational components.
3. The place of the systematic construction strategy of formal deductions will be taken over by the transformation rules of the demonstrations.

Finally, we mention a project begun in December 1987, by 13 eminent mathematicians and computer scientists from the U.S.A., England and France. A. Marden (the project was his brainchild), W. P. Thurston, R. E. Tarjan, B. B. Mandelbrot, and A. Douady, gathered at the University of Minnesota to inaugurate the Geometry-Supercomputer Project. This project, supported by the National Science Foundation, will be located at the University of Minnesota and its Supercomputer Institute. The researchers will be linked through a large-scale internet which provides access to many other networks. The basic aim of the project is to use the power of a Cray 2 supercomputer to illuminate some challenging questions in geometry, including the classification of 3-manifolds (the classification of n-manifolds, for $n = 2$ or $n \geqslant 4$, is solved).

The project will require in-depth theoretical studies not only in geometry itself, but also in the algorithms and their complexities. "...a love of geometry and a desire to understand its computational aspects" (David Mumford, as quoted by (Jackson, 1988)) are the feelings that bring them together, a member of the project said.

How to Cope with Computational Complexity

Present calculations resort to huge numbers, compared to which Archimede's number (which is approximately 10^{63}, an estimation of the number of grains of sand necessary to fill the universe, as it was then conceived) is almost negligible. How can we operate efficiently with such numbers ? A solution would probably be the devising of a new system for writing natural numbers, one which would represent a step forward from the present one, similar to the progress registered by the change from the Roman to the Arabic system.

Modern mathematical logic demonstrates a result that can be interpreted in the following way. Let us choose two universal computers A and B arbitrarily, the former a very slow one (for example A performs an elementary operation in a century), and the latter a very rapid one (B performs $10^{10^{10}}$ operations per second). Some problems are so complex that, by using computer B instead of A, we do not register any significant progress. To put it differently, he utmost complexity of the problem eliminates the quantitative progress registered in the achievements of hardware. Hence, the importance that should be given to the "soft" component which is "duller", apparently eclipsed by the "hard" one.

This is the reason why, although they do not score engineering performances, personal computers have succeeded in bringing about a radical change of outlook in the field of computer science.

Universities and Industry

The opening of higher education institutions towards the needs of industry, followed more and more often by the creation of university science (parks, and the like) in the vicinity of campuses, has led to a mutually profitable symbiosis. One of the fields in which industry-education co-operation can be achieved with good results is precisely that of artificial intelligence, of the expert systems, and the use and development of information technologies.

Computer technology has emerged as a privileged area of co-operation between higher education and industry. The record of achievements in this field is impressive. Computer technology seems to represent an area in which already the gap between "pure" research (advances in AI for instance) and "applied" research has been so much reduced as to be practically nonexistent. It has been argued even that this link accounts for the intempestive renewals of both soft and hardware in NIT's. Moreover, there are numerous examples of how ideas which originated in university laboratories were turned into lucrative industrial undertakings by the researchers involved. Universities have in this way not only made proof of their claim that ideas make money : they have now proved that ideas make *a great deal* of money and that they can make it very *rapidly*.

In industry, the future graduate will work in computer-assisted management, in computer-assisted design, in computer-assisted manufacturing. The chances that whole factories may be computerized are increasing. Industry requires schools to provide it with graduates who know how to use computers and to provide upgrading courses in this field for its own staff. It is significant that in many instances, some 3/4 of the upgrading courses for industry staff are in the fields of computer sciences, computer languages, programming, and computer simulation.

Young people have proved to be extremely skilful in computer programming, in learning and in manipulating languages, in graphics, etc. Industry has found it advantageous to finance and to sponsor projects in this field (and if it has not reached this conclusion, it can be convinced to do so). Institutions of higher education can, in their turn, derive great benefits (let alone the financial support), by being involved in the solution of real life problems of topical interest of both a practical and scientific nature.

A more advanced form of co-operation is the organization of the practical work sessions of students (an established practice for a long time) as well as stages of research or training organized in industry for faculty members (a recently introduced practice).

Discussions about the forms of higher education-industry co-operation in the field of computers could be focused on such central topics as :

1. The improvement of management decision models and of their theoretical foundation.
2. The improvement of CAD and of its theoretical foundation.
3. The improvement of CAM and of its theoretical foundation.
4. The introduction of ICAI and ICAL in the industrial and technical fields.
5. Applications of advances in AI in various branches of industry.

A New Area of Interuniversity Co-operation

The creation of courseware is a typical example of teamwork. The resources are often shared by several universities. This spontaneous co-operation exists. It can be stimulated and facilitated at the national level by various bodies in charge c' higher education : university departments themselves, university administration (the rectors), inter-university associations, professional organizations, ministries of education and research, etc.

Some possible objectives and specific domains of this co-operation are presented in the following table which summarizes the ideas mentioned above :

1. Exchange of information and experience on teaching/learning at the level of higher education.
2. Exchange of experience and co-operation in the creation of courseware.
3. The improvement of programmes which facilitate the writing of courseware (authoring systems).
4. Exchange of experience in the production and the use of higher level, education-oriented, knowledge-based software.

5. The use of computers in research, particularly through the creation of new data bases and the devising of new modalities for the use of existing ones.
6. The networking of research units and of university libraries, so as to facilitate the on-line communication and the use of pooled research data bases and of bibliographical sources.
7. The use of computers in the management of higher education institutions.
8. The use of computers for extensive studies of student populations, as required for long and short term policy and decision making (trends in student applications, admissions, actual duration of studies, employment opportunities for graduates, etc.).

There already exists a rich experience of such co-operation, particularly in the countries belonging to the Europe Region. It involves higher education institutions themselves, through their specialized departments, but also a large number of professional associations.

Based on this experience, we list below some of the forms of intra and interuniversity co-operation at the national level, which have proved successful:

1. The creation in each institution of higher education of a *unit* (centre, group, or coordinating body) with responsibilities for promoting the introduction of NIT's in teaching/learning, in research, and in the management of the respective institution.
2. The development of "computer-assisted education" programmes with special emphasis on the involvement of university teachers from various departments in an interdisciplinary approach.
3. The setting up of *national centres to* monitor, guide, and coordinate the introduction of NIT's in education and in computer-based development processes of education.
4. The development of national programmes for the introduction of NIT's in higher education (equipment, courseware, data bases, etc.).
5. The encouraging of the creation of scholarly publications (journals, bulletins, series of monographs and other periodical publications) devoted to computer-based education.
6. The organization of periodic conferences and symposia for higher education teachers and researchers permitting them to meet and to discuss topical issues related to the introduction of NIT's in higher education.

A New Area of Regional and International Co-operation

Themes 1—6 listed above are equally relevant for co-operation at the regional and the international level. To refer, for instance, to the Europe Region, we have been witnesses of late to the efforts made by practically all the European countries to put to the fullest use, in their economic, industrial and social development, the progress achieved in new information technologies, including recent advances in AI. Such efforts have also involved co-operative undertakings, with beneficial result not only in making better and more efficient use of commonly shared resources but also in promoting mutual knowledge, understanding, and goodwill among the countries concerned.

There is, accordingly, ample room for further developing co-operation among the countries of the Europe Region in the field of NIT's and their use in higher eudcation. Co-operation ventures could include a wide spectrum of modalities including such forms as :

1. Linking up national centres in charge of NIT's programmes in education into *subregional and regional networks*, so as to facilitate the free flow of experience and of information and the joint use of pooled resources.
2. The undertaking of *joint research projects*, ideally in close association with and supported by indutry, with a view to advancing research, knowledge, and expertise in the field of NIT's in the countries of the Region.
3. Publication of international periodicals and of monograph series in order to help circulate faster and wider results of research.
4. Organization of *periodic symposia* and conferences and support for the setting up of cooperative mechanisms and structures, in co-operation with international professional organizations and associations.

Regional and international co-operation in the field of NIT's and their use for educational purposes is greatly facilitated by the international organizations — both governmental and nongovernmental — which are active in the field of higher education. Unesco for instance has developed a number of activities and programmes of its own and has encouraged a large number of initiatives, meant to promote the development of NIT's and their introduction in higher education, particularly through regional and international co-operation for the pooling of resources.

Unesco has convened an international Congress on *Education and Informatics : strengthening international co-operation*, in April 1989. It will reunite educators and trainers (decision makers, administrators, teachers, educational researchers and representatives of the world of work, industrialists, and manufactures of hardware as well as authors and publishers of software and systems used in education from all regions of the world. The Congress will provide an opportunity for taking stook of the present situation with regard to the interface between education and informatics while also outlining new prospects, new objectives, and new strategies for future action in this field. At the subtitle of the Congress suggests, international co-operation is regarded as playing a major role.

In keeping with its constitutional responsibilities and areas of action, Unesco will continue its efforts to strengthen regional and international co-operation in this important field of education, particularly at its higher level. Below is a list of areas and modalities of action by which Unesco would be most beneficial to co-operation meant to promote the introduction of NIT's in higher education.

1. The integration of the activities undertaken by various units of Unesco in the area, into a *well coordinated programme*, focused on computer-assisted education and on other uses of NIT's in education.
2. At the level of the Europe Region, two decentralized units of Unesco, CEPES (the European Centre for Higher Education) and ROSTE (the Regional Office for Science and Technology in Europe) could develop, in close co-operation with tre regional governmental organizations as well as with the university organizations and with representatives of the industry, a large-scale co-operation project aimed at fostering research on and application of NIT's in higher education.
3. Support for link-ups and networking between university research laboratories, libraries, and data bases, with a view to assuring the free flow of information in the field of NIT's among the countries of the Europe Region.
4. Support for the organization of symposia and conferences which should provide platforms for a broad exchange of views and experience in the development and use of NIT's. Among the topics which could be addressed at these meetings, the emphasis could fall on broader issues of a social, cultural, and philosophical nature, relative to the introduction of NIT's in various domains of human endeavour.
5. Support for those European co-operation schemes aimed at providing assistance to the developing countries in the field of NIT's.

Item 5 in the list above is indicative of the significant impact which the assimilation of the new information technologies into the educational process is having in today's world context. The new technologies are often blamed for the widening gap between countries and levels of educational systems. Intelligent programs and user-friendly interfaces increase the accessibility and the assimilation of the new computer-based technologies. It is worth ment'oning that the acute problems faced by developing countries (shortages of personnel, shortages of textbooks and documentation, the adjustment to the training level of students) are greatly eased by the new technologies. The arguments of those who are confident in the application of computer technology in developing countries are strenghthened by the potential of the "artificial intelligence" stage characteristic of this technology in our decade.

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Chapter I

NEW TECHNOLOGIES AND THE EDUCATIONAL PROCESS

The first chapter is conceived as a general introductory debate on the vast topic of the volume as a whole. The selection of articles has left out the discussion of the man-machine relationship with its philosophical overtones, a topic which, nowadays always gives rise to polemics. The five articles cover primarily the position of the cognitive sciences, in particular of contemporary psychology, vis-a-vis the concern for enhancing creativity and innovation which is regarded as the basic aim pursued by the introduction of new information technologies in education. An overview of opinions on the effect of computers on education is then offered in one of the contributions. The chapter ends with some points of view underlining the importance of the problem for higher education, particularly for management and decision making processes, and with some challenges, namely the diffusion of the cognitive sciences and technologies and the development of electronic communication, which the university community must face.

The first article is by Margaret A. Boden, whose seminal books "Artificial Intelligence and Natural Man" (1977), "Mind and Mechanisms" (1981), and "Artificial and Natural Man" (1987), have greatly contributed to bridging the gap between human sciences and computers and have paved the way for the use of computational models in psychology. Her principal claim is that artificial intelligence (AI) makes an important contribution to the better understanding of human thinking processes and is, thus, in a position to assist them. For her, drawing concepts from AI is a gain for educational and developmental psychology. The author emphasizes the flexibility of tutorial programmes curricula based on AI as well as the importance of AI for processes of creativity. The widespread acquisition of personal computers requires that higher education studies set a new goal for themselves — namely, that each graduate should be able to use a computer and be fully aware of its potential.

Academician Ljubomir Iliev, the author of the book *The Modelling Theory* (1984), emphasizes the role that modelling plays in cognition. It has been rightly claimed that a discussion of the use of computers in education should take models like *fineware* and notions like *brainware* into account in addition to software and hardware. In the new outlook imported by AI, knowledge acquires the central place which, in a former phase of computer development, was occupied by information.

In the next article, Lloyd Steier presents the results of a study based on the Delphi method, the purpose of which was to ascertain the opinions of several persons as to possible and probable changes in education, coming as a result of the use of computers. The conclusions are summarized by nine ideas on potential effects: 1) continued commitment to computer technology; 2) technological change; 3) impact on curriculum; 4) teacher training 5) widespread experimentation; 6) teacher's role; 7) need for policy at all levels; 8) major problems, 9) and major strategies for policy makers.

Academician Germogen S. Pospelov, President of the National Council of Artificial Intelligence in the USSR, considers that the priority role of scientific research institutions is now to enrich existing knowledge bases with new elements: theories, calculation methods, etc, by means of powerful computers connected to networks. Research in the AI field is no longer considered as being purely theoretical, as was the traditional view, but as research with wide practical application. The article, which appears in the form of an interview given by academician Pospelov to the *Znanie sila* magazine, is not only convincing, but also stimulating.

The section ends with the paper of Michele Pellerey, which draws our attention to the way in which new information technologies require new solutions, especially from the higher education community, with regard to human values and human rights.

EDUCATIONAL IMPLICATIONS OF ARTIFICIAL INTELLIGENCE *

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The volcanic peaks of Fiji, described by Rupert Brooke as the most fantastically shaped mountains in the world, remind me of the well-known reason for climbing Everest: "Because it is there". This reply may be adequate justification of the mountaineer's obsession, but it would not explain why people involved in education should be interested in Artificial Intelligence (AI). AI is the attempt to write programs enabling computers to do things that would involve intelligence if done by people (Boden, 1977). Like every human activity, it has its own peculiar fascination. But there are more pressing reasons why AI is educationally relevant, reasons both theoretical and practical.

Many cognitive psychologists today look to AI for help in understanding problem solving, learning, and intelligence. Even creativity might be illuminated by AI-related ideas. Psychological theory can be expected to influence pedagogical practice, and relevant recommendations have already been drawn from the AI way of thinking about thinking. The entry of AI into the classroom in the form of AI-based automatic tutors calls for an appreciation of the differences between this approach and the traditional view of computer-assisted instruction. Current work with handicapped children suggests that AI ideas can help these children to realize their intellectual and emotional potential. And the increasing use of computers in schools and universities prompts people to ask whether social life will be impoverished by the widespread introduction of "intelligent" programs in educational institutions. For these various reasons, then, educators might be expected to take an informed interest in AI.

Educational psychology and pedagogical practice alike are unavoidably (if often implicitly) influenced by general psychology. Today, theoretical psychologists increasingly draw concepts from AI and computer science in asking questions about thinking. According to the computational approach, thinking is a structured, interpretative process.

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Given this view, AI is in accord with many non-behaviorist psychologists — such as Piaget. Indeed, AI agrees with Piaget in a number of ways, including its commitment to formalism and cybernetics, and the insight that psychology (being concerned with meaning and symbol-manipulation) is semiotic rather than causal. However, Piaget gave only vague answers to his questions about thinking and its development; he also failed to make his questions about these matters sufficiently detailed: his vocabulary of "disturbance", "regulation" and "compensation" is inadequate to express the procedural complexity involved (Boden, 1979). Nor is Piaget alone in this. Non-computational psychologists, in general, tend to underemphasize mental process, taking it for granted as unproblematic rather than inquiring into it. This is hardly surprising, since computational concepts are needed to express the content, structure, construction, comparison, transformation, function, and development of differing representations and information-processes. A central lesson of AI, then, is that our theoretical aim should be to specify the procedural complexity of thinking.

One way of attempting to do this is to write computer programs that achieve an intellectual task that human thinkers can manage. Because programmed procedures must be explicitly and rigorously defined, this exercise may provide ideas as to what psychological processes might be involved — and it will certainly help to locate lacunae in current psychological theory. However, the way in which a program does something may bear very little relation to the way in which human minds do it. We need to make careful comparisons between the various levels of the program and psychological data, to assess the degree of match between the artificial and the natural systems. In many cases, the relevant data are not available. Often, there are methodological difficulties in deciding just which aspects of the program might be worth testing empirically (some aspects are included merely in order to produce a program which will run, and have no psychological interest). And many psychologists are not sufficiently interested in the activity of programming to want to spend their time in writing complex programs. For these reasons — not to mention a positive commitment to working with human subjects — many psychologists sympathetic to AI do not desert empirical research for the computer console. Instead, they try to plan their experiments with computational questions in mind, their studies being more closely focused on the procedural details of thinking that is usual.

In developmental psychology, for instance, the computational influence has been largely responsible for the increasing interest in microdevelopmental research, which studies the dialectical interplay between action-sequences and changing cognitive representations (theories, models, heuristics, choice-criteria...). The emphasis of microdevelopmental studies differs from more traditional approaches in emphasizing the specifics of action, on the assumption that the procedural detail of performance (not only its overall structure) gives clues to underlying competence. Admitedly, Piaget was one who took seriously details of action which others had ignored as trivialities. But the degree of detail aimed at in microdevelopmental research is greater — and that which would be needed to specify an adequate computational theory of these matters is greater still.

For example, a microdevelopmental study of children's learning to balance blocks found that non-balanced block may at first be ignored as an apparently irrelevant anomaly, and only later be accepted as a genuine counterexample challenging (and prompting an improvement of) the child's current theory (Karmiloff-Smith and Inhelder, 1975). This fact is not predicted, still less is it explained, by generalized talk of "accommodation". The experimenters suggested that time is needed for "consolidation" of any theory — but they did not ask just what consolidation is, and how it is effected. These questions would need to be answered if "consolidation" is to be accepted within a computational theory of cognitive change (Boden, 1981).

In another example, microdevelopmental work has cast doubt on the common assumption that the classificatory power of five- and ten-year-olds is very similar (Thornton, 1982). This view relies on the fact that the *product* of classification may be identical between these two age-groups, but it ignores the fact that the *activity* of sorting is significantly different. Thornton's experimental design highlights many procedural differences, and she interprets her observations in broadly computational terms. She suggests that children of ten treat the whole classification as a single unit composed of interrelated classes, that at five they proceed as though each class were independent of the others, and that seven-year-olds attend to the relations between classes so as spontaneously to effect the transition by organizing their initially "juxtaposed" procedures into more coherent systems. She admits that the procedural content of concepts like these needs to be clarified if cognitive development is to be understood, and is currently attempting such a clarification with the help of AI-ideas. (With reference to bugs and creativity, both discussed below, one should note that Thornton takes her work to show that cognitive change need not be failure-driven. This conclusion is supported by the comparable finding that a child asked to draw maps may spontaneously construct a more powerful map, even though the current one has always succeeded [Karmiloff-Smith, 1979]).

The educational potential of AI has been explicitly recognized by a number of workers in the field. One of these is Seymour Papert (1980), an ex-colleague of Piaget who has been deeply influenced by Piaget's ideas about autonomous constructive learning and the epistemological relevance of the structure (not only of knowing but also) of what is known. Papert's ideas are likely to be influential, not least because in November 1981 he was invited by President Mitterand of France to advise on a new Paris computer research center (with a budget of £20 million a year) devoted to the development of a low-cost, pocket-sized computer that will be available on a mass scale throughout the world. In a recent book, Papert (1980) explores the promise of the nascent "computer culture", focusing not on the many uses people will find for computers, but rather on the power of computational environments to affect the way people think and learn — and, crucially, the way they think about themselves.

Papert reminds us that psychological theories of thinking usually affect educational practice not *via* detailed hypotheses, but *via* relatively general ideas, and he identifies a number of "powerful ideas" that enable us to think more confidently and effectively. An important example is the notion of "bugs" in thinking. This concept originated in computer programming, wherein one soon discovers the ubiquity of bugs! Bugs are mistakes, but not just any mistakes: a false factual assumption is not a bug, nor is a momentary slip in executing some procedure, nor the choice of a procedure that is wholly inappropriate to the goal. A bug is a precisely definable and relatively systematic, erroneous variation of a correct procedure.

Several AI workers have attempted to classify bugs. Sussman (1975) distinguished several types in terms of general teleological notions such as goal, brother-goals, and prerequisite; he wrote a self-modifying learning program that diagnosed its bugs so as to criticize and repair its self-programming accordingly. More recently, O'Shea and Young (1978) have analyzed a large sample of children's subtraction errors in terms of the deletion or overgeneral application of individual rules, such as the "borrowing" rule. Brown and VanLehn (1980) and Burton (1981) have also studied subtraction, and their programs BUGGY and DEBUGGY provide a notation for precisely describing bugs, as well as a diagnostic tool for identifying errors in students' work. They are developing a "generative theory of bugs", a set of formal principles that can be applied to a particular (correct) procedural skill to generate all the bugs actually observed in the data, and no others. They expect their theory to predict the bugs that occur during the learning of arithmetic, algebra, and calculus (and, possibly, operating computer systems or controlling air traffic).

Their central idea is that many bugs are "patches" (a term drawn from computer programming) that arise from the attempt to repair a procedure that has encountered an impasse while solving a particular problem. The theory defines various repair heuristics and critics (procedures for finding mistakes in a strategy) and the way in which a repair will be attempted is theoretically independent of the reason why the procedure was incorrect in the first place. This enables the authors to explain "bug-migration", wherein a subject has a different bug on two tests given only a few days apart. Using their diagnostic system, they find that only certain bugs migrate into each other, and that they seem to travel both ways. For instance, "Stops-Borrow-At-Zero" migrates into "Borrow-Across-Zero", and *vice-versa*. The hypothesis is that bugs will migrate into each other if (as in this example) they can be derived by different repairs from the same impasse. Repair theory thus makes empirical predictions about the detailed pattern of errors observed when people are learning skills of thinking.

Despite its emphasis on error, "bug" is an optimistic rather than a defeatist notion. For it implies that elements of the correct procedure or skill are already possessed by the thinker, and that what is wrong is a precisely definable error that can be identified and fixed. In this it differs from the broader notions of "anomaly" and "counterexample", the educational value of which has been stressed for instance in the Piagetian tradition (Groen, 1978). As Papert puts it, the concept of bug helps one to think about thinking in "mind-sized bites". These insights led Papert to develop the LOGO programming language (usable even by six-year-olds), in the conviction that AI in the classroom could lead children to a fruitful insight about their own thinking abilities. There is some evidence that experience of LOGO-programming does indeed encourage children to replace the passively defeatist, "I'm no good at this" with the more constructive, "How can I make myself better at it ?" (Papert, 1980 ; Howe *et al.*, 1979).

Thus Papert stresses the educational value of the activity of programming itself. But AI can enter the classroom in another way, namely, in the form of tutorial programs. Automatic teaching aids, of a sort, have long been with us. B. F. Skinner's "teaching machines", and their descendants in Computer Assisted Instruction (CAI), can vary their response to a limited degree with the student's level of understanding, by means of branched programs with predefined choice-points. But the flexibility of tutorial programs based in AI is much greater because they incorporate complex computational models of students' reasoning that enable them to respond in more subtly adaptive ways. A number of such programs already exist that are useful in limited domains, and several groups around the world are working on these issues (Sleeman & Brown, 1981). Only if a clear articulation of the knowledge involved in the chosen domain has been achieved can it be embodied in an instructional program — though before this embodiment in might be usable by a human teacher in an instructional program. DEBUGGY, for instance, is as good as or better than human diagnosticians at discovering the nearly one hundred bugs that explain a student's subtraction error. In the hands of a specially primed teacher, it can be put to use in the classroom. It has not yet been incorporated within a remedial program, with which students can interact to improve their subtraction skill ; nor has it yet been presented so as to be a diagnostic aid for a mathematics teacher. But these educational developments are in the forefront of the authors' minds ; one of Brown's aims has been to develop diagnostic and remedial principles that can be used by tutors — whether human or automatic — to help people learn (Brown & Burton, 1975). (Some practice with DEBUGGY might profitably be provided in teacher-training courses, even though it cannot yet be adopted as a classroom tool.)

We have seen that AI helps to foster a constructive rather than a defeatist attitude to our mistakes. But to emphasize the creative potential of bugs is not to say that all creative thinking is a reactive response to failure (Boden, 1981). On the contrary, it often appears to be grounded in a spontaneous exploratory urge. This much is recognized by psychological accounts of creativity in terms of "competence", "adaptation-level", "functional assimilation", and "play". However, creativity cannot be understood by way of these concepts, nor by any other structurally undifferentiated, quasi-quantitative, notions of novelty and familiarity. For such concepts enable us to say little or nothing about precisely how individual creative achievements come about. A theory of creative thinking should be able to explain how *these* or *those* novel thoughts are generated, how promising pathways are recognized in preference to probable dead ends, and how potentially interesting ideas are distinguished from novel banalities.

The idea that AI might help answer these questions strikes many people as paradoxical. It is commonly assumed that, because of its programming provenance, AI must be fundamentally incapable of modelling creativity. Were this so, its educational relevance would be gravely limited, for a prime aim of education is to encourage creativity. However, unless it is either random or essentially mysterious, creativity must be grounded in some systematic, generative principles. From the viewpoint of theoretical psychology, which assumes thinking itself to be food for scientific thought, to regard creativity as essentially mysterious is to be intellectually defeatist. That creativity cannot be a random process (though there is sometimes a random aspect to it) is recognized by all who scorn the idea that a barrowload of monkeys with typewriters could produce *Hamlet*. Rules or generative principles there must then be, and since AI is specifically concerned with transformations in generative structures, we may expect it to be relevant.

Although most AI studies do not attempt to model systems in which genuinely novel ideas arise or in which radical constraints are relaxed, some relevant work has been done. For instance, Lenat's (1977 a ; 1977 b) "Automatic Mathematician" starts off with some elementary concepts of set-theory and a collection of heuristics (rules for combining, transforming, and comparing concepts), and sets out to explore their potential in an open-ended way to discover new mathematical concepts. Significantly, the program does not merely churn out new ideas, but focuses on some heuristic pathways as more likely to be promising than others, and on some novel ideas as more interesting than others. Thus, having discovered the natural numbers and decided to explore this path, it then discovers and dubs "interesting" concepts such as prime numbers, square roots, and maximally divisible numbers (with respect to which the last program developed two minor new results in number theory).

Granted that the heuristics were thought up by Lenat (1977 b) rather than by the program, it is significant — and surprising to many people — that this sort of fruitful exploratory thinking can be formally represented at all. The degree of creativity evinced by the program is, however, difficult to assess. The concept of creativity is itself so unclear that it is not obvious just what would count as "discovering", or "creating", natural number theory (or anything else). Critics (Hanna and Ritchie, 1981) have remarked that Lenat (1977 b) does not list all the concepts regarded by the program as interesting : perhaps a high proportion were mathematically trivial. It is not clear from the published accounts whether some crucial "discoveries" were made possible only by the use of unacceptably *ad hoc* heuristics, nor is it easy to draw the line between an acceptably specialized expert heuristic and a disingenuous programming trick. Certainly, many of the heuristics are highly domain-specific, relevant only to set theory. But it is a prime theoretical claim of Lenat's (1977 b) that intelligence depends heavily on expert knowledge, as opposed to general skills.

Lenat's view that social-purpose heuristics are necessary to creative thinking is consonant with the view of intelligence now held by many people in AI. In the early days of AI research, it was a common assumption that very general thinking procedures suffice to solve most problems. This faith was reflected in the title of one of the most famous early programs, the "*General* Problem Solver" (Newell and Simon, 1963), and it motivated much of the early work in "theorem-proving". Since then, it has become increasingly apparent that, while there are some relatively general strategies (such as depth-first or breadth-first search, for instance), the intelligent deployment of knowledge also involves large numbers of domain-specific heuristics suited to the structure of the subject matter concerned.

Like the notion of "buggy thinking", this view of intelligence contradicts the all-too-common idea that intelligence is a monolithic ability, which one either has or lacks. If more ammunition against so-called "intelligence tests" were needed, there is a full arsenal here: the AI approach highlights the absurdity of trying to assess people's intelligence by deliberately *preventing* them from using any of their acquired expertise (Gregory, 1981, pp. 295—333).

Since intelligence is the deployment of many special-purpose skills, learning and microdevelopment must involve the gradual acquisition of a myriad of domain-specific facts and heuristics. Many of these are presumably picked up during the initial immersion in a problem domain, when the unskilled person may appear to be merely thrashing around. Just how they are picked up is, however, obscure. Microdevelopmental studies thus need to focus on precisely what information is being attended to by the child at a given time, and what micro-strategies he is using to deploy it, with what results.

The case for asking these informational questions, with reference to distinct procedural rules, has been argued in the context of an AI model of children's seriation behavior. Young (1976) showed that qualitative behavioral differences can result from the addition or deletion of one simply definable Condition-Action rule. Moreover, the use of a rule, once acquired, depends on tests related to its appropriateness in a particular context of information. For example, even adults will use a trial-and-error seriation strategy if given a large number of blocks, differing only slightly in length. Piaget explained this in terms of regression from the formal to the concrete-operational stage, implying that the subject chooses a sub-optimal method over an optimal one However, the informational demands here differ from those where there are only a few blocks, of obviously differing lengths. The perceptual judgment of which block is the largest (or smallest) cannot be made instantly, since the information from so many blocks cannot be handled all at once. Consequently, the optimal informational strategy is to compare the blocks one by one. Young's study of seriation (1976) is in the microdevelopmental rather than the macrodevelopmental category, not only because he is able to explain minute details of behavior (such as the stretching out of the hand towards a block that is not then picked up), but because of his AI-based view that intelligent behavior is better described in terms of many independent rules than it is in terms of holistic structures.

Handicapped children can benefit greatly from an AI-based computational environment (Weir, 1981; Weir and Emanuel, 1976). I have in mind here not the use of computers as gadgetry (controlling typewriters and the like), practically important though these are. Rather, I am thinking of recent research showing how AI can help encourage a variety of intellectual and emotional abilities; AI can be used not only to study the mind of a handicapped person, but also to liberate and develop it. Weir, a psychiatrist with a mastery of AI techniques, has worked with a number of different handicaps and has started a long-term project with the sponsorship of the Massachusetts Institute of Technology. Commenting on the varied examples she describes, Weir points out that we have as yet only scratched the surface of what is possible.

For example, her work with a severely autistic child suggests that a sense of autonomous control (over oneself and others) may develop for the first time as a result of the experience of interactive (LOGO) programming. The immediacy of results and the non-human context (in which the threat of personal rejection or adverse judgment is removed) combine to provide an inducement for the emotionally withdrawn child to venture into a world not only of action, but of interaction. Interaction with human beings follows, apparently facilitated by the computational experience.

Another example is our wish to build and improve the spatial intelligence of severely palsied children. Since they lack normal sensorimotor experience, we might expect them to suffer from generalized disabilities of spatial cognition. But manipulative tests are clearly of little value in assessing just what abilities a palsied child has or lacks. The use of computer graphics (for which LOGO was developed) provides a window onto the intelligence of these children, one that allows diagnosis of their specific difficulties in understanding spatial concepts. Weir's aim is not just to understand their minds but to help change them; she has the satisfaction of reporting considerable advances in the children's intellectual achievement and general self-confidence.

Linguistic defects, too, may be bypassed in assessments based on computer graphics. For instance, a grossly dyslexic boy was found by Weir to have superior spatial intelligence, involving highly developed metaknowledge (knowledge *about* knowledge) in the spatial domain. The dissociation between linguistic and spatial knowledge is, of course, consonant with the AI view of intelligence discussed above. Much as I suggested that DEBUGGY might be useful for teacher training even though it is not ready as a classroom tool, so ideas from Weir's LOGO projects might be useful in training teachers for the handicapped. But since it is a prime claim of her approach that the experience of interaction with a LOGO machine is itself highly therapeutic, she would recommend increased availability of computers for use by handicapped people.

This raises an aspect of the "computer culture" awaiting our children that has not yet been mentioned, namely, the enormous increase in the number of computers used in society. By 1980 there were already two million personal computers in use in the United States (Levin and Kareev, 1980), and the market is expanding; and there is an increasing use of programs by institutions (governmental, medical, educational, and commercial). In their discussion of "the future with microelectronics", Barron and Curnow (1979) point out that, as well as vocational training and adult retraining, we shall need contextual education to ensure that everyone is aware of the technology and its possible consequences. As users get less expert, there will be an increasingly urgent need for relevant nonspecialist courses in higher education. They conclude that, "It should perhaps be a target that every graduate has the capability to use computer systems and a thorough understanding of their potential [and, I would add, of their limitations]" (p. 231).

Several universities already have courses with these aims in mind, and some people are already doing comparable work with school pupils. For instance, we at the University of Sussex have found that one can alert naive (and non-numerate) users on their first day of programming experience to the facts that even an "intelligent" program is incapable of doing many things we might *prima facie* expect it to do, and that even a nonspecialist may modify the program so as to make it less limited. A conversational or visual program, for example, is initially impressive, but the user soon realizes that apparently obvious inferences about the meaning of the input words or pictures are not actually being made by it. The beginner student can then attempt to supply the missing rule so that the unmade inference can now be drawn. Since they themselves are altering these complex systems, students gain confidence in the activity of programming. More important, they realize that programs, however impressive they may be, are neither godlike nor unalterable.

These insights would not readily be communicated merely by teaching students to program — in FORTRAN, for example, or BASIC. They are best conveyed by prepared teaching demonstrations which make use of AI techniques. (Ours owe a great debt to the late Max Clowes, whose imaginative vision of student-friendly computing environments inspired us all.). Educational projects such as these are socially important, since for most people the ability to write usable programs will be less important than the ability to use — and to avoid misusing — programs written by others. This sort of computer literacy will be necessary if people are to be able to take advantage of this new technology rather than being taken advantage of by it.

Widespread access to computing environments, especially in primary or middle schools, may have significant social-psychological effects. The computer junkie, or "hacker" (Weizenbaum, 1976, pp. 115—126) has already appeared in infantile form — so much so that a brochure for a children's computer camp reassured parents that their offspring would not be allowed to remain at the terminal all day, that they would be *forced* to ride, swim, or play tennis. Whether this presents a threat to normal social development is not yet known. Research on the impact of such environments on young children's play patterns is currently being planned (Robert Hughes, National Playing-Fields Association : personal communication), in the hope that any unwelcome changes in play behavior could be forestalled.

We should not assume, however, that any changes in social interaction would necessarily be unwelcome. For instance, there is evidence in the LOGO projects that the greater self-confidence, induced by a child's experience of computing, can lead to less antisocial behavior. Moreover, programming contexts are in some ways less threatening or oppressive than interpersonal ones, and so have a liberating potential that could be useful in education. This potential has already been mentioned with respect to the autistic child who was led to interact with people after the safer experimentation in a computational environment; it has also been observed in the context of medical interviewing (Card *et al.*, 1974). A computer system is something to which (not to whom) one can direct remarks that do not carry the usual social consequences (Pateman, 1981). Interaction with the system thus avoids the sort of face-saving maneuvers which, in interpersonal contexts, can inhibit the creative exploration of ideas : "I wonder what it will do if I say this ?" is significantly less threatening than "I wonder what she will think of me if I say that ?".

In sum, AI has much to offer to people involved in the theory and practice of education. It can help both in the understanding and the improvement of thinking. Through its influence on cognitive and developmental psychology, AI promises to deepen our insight into the procedural complexities of thought. Through its applications in the classroom, AI's view of intelligence as a self-corrective, constructive activity can foster personal autonomy and self-confidence. This is so with respect to normal and handicapped students, children and adults. Used as the basis of intelligent tutorial programs, AI can offer greater aid and challenge to both student and teacher than the more familiar forms of computer-assisted instruction. Last but not least, AI ideas can be used to convey a deeper understanding of the potential and the limitations of programs, in societies where computer literacy will be an increasingly important aspect of the communal good. The satisfactions of viewing AI are not those of scaling Tomanivi or the Namosi Peaks. But AI, too, is there : let us not fail to explore it.

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ON THEORY OF KNOWLEDGE

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1. Knowledge begins from the object, passes through the image in the conscience of the subject and is formed through a description by some means in a *model*. The image is a subjective possession. The model is an object.

The initial level of every research is qualitative. This is the process of finding out the qualitative regular features in the object. The quantitative period follows, during which the result of applying specific methods and experiments on the object are measured and the data obtained are processed most of all statistically and graphycally. When these stages are developed to a great extent, a new level begins — the level of investigating most complx regular features of the object. We shall refer to it as the functional level.

Here, object may denote a given object in some science, a sphere within that science or that science itself.

At every one of these levels some processes can be described by mathematical means. This is mathematical modelling. Sometimes, the whole model can be described mathematically. This is a mathematical model of the object.

Mathematical modelling is of special significance on the functional level of research, no matter whether it is applied to a separate object or to some science, to some parts of that science or to a complex of scientific fields of different sciences. Every sphere of scientific research reaches such a level.

The creation of a mathematical model of a phenomenon under investigation, which is not fully studied, is of extraordinary importance. This is because its properties are "isomorphic", adequate, identical to the properties of the mathematical model. Research is reduced to solving a mathematical problem. If its solution is already known, then the phenomenon studied is also known. Mathematics has already treated it. Some people think that this is a knowledge "a priori". It is simply a mathematical knowledge. Mathematical models are simpler and that is why their investigation reveals faster the knowledge of some phenomena.

Reaching the stage of mathematical modelling in some field of research is a revolutionary phenomenon in this field. The effectiveness of scientific research and its applications increases in a leapwise manner. A possibility arises to predict the future state, knowing the initial conditions of the processes in this field.

At the same time conditions arise for a part of this field to be mathematized and developed as an isomorphic model of mathematical fields. In this way, sciences hybrid with mathematics are created. Such sciences are mathematical mechanics, mathematical physics, mathematical lingustics. This process has become exceptionally explosive after the invention of computers and the development of informatics.

The processes of qualitative, quantitative, functional research and mathematical modelling within them unite in a process, characteristic for every research in all science, in different sciences, in their fields or in the historical development of science in general.

The product of the object investigation is a model. It is a *new object*. It contains reflected information, knowledge of the object. We shall call it *reflected knowledge*.

The model may be every kind of object — a thing or a phenomenon. Sometimes, it may be a *hypothesis* or a *theory*.

We shall repeat: these are different kinds of *reflected knowledge*.

The model as an object can be explored by some of the methods given above. The result is a model of a model — a higher level of abstraction and knowledge. It is reflected knowledge, too.

Since hypotheses, theories, methods and other kinds of description of objective reality are models, they are objects as well — products of knowledge.

A *new* object (a new method, a new theory, an object in nature, etc.) leads to a *fundamental* stage of research A possibility for obtaining new images arises. Such possibilities stimulate greatly creativity and give impetus to it. Research may pass through all levels of the investigation process — the qualitative, the quantitative and the functional level.

At this stage. the final product is a *new* model — *new reflected knowledge*.

The theory of reflected knowledge — from the object to the model is the theory of modelling.

The levels of object investigation — from the object to the model determine a stage that we called fundamental. The investigation process applied to a given object, respectively, is usually called *fundamental research*.

Obtaining the model of a *new object* is the process of *fundamental research in the part of reflected knowledge*.

The model presents a possibility of obtaining new, still unknown images — corollaries. The procedure of *processing knowledge* in the process of fundamental research begins. The new, unknown till then corollaries may be unexpected, even mutational for the preceding knowledge. They are obtained by processing the part of reflected knowledge in the process of fundamental research. As corollaries they are liable to a test of adequacy to objective reality.

Obtaining corollaries of the model of a new object is a *fundamental research in the part of processed knowledge.*

The model of a new object and the corollaries of the model of this object *in unity form the process of fundamental research.*

Both constituents of this process are in *dialectic unity* and they define the *notion of fundamental research.*

The process of fundamental research is the *first stage* of scientific research.

When the new images and their superpositions are mastered to a considerable extent, there begins the stage of their regular use in the investigation of more specific properties and the creation of new projects. We shall call it the *engineering stage of research.* The notion "gene engineering" is well known. Many activities in the engineering sciences possess these features. This fact accounts for the term proposed.

These two stages stimulate the *technological stage* — the creative application of the results obtained. Under some conditions at this stage technologization may be reached — the mass utilization of this field.

To keep the technology up-to-date, new objects, including new methods in the different fields are needed to yield new fundamental and engineering results. They will stimulate new technologies. Otherwise, this field will get exhausted. Whole fields in science and art may be and have been exhausted in respect of objects and methods, as well.

The phenomenon of upheaval and exhaustion in different fields of human activity due to the introduction and exhaustion of new means in them will be called *pulsation.*

Science has three stages of development : fundamental, engineering and technological.

During the first part of the fundamental stage, at the different levels — qualitative, quantitative and functional, a model of the scientific object is searched — that is reflected knowledge.

During the second part of the fundamental stage and throughout the engineering and technological stages the knowledge obtained is processed.

Knowledge has two *categories :* reflected and processed.

The science of obtaining models from objective reality is called *theory of modelling.* It comprises the *theory of reflection.*

The science of information processing is called *informatics.*

Knowledge may be reflected or processed.

The theory of knowledge is a unity between theory of modelling and informatics.

We may say, that it is either *generalized modelling* or *generalized informatics.*

More generally : the science of processing information is called informatics.

Informatics aims at deriving the corollaries, following from a data complex.

For example, a logical reasoning directed to derive a corollary from some conditions is an information processing — informatics.

Every separate case of information processing is a *process*.

The information processing under a certain condition defines a *concrete informatics*, sometimes *specialized*.

Such a condition exists in the definition of the Paris Academy of Sciences : *Rational information processing mainly by computers.*

Here, the restriction does not arise from the condition "rational" — that is scientific, but from the requirement "by computers".

Since a computer carries out logico-mathematical operations, then this definition determines the notion *mathematical informatics*.

As in the modern epoch, by a mutation, the information processing is carried out almost only by computers, then the *modern state, the modern name of informatics is mathematical informatics.*

2. The processes of investigation just described — from the object, through the image in the subject to the theory and the processing of knowledge on different stages are object of the theory of knowledge.

This is the object of human knowledge, of human activities, of *human intelligence*.

What is *artificial intelligence?* What is its connection with human intelligence, with the intelligence of the subject — the man?

We have shortly described the steps of human knowledge. This knowledge must serve man. For the processes familiar to people, one seeks "simple" ways of finding out their corollaries, one seeks *algorithms*. Algorithms can be carried out by people, too, who do not know the processes. We may aquaint someone who does not understand mathematics, with the Euclid algorithm and he will find the greatest common divisor of two integers. Something more. We can construct a machine — an automaton, which carries out these functions.

Automata can be constructed for algorithms — automatized processes, starting from the weaving loom to the computer and so on. What are the consequences ?

First. Thus *knowledge mastered by man* is delivered to the machine. He is free from thinking of this phenomenon and can turn his mind to other processes. The machine takes his place. In this way thoughts and efforts are in dialectic unity. Nowadays labour — intellectural or in the field of art is what makes man. The algorithm is a synthesized thought. The automation is a materialized algorithm. It is impossible to achieve such a form for every process.

Man's habits are nothing else but the realization of this process — the transition of some mastered intellectual processes to other organs.

Second. The automaton, the machine, the computer can possess parameters and functions more perfect than those of man. For instance, speed ; or information capacity ; data bases.

In this way, what man can do with *his knowledge*, although in time unreal according to some criterions, the machine can carry out in real time, thus realizing the same knowledge. Some mutations for intellectual processing possibilities (processes) arise. The machine assumes and presents us *masses of knowledge*.

This mutational process is a result of human knowledge and the properties of the automaton's elements.

The mutations caused by the automaton may lead to some properties of the objects unknown till that time, i. e. new knowledge.

Software can programme systems analogical to the processes carried out by human intelligence — linguistic problems, assimilation of knowledge, solving problems, pieces of reasoning. Of course, for this purpose, the architecture of the machine must possess the necessary algorithms. All of this is done by human intelligence. But the machine also performs these "intellectual" functions, acts like an intellect. These are intelligent systems of data bases. In some cases, mutational with respect to some parameters, the results cannot be obtained by man. The systems are man's product, but the results cannot be obtained by him. The *artificial intelligence* comes into existence.

So we get the link — man, machine, intelligent system, mutational possibilities for human knowledge — the problem of what comes first.

The important thing is that the theory of knowledge cannot ignore this complete process any longer. There is a new component in this theory, too. Its object is called *artificial intelligence*. As far as it contains such notions as algorithm and information processing, it is related to mathematics, too. There also exist mathematical problems of artificial intelligence.

Creating artificial intelligence is a man's art. Or in other words, it is of no importance what is stronger — human or artificial intelligence. What matters is that artificial intelligence makes man stronger than he is without it. Artificial intelligence is a revolutionary new part of natural intelligence. The origin of artificial intelligence has other aspects, too.

3. Now let us make some additional reasoning. The assimilation of knowledge, from the object through the image to the model, passing through qualitative, quantitative and functional stages presents an *immediate, directly reflected knowledge*. The model is a description of the image of an object. It is a new object. It can be a thing, a functionality, a hypothesis, a theory. Still, let us repeat, it is a directly reflected knowledge. The model gives knowledge which can be processed. New corollaries are obtained. They are knowledge. Some of them may be new. This knowledge is not immediate. Let us call it *processed knowledge*. So we have introduced the categories : direct knowledge and processed knowledge.

In order to obtain the two kinds of knowledge, science creates methods. Sometimes, some method may create mutational states in the knowledge obtained.

Thus, the invention of microscope and nowadays of the electronic microscope led to a mutational state in direct knowledge, for instance in biology. The invention of the telescope brought about such a state in astronomy.

The invertation of the computers created the computer mathematical modelling or contemporary informatics, i.e. the information processing by computers. It caused mutational states in all fields of processed knowledge. Even the notion "artificial intelligence" came into being. The terms "natural intelligence" and "artificial intelligence" denote the mutational processes in assimilation of processed knowledge and in theory of knowledge in general.

Mutational phenomena may give rise to new situations also in some past fundamental stages in different fields of scientific knowledge, i. e. to renew the process of knowledge, to pose new fundamental problems. That is quite natural, as new methods are introduced in this field. In this way, it is possible to find out an object for new direct knowledge.

COMPUTER TECHNOLOGY AND EDUCATION *

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It is generally agreed that computers are the dominant technological artifact of our time. Lepper (1985) reflects the view of numerous writers : "We are currently on the edge of a revolution in technology that may evntually prove more sweeping and significant than any other technological advance in the last 200 years — the revolution that is likely to occur as powerful microcomputers begin to infiltrate our lives" (p. 1). Masuda (1980) describes computer technology as fueling a transformation from an industrial society to an information society. The widespread acquisition of computers by schools is often cited as reflecting this societal transformation. Numerous reports attest to the rapid growth in numbers of computers in the schools of most of the provinces and states (Bork, 1984 ; Morgan, 1984 ; Petruk, 1985 ; Weiner, 1984). Computers have generated a great deal of enthusiasm and excitement as schools continue to acquire them at a rapid rate. Shavelsom and Salomon (1985) identify a major reason for these developments : "For the first time, a genuinely 'thinking' interacting, technology, the computer, has become readily available to education... The pedagogical promise of the new information technology is boundless" (p. 4).

Despite the large-scale acquisition of computers in schools there is increasing concern that they are having a limited impact on the instructional process (Becker, 1984 ; Bork, 1984 ; Ebisch, 1984 ; Papert, 1979 ; Shavelson et al., 1984 ; Sheingold, Kane, & Endreweit, 1983 ; Weizenbaum, 1979). Two contrasting visions of the potential of computers in education are presented by Kohl (Ebisch, 1984) :

> Computers are special, they're not just an electronic version of the same old boring school tools. But they could be used to reinforce the worst practices of schools... The other possibility is that the computer becomes a tool to extend the capabilities of one's mind, a device for modelling possible worlds, for doing scientific simulations, for allowing kids at a

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very young age to begin to see that you can control variables and understand systems and do these intellectual things visually. (p. 38).

Kohl's more promising pedagogical vision of computer technology will not be achieved easily. Shavelson and Saloman (1985) suggest that: "The impact of the new technology on cognition is not guaranteed. Its impact depends largely on how students and teachers use the new technology" (p. 4). For Lepper (1985), the time for research is now: "Yet it seems critical to examine the larger issues, before this technology becomes such an integral part of our daily lives that it will be, as was the case with commercial television, too late to ask critical questions" (p. 16). Representative of much of the questioning in the area are those questions with a future orientation. By gaining a clearer vision of the future, asking critical questions, and establishing appropriate policies, we can make better use of this new technology.

Realizing the educational potential of computer technology largely depends on developing appropriate policies relevant to the technology. Dunn (1981, pp. 6—24) establishes that historically there has always been a need for information relevant to policy making. He also observes that the industrial revolution and more recently the advent of a "postindustrial society" have accelerated the need for information relevant to policy making.

A recognized means of generating information relevant to policy making are policy analysis studies. Quade (1975) describes policy analysis as: "any type of analysis that generates and presents information in such a way as to improve the basis for policy makers to exercise their judgement" (p. 4). A commonly used technique in policy analysis studies is forecasting. Dunn (1981) suggests that forecasting techniques are suited for problems related to uncertainty, especially those that are "mossy" or "ill structured" (p. 195). This article reports on a study which utilized a forecasting technique known as Policy Delphi.

The purpose of the study was to identify those changes in education, over the next five years, which were both probable and possible through the continued introduction of computers, as well as to identify potential patterns for arriving at a normative (desired) future. As previous studies (Barrington, 1981 : Sollinger, 1984) had reported problems related to the Delphi technique, an additional purpose of the study was to further refine the Delphi, particularly in the area of maintaining panelist support. The study clarified some of the immediate concerns related to computing in education as well as exposed future policy options and issues related to a continued introduction of the technology. In addition, it provided a framework for collecting information relevant to policy making.

Methodology

Yeakey (1983) characterized policy as "the culmination of action and inaction of the social system in response to demands made on it"

(p. 256). In their definition of policy analysis and policy studies Nagel and Neef (1980) emphasise the importance of the study of alternative policies: "Policy analysis or policy studies can be broadly defined as the study of the nature, causes, and effects of alternative public policies" (p. 15). Dror (1971) also recognizes the importance of studying alternative policies in a future context: "The establishment of explicit alternative future assumptions, to serve as contexts for concrete policymaking, is an important contribution to the improvement of policymaking" (p. 70). Stokey and Zeckhauser (1978, p. 22) represent the study of alternative policies as similar to an economic model wherein there is a possibiblity frontier and decision makers must decide among the alternatives available. On a basic level, they describe it as "fundamental choice model" that involves two primary elements:

1. Identifying the alternatives open to the decision maker; and
2. Determining his preferences among these alternatives.

The rationale for the study was derived from these and other aspects of the policy literature that relate to establishing policy alternatives. The study first identified alternative futures related to computer technology and education and then explored policy alternatives for achieving a desired future. Essentially, using definitions provided by Dunn (1981, p. 143), it identified those future that were plausible, potential, and normative, and then identified potential patterns for arriving at a normative future.

The Delphi

A Delphi is an iterative procedure which allows a group of individuals to collectively address complex problems. It is usually future oriented. An essential feature of a Policy Delphi, unlike the more common Conventional Delphi, is that it is designed to explore policy issues and does not strive for consensus. The study involved three distinct iterations or rounds. The first round identified those changes in education which were either probable or possible within the next five years as a result of the continued influence of computers. The second round involved a rating of the desirability and probability of those changes identified as either probable or possible. The third round explored potential patterns for achieving a normative future.

Critical to the success of Delphi studies is the Delphi panel. The Delphi panel was identified through a two-step selection procedure. In the first step, six prominent educators who represented different organizations were selected on the basis of their involvement with computers. After participating in the pilot study and the first round of the Delphi, these individuals were asked to nominate other participants on the basis of supplied criteria. An additional 12 participants were obtained for the study on the basis of nominations received from this nucleus. Hence participants in the study panel consisted of 18 individuals with a knowledge of computers and a background in education. Participation included representation from central office, government departments, industry, in-school personnel, and university. A 100% participation rate was maintained throughout the three rounds of the study. Cost constraints delimited the study to the province of Alberta. However, as at the time of the study Alberta was one of the leading provinces/states in terms of computer-related acquisition and activity (Petruk, 1985), the environment provided a very suitable setting in which to identify futures oriented policy issues and concerns.

Data Collection and Analysis

Data for the study were collected through a preliminary pilot study followed by a three-round Delphi. These data were collected from April 1984 to January 1985. The instrument used in each round of the study was developed on the basis of information collected in the previous phase.

The pilot study consisted of six interviews. These interviews were designed to explore concerns related to the impact of computers on education and help conceptualize the problem to be explored throughout the Delphi technique. Information obtained in the pilot study was used to develop the Round I instrument.

The purpose of Round I was to identify those developments within education which were either probable or for which there was potential as a result of the continued introduction of computers to education. Data collection in Round I was by way of interview. The interview guide was developed from information obtained in the pilot study as well as the literature. The 18 participants were asked to consider educational computing and then identify the major plausible and potential futures in the following distinct areas: acquisition and funding, courseware, curriculum, organization, and teacher training. In addition to the five areas identified, participants were asked to comment on any other areas they felt important to the study. Data obtained in the interviews were summarized, categorized, and synthesized in a series of nine steps. This process provided 100 statements about future developments in education as a result of the continued introduction of computers. These statements were used in the development of the Round II questionnaire.

The purpose of Round II was to rate the overall probability and desirability of statements identified in Round I. The questionnaire consisted of the 100 statements about the future which were grouped into the following eight categories: acquisition and funding, courseware/software, curriculum, teacher training, organizations, ethical concerns, equity, and other areas. Participants were asked to rate the probability and desirability of each of the statements. Each questionnaire item required two separate responses wherein the respondent had five choices for each response. The choices related to probability were: highly probable, probable, uncertain, improbable, and highly improbable. The choices related to desirability were: highly desirable, desirable, uncertain, undesirable, and highly undesirable. Analysis procedures related to Round II included reducing these five choices to three categories, a positive, uncertain, and negative. A frequency count was done for each of the items and the informtaion cross-tabulated. A 3x3 matrix was produced for each item on the basis of ratings of probability and desirability. Seven categories were created from the cross-tabulation on the basis of participant rating of probability and desirability. These categories were : (a) Agreement on probability/no agreement on desirability ; (b) Agreement on desirability/no agreement on probability ; (c) Agreement on probability/no agreement on desirability ; (d) Agreement on probability/low desirability ; (e) Agreement regarding low desirability/no agreement on probability ; (f) Agreement regarding low desirability/improbability ; (g) Scattered items. Four of these categories were later used in development of the Round III instrument.

The purpose of Round III was to identify potential patterns for achieving a normative future. A questionnaire was again used for this final round. It consisted of 24 statements which were selected from the original 100 statements used in Round II. These statements were selected from categories identified in Round II. Four categories were selected on the basis of containing information relevant to the purpose of Round III. Each of these four categories was represented in a separate section of the questionnaire. Section I included 16 statements which had been regarded as highly probable as well as highly undesirable. Participants were asked to recommend strategies for reducing the probability of these developments. Section II included four statements which had been regarded as highly desirable with little agreement regarding probability. Participants were asked to recommend strategies for increasing the probability of these developments. Section III included two statements which had been regarded as highly probable with little agreement regarding desirability while Section IV included two statements which had been regarded as highly undesirable with little agreement regarding probability. Participants were also asked to make specific comments regarding each of the statements in Sections III and IV. Data collected were analyzed through a seven-step procedure which included categorizing, summarizing, and frequency analysis. In addition, participants were asked to consider each of the 24 statements and specify the greatest levels of concern from each of the following : provincial, regional, system, school, and university. Frequency analysis was used to analyze this data.

An additional purpose of the study was a further refinement of the Delphi technique. Design features of the study attempted to address problems identified in earlier studies. Particular attention was devoted to addressing the problem of maintaining panelist support (Barrington, 1981, p. 265 ; Bright, 1978, p. 42 ; Sellinger, 1984, p. iv). A 100% participation rate was maintained throughout the study. Major design features of the study which may be attributed to achieving this unusually high participation rate include the following : conducting an interview-based preliminary pilot study, use of an expanding nucleus nomination procedure to select participants, establishing early personal contact with participants through the Round I interviews and maintaining the contact throughout the study, procuring panelist support at the commencement of the study, selective anonymity wherein participants knew the names of other panel members while individual responses remained anonymous, field testing instruments, limited use of the mail system, and minimal turn-around time.

Major Findings of the Study

The study identified a wide variety of developments which were regarded as both probable and desirable. These developments were described as being either a reaction to technological change or part of a continued technological experiment wherein much of the present computer-related activity could be justified on the basis of exploiting a future potential. Developments which were identified as probable and undesirable included: underutilization of equipment, problems related to the allocation of equipment, lack of appropriate courseware/software, piracy, confidentiality of files and information, equity, funding, resistance to change, software and hardware inertia restricting upward capability of hardware, migration of human resources, and increased and conflicting demands on educational organizations. Developments identified as desirable with little agreement regarding probability included: development of a local software industry tailored to provincial curriculum, a strong emphasis on computer-related in-service, an awareness of the social impact of computers, and increased parent involvement in school matters. Major potential patterns for achieving a normative future included: increased courseware/software development and evaluation, increased levels of funding, inservice, a recognition of the need for policies related to educational computing, curricular development, preservice, planning, security procedures, and communication among organizations and stakeholders.

Overall, the Delphi provided useful information for futures oriented planning and policy making. The findings tended to support the view that realizing the educational potential of computer technology will continue to require a great deal of continued activity related to policy making. This activity, while not necessarily uniform, needs to occur at a variety of making levels. The following conclusions and implications are presented as considerations for educational policy makers.

Conclusions and Implications

Nine major conclusions regarding developments in computer technology and education are presented below. As Rounds II and III of the study were used to refine information collected in the pilot study and Round I, the conclusions are based primarily on data collected in Rounds II and III. These conclusions begin with the general and move to the more specific. Following each conclusion is a brief discussion of implications. An attempt is also made to incorporate aspects of the literature in the discussion of implications.

1. Computer technology, like other technological developments, has potential to have positive, negative, or neutral effects on the educational enterprise. The nature of these effects will largely be determined by the actions of educational policy makers. Policy making relevant to computer technology would be vastly improved if we placed more emphasis on determining our educational preferences and priorities.

In addition to identifying benefits, the study identified a number of potential negative outcomes related to the impact of computer technology on education. This finding suggests that viewing computers as a panacea for all that ails education has the potential to do much harm. A critical role for policy makers is to ask questions related to the negative effects of computer technology. More importantly, meaningful computer-related changes must be founded on substantial values if they are to be of lasting worth to education. In this context, computers may be viewed primarily as a catalyst, and the major question is not what should we do with computers but rather: What should we be doing in education?

2. There will be a continued commitment to computer technology. This commitment will be reflected in a continuation of computer-related activities at all grade levels. Much of this activity will be justified on the basis of a general technological experiment. Policy makers will continue to assume that computers will improve educational practice. This improvement will be viewed as taking place within the existing educational structure.

A continued commitment to computer technology will consume a large amount of human and financial resources. Despite this commitment, the findings of this study and the literature (Bork, 1984, p. 242; Shavelson et al., 1984, p. 30; Sheingold, Kane, & Endreweit, 1983, p. 431) express a concern that computer technology is having a limited impact on the instructional process. Clearly, a major challenge lies in further exploiting the potential of computers in education. Exploiting this potential will involve further experimentation, but much of this experimentation will be of little worth unless there is a mechanism for identifying, communicating, and implementing those activities which are truly beneficial to education. Also, while experimentation is necessary, it is inevitable that attempts will be made to use computers for activities for which they are inappropriate. In the process of experimentation a critical question that educators must ask is one posed by Fullan (1982): "Can rejecting a proposed educational program be more progressive than accepting it?" (p. iv). Given the massive amount of resources devoted to computer technology, this question should also be asked on a broader, macro level. If future computers are truly capable of delivering what they promise in terms of ease of human interface, they will be, as Weizenbaum (Ebisch, 1984, p. 36) suggests, nearly transparent. If this is the case, and computers do indeed become so transparent that we need very little knowledge to actually use them, many of the resources presently being devoted to computer technology are not necessary. There is a possibility that many present-day computer-related activities might soon be described as paralleling the Sputnik phenomenon where there was a race to train individuals in areas for which society later had very little demand.

3. *Technological change is inevitable. A commitment to technology in education is a commitment to ongoing change. Change will occur as an ongoing continuous process. Rapid technological developments will further compound problems related to change in education. All educational organizations will experience changes precipitated by computer technology.*

While meaningful computer-related change is possible, realizing the potential of computers largely depends on developing appropriate strategies for dealing with change. "One-shot" acquisition of equipment or "one-shot" inservice will not suffice. The rapidly changing technology requires strategies that are ongoing, especially in areas related to acquisition, curriculum, and teacher training. In this regard Fullan's (1985, p. 392) notion that change is a process is reinforced by Uhlig (1983) in the area of technology: "Technological literacy, unlike some other kinds of literacies, is not an event; it is a continuous process" (p. 2). Key issues for policy makers to address in relation to the "race" with technology is whether we are playing "keep up", "catch up", or if we should even be in the "race". Developing strategies to deal with the rapid process of change presents a mammoth challenge. It is likely that the technological capability to produce new and innovative computer devices will continue to be far ahead of our ability to use them in education. Somewhat illustrative of this problem are the many conferences related to computers in education which often more closely resemble an industry "show and tell" more so than they represent any meaningful dialogue related to pedagogy. Mumford and Sackman (1975) suggest: "Society should deliberately lead and direct the application of computers in the image of its most cherished values and ideals rather than be the unwitting victims of the vagaries of technology and the fluctuations of the market-place" (p. v). What is required from policy makers is a focus upon developing a clearer philosophy of technology.

Resistance to change is often cited as a major problem facing the implementation of computer technology. Ironically, the technology itself will foster its own resistance to change as it creates problems related to the "saber-tooth" curriculum (Peddiwell, 1939). For example, sunk costs in software, hardware, or training may mean that educational organizations as well as individuals have a vested interest in maintaining certain learning environments. Given that much of the recently acquired equipment is of an older generation, policy makers should address the following questions: Has much of the recent activity, aimed primarily at acquiring large numbers of computers, been inappropriate? Have we already installed a base which will be resistant to further technological change? Has there been an error in identifying the problem related to computers in education as being primarily one of acquisition?

4. *Computer technology will provide the impetus to ask basic pedagogical questions related to curriculum and teacher training. There will be continued experimentation related to the organization and dissemination of knowledge.*

This conclusion suggests that computer technology will provide a powerful impetus to ask questions fundamental to curriculum, including a reconceptualization of both knowledge and the delivery of instruction. Such a reconceptualization will also involve a change in the role of the teacher and will be reflected in teacher training programs. These developments have the potential to profoundly affect education in the long term.

5. *Most changes related to computer technology will be external to the learning process. While there will widesprend experimentation, basic curriculum content will remain unchanged. Areas such as business education and computing science will continue to assimilate the technology.*

There are two major implications, representing opposite scenarios, related to this conclusion. The first is that meaningful change takes place over time and the next five years will continue to be an assimilation period whereby technology follows the path of least resistance while at the same time improving existing technologies and practices. These activities will continue to be viewed as providing a foundation for realizing a much greater potential some time in the distant future. Such an interpretation justifies much of the current computer — related activity on the basis of a general technological experiment. The second implication of this conclusion is that organizations may be avoiding meaningful changes through the assimilation of technology (Sheingold, Kane, & Endreweit, 1983, p. 431). If the technology is being assimilated and little meaningful change is actually occurring, a tremendous amount of ressources are currently being wasted.

Somewhat related to this conclusion is the ongoing implication of attempting to cope with the myth and the reality of computer technology. First, expectations often far exceed the reality of what the technology can deliver. Second, without adequate consideration for the realities of the change process, there is no guarantee that the pedagogical applications, which are possible in theory, will automatically find their way to educational practice. Decisions that continue to be based on the myth will inevitably lead to disillusionment.

6. *Developments related to computer technology will place increased demands on teachers. These demands will be reflected in increased preservice and inservice activity. The tacher's role will gradually begin to change from a disseminator of knowledge to a facilitator of learning.*

Charters and Pellegrin (1972) cite as one of the major problems related to educational change: "The failure to recognize the severity of role overload among members of the instructional staff when innovation is attempted" (p. 12). The findings of the study identified computer technology as contributing to role overload among teachers. Policy makers need first to recognize that this overload exist and then incorporate strategies to deal with it when developing policies related to computer technology and education.

7. *All educational organizations will be required to make decisions and establish policies related to computer technology. Many of these*

decisions will be made at the school, system, and provincial levels. While there is a need for policy at all levels, decisions made at the school level will have the most significant impact regarding the effective utilization of computer technology. Policies will be established both through action and inaction inasmuch as organizations that do not respond to the changing technological environment will be establishing policies through their omission.

It is of critical importance that policy makers recognize the importance of the institutional setting of the school with regard to the use of computers. The findings of the study and the literature or change suggest that successful adaptation of an innovation largely depends on activities at the school level. Berman (1980) provides additional insight related to the implications of this conclusion for policy development: "once policy makers dispense with the image that implementation must be uniform for all policy situations, invariable over time, and homogeneous across organizational levels, thay can search for matching, mixing, and switching strategies to improve policy performance". (p. 222).

8. *Continued efforts at realizing the potential of computers will create a number of issues and problems for policy makers. The study identified the following major problems as requiring consideration: (a) underutilization of equipment, (b) allocation of equipment, (c) lack of appropriate courseware/software, (d) piracy, (e) confidentiality of files and information, (f) equity, (g) funding, (h) resistance to change, (i) software and hardware inertia restricting upwards capability of hardware, (j) migration of human resources, (k) increased and conflicting demands on educational organizations.*

Each of the problems is discussed separately below.

Underutilization of Equipment

A general public support for computers, compounded with generous funding allocations, has resulted in the recent acquisition of a great deal of computing equipment. Much of this newly acquired equipment will be underutilized. This underutilization may occur at two levels. First, machines that have been acquired to take advantage of existing grants may see limited physical use. Second, because machines see maximum physical use does not mean that they are being properly utilized. For example, there has been concern over the misuse of games and drills and practice activities (Shavelson et al., 1984, p. 31; Sheingold, Kane, & Endreweit, 1983, p. 427). Given the large amount of resources being devoted to computers in education there may occur a negative backlash of support for computers should the perception increase that computers are not being properly utilized and that some of the resources could be better devoted to other activities. Large-scale acquisition and widespread physical use of the machines does not guarantee that the potential of computers in education will be reaolized.

Allocation of Equipment

Computers are being acquired at a rapid rate. They are presently housed in a variety of configurations and used at all grade levels. A major issue is how to allocate equipment in order to maximize benefits from its use. As Peterson (1984) observes, equal distribution is fair and simple; however it often does not provide the critical mass necessary for "ideas and creativity to take off" (pp. 11—12). Configurations such as labs may provide a sense of fairness as well as the necessary critical mass; however, they have the disadvantage of portraying computers as something separate and apart from the curriculum. While increased acquisition will undoubtedly alleviate some of the problems related to access it will also create new ones. For example, as newer generation equipment is acquired who will get access to it? Administrators? Innovative teachers? Designated grade levels or subject levels? Will older generation or underutilized equipment be passed on to less than enthusiastic recipients or merely placed in storerooms? Policies regarding equipment allocation as well as migration will have to be established.

Lack of Appropriate Courseware/Software

Both the findings of this study and much of the literature (Alberta Education, 1983, pp. 57—58; Bork, 1984, p. 240; Komoski, 1984, p. 247; Rockman, White, & Rampey, 1983, p. 42; Sheingold, Kane, & Endreweit, 1983, p. 429) strongly suggest that lack of appropriate courseware/software is a major area of concern. This problem has been magnified by policies allowing the large-scale acquisition of computers. Large-scale acquisition, without adequate consideration for applications, often results in the use of inappropriate software programs simply because they are readily available. The problem of selecting appropriate courseware/software is further compounded by the extremely high ratio of poor quality programs being marketed for use in education.

Piracy

Lack of appropriate courseware/software, high costs, inadequate funding, the need for multiple copies of a program, and inadequate copyright laws will all contribute to problems related to piracy. This problem will further reduce the development of quality courseware/software when developers do not receive fair compensation for their efforts. A further problem, in major conflict with a fundamental goal of the educational enterprise, is that students who witness acts of piracy are being encouraged, through example, to participate in activites that are dishonest and illegal.

Confidentiality of Files and Information

The increased reliance on computers, especially in tasks related to administration, will create problems related to confidentiality of information. These problems will be further compounded by the increased use of computing networks. Two major areas that will have to be dealt with are those related to unauthorized access and the establishment of policies related to access.

Equity

Computer technology has the potential to remove some of the problems related to equity. For example, improvements in networking and storage capabilities will allow smaller schools to increase their level of service. However, there are also problems associated with the equity issue. Two major dimensions of the issue are actual physical access to computers, and applications to which students are exposed. Not all school districts are adopting computers at a similar rate; consequently, this will lead to problems for students who do not have a background in computing, particularly those who enter postsecondary institutions. Should problems related to equality of access be overcome, it will not necessarily lead to equality of opportunity. Decisions related to the allocation and configuration of equipment, as well as how computers are used for instruction, will vary within districts, schools, and classrooms. There is also concern that individuals from higher social class and boys are receiving the most benefit from computer instruction. If computers really do make a difference in education, then policies that further address the problem of equity are required.

Funding

A substantial amount of funds have already been allocated to educational computing, a large portion of which has been designated for the acquisition of equipment. A commitment to technology requires a further significant ongoing commitment of funds in areas such as the acquisition of new equipment, courseware/software development and acquisition, curriculum, and teacher training. Related to this issue is the problem of obtaining significant levels of funding accompanied with questions related to whether it is worth allocating funds for computing that might be better directed to other areas. Theoretical speculation about the pedagogical promise of this technology is widespread. However there is comparatively little literature which addresses the financial cost of realizing this promise.

Resistance to Change

Computer technology, like other innovations, will meet resistance to change. Fullan (1985) describes attempts at initiating change as "a complex dilemma-ridden, technical, sociopolitical process" (p. 391). There is the constant problem of technology having limited impact on schools, or as Sheingold, Kane, and Endreweit (1983) concluded in their study, "The study more strikingly illustrates the assimilation of technology by school systems than the impact of technology on them" (p. 431). Policymakers must be prepared to deal with the complexities of initiating change. Fundamental to the development of policy (Berman & McLaughlin, 1976) is that it be "concerned with more than the mere adoption of change agent projects", and take into account "the critical significance of the institutional setting" (p. 347).

Software and Hardware Inertia Restricting Upward Capability of Hardware

Continued new developments in technology will make further change inevitable. Sunk costs in areas such as hardware, courseware/software, and training may act to reduce an organization's capacity to further adapt to change. For example, an organization with a large investment in existing hardware and software may resist opportunities to adapt to new generation equipment which requires a significant departure from what already exists. Papert (1979) describes an additional dimension of this problem when he portrays existing computer-related practices as sharing "a model of education which leads them to reinforce traditional educational structures and thus play a reactionary role, opposing the emergence of radically new forms of education" (p. 74). Policies are required which reflect the long term nature of computer-related change.

Migration of Human Resources

Many talented, knowledgeable people in the area of computing will leave education. Some of these individuals will pursue careers in business and industry while others will simply burn out. Many other successful computing teachers will also migrate to administrative positions. Policies are required that address the problem of retaining those individuals who can make a positive contribution to education. These policies would also address the problem of role overload and burn out.

Increased and Conflicting Demands on Educational Organizations

Computers have simultaneously been presented as a panacea for all that ails education and as having limited significant impact. Kohl (Ebisch, 1984) describes them as having the potential to reinforce the "worst practices of schools" or become a "tool to extend the capacities of one's mind" (p. 38). They have also been presented as having little impact on the instructional process (Bork, 1984, p. 242 ; Shavelson et al., 1984, p. 30 ; Sheingold, Kane & Endreweit, 1983, p. 431) yet potentially fostering revolutionary changes in curriculum (Henchey, 1982, p. 13 ; Papert, 1980, p. 140) and teacher training (Alberta Education, 1983, p. 36 ;

Friedman, 1983, p. 16). Weizenbaum (Ebisch, 1984) presents computers as "a powerful distraction that will leave the original problems—money, teachers, time, and energy—untouched" (p. 36). Conflicting viewpoints such as these will increasingly be reflected through demands placed on educational organizations. This problem will be compounded by rapid changes in the actual technology. Policy makers will have to continue to address the role of computers in education.

9. Major potential patterns or strategies for policy makers to consider when dealing with the impact of computer technology include the following: increased software/courseware development and evaluation, increased levels of funding, inservice, a recognition of the need for policies related to educational computing, curricular development, preservice, planning, security procedures, and communication among organizations and stakeholders.

Much of the recent activity related to educational computing has been directed at acquisition. However, as this technology continues to place increased and conflicting demands on educational organizations, policy makers must recognize the need for further policy development. Enhanced communication and dialogue for the purpose of establishing policies relevant to technology, will become increasingly necessary. Rapid change, precipitated largely by technology, makes the development of ongoing strategies an essential activity of educational organization. Realizing the educational potential of computers, in addition to requiring strategies that address technical issues, requires strategies that address people-oriented issues. Developing these strategies will require a huge amount of resources.

Contribution to the Study

Decision makers have always required information relevant to policy making. An important aspect of policy making is the establishment of alternative futures to serve as contexts for policy making. The rapidly changing technological environment, precipitated largely by the advent of the computer, has accelerated the need for information relevant to policy making. The study provided information relevant to educational policy making by clarifying some of the immediate concerns related to computer in education as well as exposing future policy questions and issues related to a continued introduction of the technology. It also illustrated that computer technology is not a panacea for all that ails education and is more appropriately viewed as a catalyst for basic philosophical questions related to the general role of technogoly, change, curriculum, and teacher training. Finally, it emphasized that we have to have a clear vision of our educational priorities before we can begin to seriously address questions related to what to do with computer technology.

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NEW INFORMATION TECHNOLOGIES ; THE ROLE OF ARTIFICIAL INTELLIGENCE *

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Until very recently, research in the field of artificial intelligence (AI) was considered a purely theoretical undertaking. Nowadays the results of this research are applied on a large scale in the most practical aspects of computer science. Academician G. S. Pospelov, President of the National Council for Artificial Intelligence of the USSR, claims that scientific research institutes need no longer concern themselves with the design and the elaboration of various products. Their task now is to enrich existing knowledge bases with new elements: theories, methods of computing, etc., by means of powerful computers linked to networks. Data base management systems (DBMS) are able to administrate all the data obtained not only from related fields, but also from very diverse domains of science and technology, providing all the necessary information to the workers in the technical offices, thus enabling them to create a really new and modern establishment, making use of the entire economic-technical potential. In other words, we are confronted with a real revolution in this boundless field, namely one of the design of new technologies.

Question: During the last few years, *Znanie-sila* magazine has published several articles on computers of the so called "second literacy" era. These articles have dealt mostly with personal computers, programming, the computer assisted solution of various scientific and technical problems, etc. At the same time, the magazine has always focused its attention on research in artificial intelligence because this field can be expected to provide solutions to the many problems with which computer science is confronted. Do you share this opinion ?

Answer : Unconditionally and entirely. Only limited and badly-informed people regard research in artificial intelligence as the "Cinderella" of cybernetics. At present, even the fiercest enemies of our would-be "purely theoretical" studies have begun to understand that research in artificial intelligence represents a practical and extremely useful direction in our science. Its task is to find a way of making computer science less complicated.

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* Source : *Znanie-sila* (Knowledge is Power), February, 1986.

Today the computer can contribute to any activity. It can be put into contact with the average man having a basic notion of computer science, even if he is an amateur in computer technology. In other words, in spite of their compactness, the new machines must necessarily have an increased storage capacity and other technical improvements, in addition to great work speed. They must also be endowed with a certain amount of intelligence, which means in this particular case, that they have the capacity of understanding and of being understood. It is this capacity which makes the 5th generation computers superior to present-day computers, not any other technological improvement. The inspiration of the 5th generation computers first sprung up in Japan and then spread throughout the world, including the USSR.

Yet, it would be a great mistake to consider the "computer revolution" an unexpected and momentary event. Important and radical changes in the fields of science and technology have accumulated gradually, sometimes imperceptively and unnoticed by society. A negative aspect of these changes has been the existence of intermediaries between the computers and the specialists — tasks which are taken over by programmers. The main occupation has been the translation of initial information, formulated in the specialized language used by the client (usually known as the final user) first into a mathematical language and then into a language understood by the computer. As a rule, a programmer and two or three specialists (with full-time work-quotas) stands between the final user and the computer. One of the specialists, usually the one known as an analyst, formalizes the problem given by the final user and provides a rough description of its program leading to its solution in the form of a "scheme-block". The second specialist, the application programmer, transfers this "scheme-block" into a program written in one of the languages (codes) of the respective computer. He next revises the program, correcting the errors. In some large computing centres, the application programmer does not use the computer, but transmits the program to the operator, who is the only one who works with the computer.

Along with increases in the number of computers and of specialists that operate them, the number of programmers has also grown rapidly (at present there are over a million people throughout the world who are operating the "insatiable" computers). If the present technology of problem solving on computers continues, the entire adult population of the developed countries, in the very near future, will be drawn into programming activities. In other words, the development of automatic methods of information processing has reached a deadlock.

Question : Is this situation the same as that of the "young ladies of the telephone exchange", one well known to other fields of technology ? It was once believed that, because of increases in the number of telephone users, all the girls in the world would have to sit and operate switches. And yet that particular problem was solved by the invention of the automatic telephone exchange. The logic of scientific development shows us that something similar is bound to happen in our relationship with the world of computers.

Answer: Both "yes" and "no", even though the answer is more likely to be "yes". Let me explain. The causes of the present crisis in the domain of information processing are much more deeply rooted than those which had such a strong impact on people's minds when the telephone exchanges were set up at the beginning of our century. It is not only a matter of an old-fashioned way of preparing problems to be solved by the computer. There is indeed some hope, in this field, of creating equipment analogous to the automatic telephone exchange, albeit much more complex. The essence of the present situation in all the developed countries is the fact that a perceptible lack of balance has appeared between the automation of production and the automation of the manageme.t of this very production. Consequently, for the last century the share of the manpower involved in the informational field — science, education, management, and planning — has been constantly increasing, while its share in production has accordingly decreased. In the U.S.A., almost half of the total number of employees are linked to the information field. A hundred years ago, this proportion was only 5 per cent. A similar situation can be observed in Finland, a country very different from the U.S.A., in which in the last thirty years the share of the workers has remained practically unchanged, while the proportion of office workers has increased more than two-and-a-half times. The cause is the same everywhere : the automation of production takes place in a most systematic way, while its management does not. Also in the U.S.A., investments for the equipment used by workers exceed by 10 times the investments made for the equipment of office workers. The result has been that at a time when the productivity of workers in the highly automated fields grew by 83 per cent, the productivity of office workers grew by only four per cent. This tendency which is manifesting itself more and more is the reason why the problem of the information fields is becoming more and more acute. Achievements in robotics and in microelectronics (the LSI and the VLSI microprocessors) have paved the way for highly automatic and flexible production. Given these circumstances, the speed of processed materials should increase, and so should the main indicator of technical and scientific development, the rhythms of the renewal and the enrichment of the lists of goods and services offered. And yet the future possibilities of robot-planned production are limited by the information field itself. Two delay-causing factors are manifest : the methods of projection and elaboration of the new technologies and of the complex technical systems (with their large numbers of outlines) and the unsolved problems of planning and management of the increasingly accelerated production processes, at a time when the relationships among the various branches are considerably interlinked.

Some time ago, academician V. M. Gluskov wrote that in the history of the development of the management of the economy, mankind was confronted with two informational barriers. The first appeared in the period of transition from separate trades to vast industrial production and was done away with by the division of management and planning among a large number of persons. The second barrier came after the technical-scientific revolution, when the number of new and very new materials, goods, services, and technological processes increased tremendously. The one way to remove this barrier or, as it is also called — the informational crisis — is to use computer technology on a large scale in planning and management, in research, and in other activities, in other words, to equip all final users with computers of various types, connected to appropriate networks. But in order to achieve this goal, the entire problem of communication by means of computers — that is, all the people who are not trained as programmers — should be solved. In so doing, we cannot be satisfied with even the most ingenious research; a new informational technology is needed. Its advent is like a historical law.

Question : In one of your lectures, you argued that the new information technologies save paper. But of course, the importance of these technologies does not limit itself to economies in the consumption of paper. Could you tell us what the essence of this problem really is?

Answer : Let me begin by talking about paper, which among other things, is needed by scientists because they too, write books, monographs, and articles. According to current conceptions, the information field is expected, in principle, to work without paper. All the information is to be kept in the electronic memories of computers and transmitted through cables or via radio and bt edited on display screens. Only in certain special situations will the required information be printed by special terminal computer equipment in the required number of copies. Thus a huge quantity of paper will be saved. At present, we are using paper with very low efficiency in really tremendous quantities; for example, in the American business field almost 100 billion dollars are spent for paper every year.

However, the replacement of paper for the recording of information is not so simple. One of the paradoxes of the unsystematic use of computer technology is a very great consumption of extra paper, much of it of particularly high quality.

Data bases provided with systems of knowledge representation, aided by user-friendly computers connected to a local network already permit a great reduction in the volume of paper required for the representation and the transmission of information, particularly in the correspondence and documentation done at one's work place. For this reason, incidentally, the appearance of knowledge bases is considered to be even more valuable for mankind than the printing of books. Information stored in these knowledge bases not only represents concrete facts, formulae, theorems, etc., as was the case with the first data bases, but information which is interpreted and internally connected, and structured, in short, knowledge in the true sense of the word. Of course, the creation of such knowledge bases is not easy — one has to know how to complete and synthesize information taking care lest it be incomplete, eliminate redundancy and find solutions to a great range of other problems, that can only be solved by collective, interdisciplinary research in which psychologists participate alongside specialists in intelligent systems. The psychologists study the cognitive structures of man's memory, that is, his special means of memorizing, extracting from memory, and of grouping various elements of information, etc.

Evidently we have now reached the point at which we should answer the latter part of the question : what are the potential characteristics of the new information technologies ?

Certainly, they should have such properties that anyone who needs to solve problems with the help of a computer should be able to interact with it directly. The solution to the problem will be found through the automation of the entire process, from the expression of the problem by the final user as a formula, to the programming of the computer. Thus, the intellectual possibilities of the computer should grow rapidly. At this point in our discussion, we should mention that such specialists in the field of artificial intelligence are required, who include in their spheres of interest the methods which enable the simulation, with the aid of technical systems of certain fragments of man's creative activities. For this reason, indeed, the problem of creating new information processing technologies for computers is one of the fundamental problems in the field of artificial intelligence.

The automation of the programmer's activity requires the addition of new components to its traditional structure. To the "traditional" computer, three more blocks must be added : "the communication processor", "the knowledge base", and he "planner". These blocks will synthesize the program for the traditional computer, a task which was formerly done by the programmer and by the help of which the traditional computer solved the user's problems. These three blocks are sometimes merged under the heading of "intellectual interface". The communication process has the task of translating the primary text of the problem into the internal language of the system. This block then transfers the result obtained by the computer into the language understood by the user. The planner builds up the working program using the description of the conditions of the problem received from the communication processor. For this purpose, it uses a model existent in the field of the problem, stored in its knowledge base. This model describes all the necessary knowledge, with respect to the solving methods in the field of the respective problem. This model also stores standard programs with the help of which standard problems are solved. Out of these, as if out of bricks, the planner solves the problem of particular concern to him.

Intelligent interfaces need to be created in such a way, that the computer may be used by practically anybody. Contact with this interface should be no more complicated than communication with a washing machine having several programs. The creation of computers with such interfaces provide the solution to the information crisis. Such computers indeed may appear in less than ten years, for separate elements of intelligent interfaces already exist. So far, only a first type of plan deviser ; one not too powerful has been built. Communication systems that permit dialogue in a natural language limited to one's professional circle have also appeared. The first knowledge bases, although not exhaustive, are already in use.

But one should not conclude that we should do nothing during the next decade. The possibility of a complete change in the way of working with the computer has already been outlined. Those elements of the new technology which draw on the achievements of artificial intelligence can aready be conceived without waiting for increases in the numbers of intelligent computers.

Question : Research in artificial intelligence goes beyond strictly academic concerns. The time when this very notion was treated erroneously and anthropomorphically is long past. The progress made with regard to the methods used in the field of artificial intelligence is already very evident in the market place.

What is put into this product to give it such a high price on the market ? What do the over eighty companies in the West, the production of which is entirely geared to the domain of artificial intelligence, as well as the nearly 250 companies producing such products to a greater or lesser extent, turn out ? What are the fields in this domain in which research is undertaken throughout the world and in our country ?

Answer : To put the answer to you in a nutshell, we consider that a new style of work is being created for computer specialists.

Three types of new systems are penetrating more and more into our lives : intelligence systems for retrieving information, expert systems, and logical computing systems.

The intelligent systems for the retrieval of information are the successors of the so-called "ordinary" systems of information retrieval. The intelligent systems however, are different from the latter, not only because of the much increased quantities of information which they can permanently store and renew, but also because of their ability to formulate adequate solutions to the problems formulated by the user, even when the respective requirements are not direct ones with respect to the system involved. In other words, these systems are even "intelligent" enough to understand what the person, who did not know how to formulate a clear question, really meant. In order to create such intelligent systems, it is necessary to devise a special logic of the question-answer type and methods for the classification and the structuring of information. Presently we are trying to develop such logical systems.

The most wide spread new-type systems are the expert systems. Their task is one of accumulating the experience of specialists working in such fields as medicine, biology, history, etc. In other words, a concrete expert system oriented towards a certain domain of problems (for example, an expert system for the diagnosis of acute hepatic insufficiency) is an automatic adviser for the specialist. From the psychological point of view, expert systems have a qualitatively new and very important property : with the aid of special systems, they are able to provide explanations. A task of the system is to enumerate those explanations upon which the given recommendation is founded. It is evident that such a system increases the specialist's confidence in his "electronic consultant".

Finally, logical computing systems can undertake a multitude of procedures which are used in projection, planning and as common diagram systems. For instance, the GRANIT and DISFORP systems are used in solving problems of national economy planning, and the MAVP system, in the automation of projection.

Question: In our discussion, you have pointed out that the modern methods used in the projection and the elaboration of the new technology represent an obstacle for technical-scientific progress. Can we conclude that research in artificial intelligence permits the broadening of this "narrow area"?

Answer: It is both possible and necessary to do so. I would like to present, in a more detailed manner the systems included in the last group which I mentioned — these systems performing logical computations — as they are required for performing a major part of the problems under discussion. The ways in which computers are currently being used for research in the domain of the new technologies require a series of intermediaries between computer and final user. I mentioned this fact above; it is worth mentioning again, for it is only rational to examine the way in which the "final user — the analyst — the application programmer" interact in this specific case. Drawing on his knowledge of and experience in the domain engineering, the final user devises a prospective project for a future technical system. He establishes the totality of its components and the possible ways of connecting them to the system. Using his knowledge of applied mathematics and studying the given domain with the help of the computer, the analyst translates the problems which are to be solved into a mathematical language, an activity which is nothing more than the reformulation of the system description from its given level of study into its description at the mathematical level. Upon receiving the results from the mathematician, the programmer making use of his special knowledge, and grasping the essence of the mathematical models and problems, reformulates the problem from its mathematical level to that of a workable program. This program is then reintroduced into the computer, the shift from the high level language into the code of the machine being undertaken automatically. Of the three transfers, this one is the only one which is automatic. Thus the preparation of computing variants is excessively slow.

If we refer to the whole problem of the elaboration of new technologies we cannot fail to be aware of the excessively slow reaction time between our projection system and human intervention. Some delay is inevitable, for in any research some corrections are always needed. Thus the final goal of the creation of the new information technologies is the automation of the shift from the object level to the mathematical level and from the latter to that of the program.

The devising of such a technology of projection was carried out in several stages that were marked by huge qualitative leaps and by the gradual elimination of the intermediaries existing between the computer and the final user. The first qualitative leap of this kind was the birth of knowledge bases along with their management system (DBMS). These new circumstances accelerated the revision of programs by a factor of a hundred. This process is the most tiring because, when the program is conceived, errors are inevitable, due to man's lack of attention, and they slow down the preparation of computing variants and their comparison — the main stage of designing. But now the programmer has the possibility of setting up a library of revised programs or of parts of the latter — program modules — so as to make working programs of them.

Technical systems computations consisting of a series of components take place in the following manner. According to the general requirements of the system, the various components are calculated on the computer and then correlated. With the help of scheme-like modules, the particularities of the system as a whole are determined. If the particularities prove to be unsatisfactory for whatever reason, the components are again calculated and the correlation system is repeated until a positive result is obtained.

Although this procedure reduces the time required to complete a given job, it is still very long because the connections of the components among themselves are still not automated. The question evidently becomes one of whether or not it is necessary to include all computation programs in one system in which all processes are automated according to a common information base — the general data base. Statement of this question brings us close to the next qualitative leap which consists in the correlation of applied programs to a system leading to the advent of PPA. There are two types of PPA's : one type oriented towards methods of solution and one towards one domain or another. The stocks belonging to the second type — those oriented to the solution of problems — are often used in design systems and are known as automatic design systems. In the USSR, design systems for chemical plants, airplanes etc., have already been created. They react rapidly to human intervention thus permitting the examination of a large volume of variants over a short period of time.

Finally, the third qualitative leap in the automation of projection consists in doing away, in most cases with the programmer and the problems connected with him. Here we can notice two complementary directions that evolve simultaneously. The first consists in the fact that the language used for communication is increasingly simplified and formalized, thus coming closer to the language of the computer. The final goal is to devise simple means of communication which can be easily learnt even by non-professional programmers. The second direction is a process opposed to the first : the language of the computer is approaching that of humans. This is the fundamental solution to the problem of communication, the direction followed, for instance, by the Japanese when they devised the 5th generation computers. The means of communication derived from the second direction are most aptly referred to as "intelligent", for they are made up of the soft-hard elements of artificial intelligence, that is of those programs that are stored in the knowledge bases of the computers and of the related equipment (for instance, the I/O of information, which, with the help of some computer annexes, "speak" and "listen"), which are created in our labs. Thus, the world of the computer merges with the world of the final user, and we pass on to a new information technology.

Question : Therefore I am not wrong when I assert that the methods used by artificial intelligence permit a completely new organization of the activities of the technological engineering and the scientific research institutes, the tasks of which are to devise and to execute experimental models of new, and improved technologies ?

Answer : Indeed you are not wrong. Research in the fields of intelligent systems, of information retrieval, of logical computation systems, and of expert systems have reached such a degree of development that it is high time for a radical change in the traditional organization of scientific research and prospective design. Many research institutes, for instance, no longer need to participate along with technology offices in the conception of concrete applied systems. Their main role is to carry out research, the results of which should increase the knowledge base of the new types of systems which we have mentioned earlier. With the help of these systems, builders and projectors will be able to calculate and to project everything they need. Thus, a permanent division of labour will take place in the fields of machine and material building, and conditions will be provided for their further specialization.

However, we are also witnessing the beginning of a new stage. The advent of intelligent computers and, particularly, of computer networks help to advance the solution of another extremely important problem. The specialists who make up the teams assigned to solve certain problems by means of a joint effort always have different opinions and different levels of responsibility. Along with the creation of computers comes the solution to a number of social-psychological problems. The notion of the isolated executor has given way to a notion, not too aptly labelled, of "divided artificial intelligence". Within such a type of organization, specialists at their respective work stations can operate over the entire information field stored in the memory of the computer, agreeing on their actions by means of the computer. In addition to one computer, a whole computer network, distributed geographically, can be used. In fact, although it may not concern the users, they will actually come into contact with a sort of mythic computer, known as a "virtual" computer, which correlates their efforts in the solution of the general problem. In such a network, knowledge and responsibility may be distributed among several subsystems connected both vertically and horizontally.

The development of research in the omain of artificial intelligence has led to the development of means permitting a transition to new ways of solving problems with the help of computing technique. In the next five years, transfer to a technology by means of which the final user will work directly with the computer, without addressing himself to a programmer, will occur everywhere. At the present moment, one can implement elements of the new information technologies in many important situations, even on computers that are not equipped with an intelligent interface. Thus the efficiency of even the computers of today can be enhanced.

In a not too distant future, the progress being made by specialists in artificial intelligence will make it possible for certain computers and methods to be used efficiently to identify and to classify situations so as to diagnose and to devise solutions for those domains that have been formalized to a reduced extent which represent the largest part of are linked together in a strong relationship. None of these domains to be intensified and to give rise to even more fundamental solutions.

Artificial intelligence theory, computing technique, and robotics are linked together in a strong relationship. No one of these domains can evolve successfully without taking into account the interests and objectives of the others ; hence, the merging of purely scientific, purely technical, and applied research. The result is that the activity of artificial intelligence becomes a true technical-scientific problem, the solution of which is vital for serving progress in the development of the material resources of human society.

THE CHALLENGES OF COGNITIVE SCIENCE AND INFORMATION TECHNOLOGY TO HUMAN RIGHTS AND VALUES IN UNIVERSITY LIFE *

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In an age of rapid microelectronic technological development, the university community has to face many challenges. In my report I want to focus on some of these challenges, namely the diffusion of cognitive sciences and technology and the development of electronic communication

I shall analyse this diffusion and development from a particular point of view: the possible threats to commonly recognised human values and human rights. This does not mean that I deny the great improvement they have brought to professional and academic knowledge and competence. The fact is that legislators cannot keep up with such rapid diffusion and development, and promulgate positive laws that safeguard the rights of individuals and groups and give common, agreed-upon norms and decision criteria and procedures for choices involving shared human values. But the university is the very place where new perspectives and new approaches may be conceived and tried out in many fields of research, and where human rights and values are often involved. Consequently the university community itself has to be concerned about such problems and to find ways of solving them from an ethical point of view.

1. Cognitive Sciences and Technology

1.1. Cognitive sciences study human cognition, that is, mental processes and representations from different perspectives. Among them, today, the most influential are: cognitive psychology, which studies the architecture of the mind; artificial intelligence, which tries to make machines do things which require intelligence when carried out by humans; linguistics, which explores computational models of the understanding and production of language; neurology, which looks at the interface between brain and cognition, as in vision; philosophy, which reflects on the foundations of cognitive sciences. All this can be said

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to be the new mind science and a good part of it could be called the science of the artificial. A common feature of these new fields of study is an analytical, explicit, unambiguous and non-metaphorical description and performance of intelligent processes. Thus the modeling process involved is a formal one, and implies a certain amount of reductionism of problems and situations.

1.2. One field of application of cognitive sciences is cognitive technology which deals with artificial cognition. The most common and widespread result is the cognitive computer: an implementation of information technology from the point of view of the cognitive processes that are simulated or aided by the computer. Society and human culture are more affected in general by cognitive technology than by cognitive sciences. The university community is deeply involved in and affected by both cognitive sciences and cognitive technology. The values and attitudes of individuals and groups, and entire value systems, that pervade the culture of society in general and of the academic community in particular, seem to be strongly influenced: just as attention given to the decay of the natural environment has had a great impact in past decades and new stress has been given to some fundamental human rights and values (the right to breathe unpolluted air, the right to live on unpolluted ground, the value of experiencing nature in its most exciting aspects, etc.), in the same way we must today pay closer attention to the transformation induced by the cognitive technological environment.

1.3. Cognitive sciences and technology have a strong impact on the teaching and research activities and the management of a university. Traditional disciplines such as mathematics, engineering, medicine, biology and physics undergo a deep change in their internal structure and methodology; new disciplines and professional specialisations (such as computer science, cognitive science, and research using new technologies) come to the fore. The moral behaviour of researchers and professionals is greatly challenged; in fact many of them, through the technological environment, manipulate human beings directly or indirectly. To make this point clear let me turn to the issue raised by expert systems.

1.4. A collection of artificial intelligence techniques that enables computers to assist people in analysing problems and making decisions is known as a knowledge-based expert system. Expert systems have been proved effective not only in university research laboratories, but also in commercial applications, like assisting managers with complex planning and scheduling tasks, diagnosing disease, locating mineral deposits, configuring complex computer hardware, placing financial assets in the market, etc. Expert systems change the way people operate by altering the way they think about problem-solving. This new technology makes it possible to develop quick, pragmatic answers for a wide range of problems that currently defy effective solutions.

Expert systems have been defined as intelligent computer programs that use knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution. The knowledge consists of facts and heuristics. Facts are information widely shared, publicly available, and generally agreed upon by experts in a field. Heuristics are mostly private, little-discussed rules of good judgement that characterise expert-level decision-making in the field. Generally speaking facts and information are condensed and represented in and by concepts, principles and theories. To build the knowledge basis of an expert system we must identify and represent in a formal way the specific knowledge and competence that an expert used in solving a set of related problems: facts, rules-of-thumb, inference strategy, etc. For a program to perform in the way that a human expert commonly does, it must react to specific answers, ask question, explain its reasoning, justify its conclusions, and use a language that the user can easily understand. Because of the formal representation process needed to develop such programs, expert systems lack common sense, cannot reason by analogy, and their performance deteriorates rapidly when problems extend beyond the range of tasks they were designed to perform.

From our point of view the core of the issue is the decision-making process guided by the knowledge and the heuristics of the program. Such a process can be viewed either as an aid to the professional or the researcher or as automatic. In both cases the system needs to be able to perform the tasks intended: the formal representation and registration of all the pertinent information.

1.5. If the decision-making process in a particular field is only aided by an expert system, and the final decision is left to the responsibility of an individual, no serious concern would arise about human rights and values. More and more in the future professional expertise will be affected by the ability to exploit such machines in the solution of difficult and complex professional problems. The challenge to the university has been to educate academics, researchers, and professionals to reach a good level of competence in making decisions in a more efficient and comprehensive way with the help of these new technologies and in carefully checking the reliability on the one hand of the computer program and on the other of the data collected.

Quite different is the case of an automatic decision-making process. Any automatic decision-making process based on personal profiles derived only from registered data could give rise to serious concern about the rights of individuals. This is particularly evident in police, judicial, medical and psychological decisions. This does not mean (it may be necessary to repeat it) that people cannot use expert systems is such contexts as an iad for analysing situations under discussion in a systematic way and for exploring possible solutions. But leaving the final decision to the machine where the decision is taken in an automatic way, in a field involving human rights and/or values cannot be allowed, in any way, or, in some cases, the right could be asserted to know the process model used. To make clear the point, in this particular situation there is the possibility of a reduction of an individual to a collection of formalized data, and of the consequent automatic decision process being left to an automatic connection of a formalized profile with a formalized knowledge base and a formalized inferential set of rules. Consequently, personal values and beliefs are seriously threatened by such procedures.

In general to place undue confidence on the conclusions derived from programs that formalize the relation between a lawyer, teacher, doctor, psychologist, etc. and an individual could lead to a depersonalized professional relationship with the client, be he a student, patient, prisoner or other.

2. Electronic Communications

2.1. Electronic communications have undergone great development in recent years. It is no longer a matter of big mainframes with large amounts of stored information, but of a rapidly increasing distribution of strong professional computers with vast memory capacity, interconnected through local networks and/of telecommunication systems.

The possibility of collecting and having access to large data bases and processing information at high speed may induce, from an academic perspective, dispersion and lack of control of the pertinence and value of the gathered data. In this case the solution is an educative one : to develop a better capability to select and use in a valid, coherent, and pertinent way the data needed ; to foster the ability to follow and steer from a higher point of view, understanding and evaluating the process that has been developed and the results obtained.

2.2. In a university almost every scholar, researcher, administrator, and even student has access to a work station that is able to store and process large amounts of data from different sources. The collection of data stored on optical or magnetic supports and related to particular individuals or groups can be easily reached through electronic connections. Large amounts of data can be tranferred from one research place or domain to another place or domain, and through convenient elaborations from anonymous and general data we can sometimes draw the private features of particular persons. Particularly dangerous could be the data collected in longitudinal microstudies or the data conserved in the administrative files. Remote maintenance of central mainframes and of distributed workstations can give room for criminal intrusions.

2.3. So, both privacy and the right of informed access are placed under discussion ; personal values and beliefs are given a new challenge. In fact it is not only a question of protecting personal and private information, but also of giving individuals access to the information they need for their studies and problem solving. There may be two conflicting rights.

2.4. To rely unduly on electronic media in interpersonal communications can give rise to an inhuman climate, insensitive to the whole reality of the person. Electronic communication systems are replacing direct oral dialogues and interpersonal non-mediated relations. Now electronic codes and protocols stand between individuals. And from the cognitive and the cultural point of view, the form of coding of information and thought is not indifferent. Oral communication language is rhetorical and pragmatic. Written communication is logical and discursive, and needs a complex process of interpretation. Electronic communication in most cases is formal and analytical, with an automatic interpreter. Our way of thinking and problem-solving is affected by the communication technology we are using more and more often. The value placed on direct, good, interpersonal relations, is gradually transferred to the syntactic correctness of statements. Such attitudes may then be transposed into academic and professional activities.

3. The Action that Can Be Taken

3.1. From what has been said it becomes clear that even in the university context the rights of individuals, families and groups may be threatened, if approapriate action is not taken. It is time to pay more attention, not to the technological aspect of these developments, but to their cultural and ethical implications. The more technologies become transparent to the user, the more central is the ethical issue. In-road safety issues today, the cultural aspect and the moral responsibility of individuals increasingly appear more central than technical and driving performance. New technologies become more and more friendly; they are placed, many times, between one man and another and have the side-effect of inducing the one to consider the other only through the reductive and deformed medium of a collection of data and a formalized profile. New moral issues arise in this context: the right of all human beings to be treated as such and not like objects or collections of data.

3.2. So the first step is to be aware, at the various levels, of the complexity and extent of the problems and forms of the impact mechanism on ethical and cultural systems. Becoming aware means perceiving, paying attention, studying the human values and rights involved in the diffusion of the artificial in biology, genetics, medicine, environmental sciences, cognition, etc.; reflecting upon the challenges arising and then behaving according to an ethical and professional code defined by the academic community, besides the existing laws. This can be done by a permanent independent body placed inside the university with the job of defining the rules to be followed by every member of the university community and of settling possible conflicts and claims. This has been done in some university communities and we could analyse the problems they faced, the action taken and the results achieved.

3.3. Among the issues to be carefully considered by such a body is the possibility of forbidding or preventing the transfer, like commercial goods, of automatised profiles of individuals, families and groups collected in the files of all the academic staff (adminstrators, scholars, researchers). This is particularly so if the data collected refer to private behaviour and not to public performances like examination results. And in this venture the right to be informed and to have access to information useful for studying and participating in the life of the university must be simultaneously taken into account.

3.4. Another action that can be taken is the development and insertion into all academic and professional curricula of introductory courses on the cultural and ethical issues raised by cognitive sciences ond technology, and of the development of communication and information technology in general.

3.5. Moreover, we can be more attentive to the supervision of professional and research training and pay special attention to the cultural and ethical issues involved in activities carried out inside the university and, in perspective, outside.

3.6. All the action taken must be matched by the development of multiple forms of communicating and relating: from direct, interpersonal relationships, based on dialogue and discussion, to the systematic use of written sources of knowledge and the capacity to communicate in a logical, valid and effective written form and finally the use of the different electronic media, analogical and digital, through which to interact in a valid and productive way with the knowledge codified and conserved in different bases.

Chapter II

STRUCTURES AND STRATEGIES

The five papers included in this section give a broad overview of well established experiments in organizing the introduction and development of the new educational technologies in higher education institutions. The experiments under discussion were undertaken in a major university in the USA, a new and small university in England, in a network-type higher education institution aiming at permanent education in Austria, as well as in two European countries, the GDR and Switzerland, the latter two conveying a broad-scale macro-perspective.

Professor Patrick Suppes gives an overview of the ways in which computers are utilized at Stanford University. He enumerates the responsibilities of the various services of the University in charge of computers. Special emphasis is laid on the institution meant to facilitate the implementation of computers, to offer free computer time to students, and to organize the network. The latter is the most recent preoccupation as well as the quintessence of the rational use of computers within universities. Each faculty has its own facilities which it applies according to the requirements of its courses of study. Professor Suppes, who has edited the volume "University-Level Computer-Assisted Instruction at Stanford : 1968—1980" and who is well-known for his already classical studies on logics and the methodology of science, as well as for supporting the extensive use of computers in education, offers a number of insightful remarks on the most up-to-date ways of using computers and their future at universities. Of special interest are the "finding-axioms exercises", which are subtler and offer more shades of meaning that the ordinary demonstrations of the same theorems.

The article by John E. Galletly of Buckingham University offers a description of the Computing Science Laboratory, the micro and macrocomputers of which are connected to a network. Personal computers may be used as terminals linked to a network or as stand-alone computers. The list of disciplines for under-graduate students, spread out over two years with four ten week terms each, is most enlightening. So is the idea of introducing a Computer Literacy course for each and every student.

Peter Baumgartner and Sabine Payr's case study deals with the introduction of computers in an interuniversity research institution with six centres, aiming at facilitating distance studies, the further education of teachers as well as aquaintance with other topics of acute social interest (ecology, health, energy, etc.). The study emphasizes the importance of new technologies for supporting the increasingly important role of universities in new social matters, the new didactic concepts this role entails, as well as strategies for the introduction of computers, which start with personal ones, continue with user-stations, and end with networks.

An overview of the problem at the level of a whole country is offered by Professor Horst Möhle, of the Karl Marx University in Leipzig for the GDR and by a survey on the introduction and development of the new information technologies in Switzerland. In his article Professor Möhle illustrates the introduction of computers for students whose basic fields of study are mathematics, informatics, and economics — fields which are well suited for the widespread use of computers in education —, for all students irrespective of their basic courses of studies, and for students in further education. The article discusses ten points which have required the reshaping of the university pedagogical process and have entailed the organization of a one-year postgraduate course for all the young scientists and academics (researchers and graduates). The study reaches a most valuable conclusion according to which the introduction of informatics is more efficient when closely linked and adapted to the basic field of each profession.

The article on informatics in Switzerland represents a very interesting review of the specific way in which this science has developed and implemented itself in a country in which private initiative, particularly at the educational level, plays a special role. The report presents the situation of scientific research in the field, the services offered, the existing infrastructures, the various domains of collaboration — interuniversity, university, and others — various forms of coordination, and Swiss participation in European projects (for instance ESPRIT and RACE).

COMPUTERS AT STANFORD : AN OVERVIEW

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My objective in this paper is to give an overview of the many different ways in which computers are now being used in universities, and also to give some projections for the future. I hasten to add that the sense of overview here is not a statistical one. I shall, in fact, not make any effort to collate data from a variety of universities, but rather will examine in some detail the highly pluralistic use of computers at Stanford, my own university. It is generally recognized that in the United States, Stanford is among the research universities making the most extensive use of computers. The other two examples that immediately come to mind are the Massachusetts Institute of Technology (MIT) and Carnegie Mellon University in Pittsburgh, but the overall scene in the United States is complicated and highly pluralistic. No single university is doing the most in every direction. There are important and pioneering efforts that are not duplicated elsewhere in any one of 25 or 30 major universities in the country.

I have organized this paper in the following way : the next section gives a broad overview of the ways in which computers are institutionally organized at Stanford. The following section, Section 2, discusses the special role of networking and some of the problems that have been encountered in implementing a satisfactory network at a place like Stanford. Section 3 gives a survey of some of the different instructional uses of computers at Stanford. In Section 4 I treat in somewhat more detail my own years of experience in computer-assisted instruction at Stanford and also, but to a lesser extent, my experience in American secondary schools. The final section makes some projections about the future based on my current impressions of developments that are taking place in the United States and other parts of the world at the present time.

1. Overview of Computers at Stanford

To the visitor coming in from the outside, the main administrative unit in charge of computers at Stanford that he would perhaps first encounter would be the Information Technology Services (ITS). ITS is primarily responsible for the administrative use of computers which includes everything from payroll to course registration. ITS is a large organization and consequently has divided itself into a number of subunits, the titles of which will give a sense of the kind of work ITS does :

- Director's Office
- Administrative Information Services
- Communications Services
- Communication Information Resources
- Computer Operations
- Data Resources Group
- Graphics and Computer Systems
- Mailing Services
- Administrative Services
- Financial Services

I will not try to describe each of these subunits — their titles are reasonably self-explanatory — but the main reason is that ITS is just the beginning. ITS mainly uses large IBM mainframes.

The next unit to mention is Academic Computing and Information Systems (ACIS). The mission of ACIS is clear from the title ; it is to facilitate academic computing. ACIS uses a great variety of computer equipment. I will say more about each of its subunits here because they are less self-explanatory. The first is Instruction and Research Information Systems (IRIS). IRIS's role within ACIS is to provide help to faculty who want to get into the use of computers for instruction, but do not have much in the way of computing facilities or experience. The second and major activity is Low Overhead Time Sharing Computer Facility (LOTS), which is a facility that has had major impact on the campus. LOTS provides free computer time to students. It has been an important experiment in making computer facilities available on a broad basis to undergraduates. It continues to be a major force in the use of computers by undergraduates at Stanford. Students use the LOTS facilities for doing problem sets in mathematics, science and engineering, for writing papers in almost any subject, and for conducting various research projects under some faculty supervision or often without such supervision. The third component of ACIS is networking systems, which has the responsibility for the Stanford University network about which I will have more to say later. Finally, the fourth subunit of ACIS is the Video Education System, which provides video facilities for faculty use in the preparation of instructional materials.

ITS and ACIS are the two university-wide organizations, but perhaps the most important single lesson administratively about Stanford's use of computers is that that use is not in any sense organized centrally. It is a blooming chaos of pluralism and I think most faculty very much want it to be that way. Let me just review some of the other main university organizations that have major computer facilities independent of ITS and ACIS. First on this list is the Stanford Linear

Accelerator Center (SLAC) which has very large computers as part of its facilities for research in elementary particle physics. SLAC mainly uses large IBM mainframes. The computing facilities available at SLAC would alone exceed that at probably 75 to 85%, and possibly more of American universities. Secondly, there is the Department of Computer Science which has major facilities available, especially for research in artificial intelligence. These facilities are run as a separate facility in the Department of Computer Science. The Department of Computer Science has a variety of equipment. Until recently, it has extensively used DEC equipment, but is moving increasingly to a variety of recent machines, especially those well suited to efficient execution of LISP programs. The Department of Computer Science is now a part of the School of Engineering, but I also list the variety of facilities available in the School of Engineering which are separate from the Department of Computer Science. It is important, however, to emphasize that the variety of computing in the School of Engineering is even at this level, not organized in the Dean's Office, that is, centrally in the school, but is decentralized to various departments of the School of Engineering. These decentralized facilities in the various departments of the School of Engineering are used both for instruction and research. It is fair to say however, that there is some tendency for the instructional facilities to be more centralized at the school level than the research facilities. The variety of computer equipment in the various departments of the School of Engineering is too great to survey, but there has been a very strong move to having a large number of personal computers available both for faculty and students.

Next in size is the School of Medicine, which has extensive computer facilities primarily for research purposes. Many readers probably have heard of the artificial intelligence programs developed at the Medical School for Medical Diagnosis such as MYCIN, but there are also extensive use of computer facilities for data analysis and a variety of other purposes. Again these facilities are independent of other administrations in the university. The School of Medicine has in the past used IBM mainframes mainly for data analysis and DEC 36-bit word machines, originally PDP10s and later PDP20s, for the work in artificial intelligence. Given that DEC has terminated its line of 36-bit machines, the future is less clear but undoubtedly the work in artificial intelligence will move in the same direction from the standpoint of computer facilities as that in the Department of Computer Science.

The School of Business has a centralized facility as part of the school with a staff to run computer facilities, but I emphasize again that this facility runs at a decentralized level from the standpoint of the entire university. The School of Business is essentially responsible independently and without further consultation for the way in which this computer facility is run. The facilities are used for both research and instruction. The School of Business is encouraging every student to have a personal computer. The use of personal computers is extensive. In addition, the central computing facility of the school runs two DEC

2060s plus some other equipment. Again, as in other cases mentioned, transition to new equipment is now being actively discussed, in view of DEC's termination of the 2060 line.

There are may other places that have an independent use of computers in the university. I mention here only various research institutes of which my own Institute for Mathematical Studies in the Social Sciences is an example. I have been running independent computer facilities at IMSSS since 1963. These facilities are modest in comparison with SLAC or the Department of Computer Science, but what is important is the long history of research and development conducted within these facilities on a continuous basis and again with responsibility for their development being entirely decentralized. No university funds have been used for the purchase of any of the equipment in IMSSS and this is true of much of other parts of the University, once ITS and ACIS are excluded.

There is an important second generalization that goes with the decentralization, namely, as research is organized in the United States, most groups have responsibility for raising their own funds for computing facilities external to the university. There are only limited funds from the university budget that flow directly into research. The computing facilities used for research are almost entirely funded by grants from the federal government, although there is beginning to be a certain amount of funding from private industry.

To those readers entirely familiar with this pattern of funding, I should mention that from a legal standpoint the contracts or grants for research are between various agencies of the federal government and Stanford University but, in actual fact, the research proposals that constitute the substantive basis for the granting of the research are made by individual investigators, and these individual investigators really have the responsibility for raising the research funds by making proposals to granting agencies, and also for managing the use of the funds once they are granted. The university has a fiduciary responsibility, but not a substantive research responsibility at the central level, in the use of the funds.

2. The Stanford Ethernet *

An important problem for a university campus on which there is extensive computer usage is how various computers and terminals are to be connected. Fifteen or twenty years ago the matter was simple; there were a relatively small number of computers with each computer supporting a number of terminals. On occasion an effort was made to establish direct communication between computers, but no general network was put in place. Not only on campuses but throughout the world, perhaps the central technical hardware and software problem of data

* I have benefited from discussion with William Yundt, Director of the Stanford Networking Staff, and Ron Roberts, a member of that staff with whom I have worked for many years.

processing managers at the present time is establishing an efficient and reliable network.

The Stanford network has grown up in a different way than many that are being installed at the present time, for it has evolved in a piece-meal fashion. The first ethernet networks were based on experimental 3-megabit ethernet hardware and software given by XEROX to Stanford. It was realized quite early that the expansion of the ethernet as such to the entire campus would not be feasible. There were two reasons for this view of the matter : first, the ethernet hardware did not work well at distances longer than about 2 kilometers ; second, the ethernet was subject to various kinds of failure. These local failures needed to be isolated so as not to disturb other parts of the network.

What Stanford did was to introduce a gateway technology. In principle — though in practice a little different —, each building addresses the main network through a gateway. This gateway protects the main network from points of failure in the local ethernet in a given building.

The Stanford Gateway is a packet-routing device but the hardware and software were specially designed at Stanford. A gateway is capable of interconnecting up to four ethernets, which consist of experimental 3-megabit ethernets or standard 10-megabit ethernets. There is, in principle, no limit to the distance between gateways.

At the present time, the total number of gateways is 31 and the total number of subnets is 53, but it is evident the network will continue to expand. Also, by this time, most of the local ethernets are standard 10 megabits.

Another feature of the net are TIPs for terminals, where TIP stands for *Terminal Interface Processor*. TIPs are built at Stanford with the same hardware components as the gateways. A TIP uses Telnet protocol software to establish communication between standard ASCI-II terminals connected to the TIP and computers attached to the network. The Stanford TIPs are widely used. For example, many of the timesharing computers do not interface any terminals directly, but only through the ethernet at TIPs. There are approximately 2,000 terminals connected to the ethernet by way of TIPs and well over 500 different computers, with that number continuing to expand as a variety of personal computers are added.

Stanford has been the recipient of a large IBM grant of equipment, the impact of which I will discuss in more detail in the next section, but it is worth remarking that the IBM PC family is supported on the network by the fact that the network supports the 3-Comm ethernet board which costs something like $ 500. The software supports both file transfers and protocols for remote terminal access. In the latter case, it uses IP/TCP which is the standard ARPA net protocol. However, most of the PCs are actually interconnected on a local net which uses the same board.

A natural question about networks is the same question that arises about large numbers of terminals on timesharing computers in the recent past. What about saturation? Thus far the operational experience, which has not been studied carefully statistically as yet, is that no part of the network is utilized for more than 20% of capacity. Usually 5 to 10% of capacity represents the maximum use in any given day. It should be mentioned, of course, that a network of this kind cannot really operate effectively at 100% of capacity; the service begins to degrade once something like 50% of capacity is reached.

It was mentioned earlier that one of the reasons for gateways was to increase reliability. It should also be emphasized that a feature of the network that will increase the reliability still further is to have between any two gateways alternative routes so that if a given gateway fails, it does not bring down communication between other gateways.

Let me mention some problems from an operational standpoint. Perhaps the most obvious one is that the network is not an effective way for dealing with character-by-character interaction from a remote terminal to a timesharing computer. I have had personal experience with this because we access from a computer-based classroom an IBM 4381. One of the prime uses of this classroom is to run the computer-based logic course which I discuss below. In this logic course, there is very rapid interaction between the student at the terminal and the program. The student has a control language that is based on single key or small number of multiple-key entries. The network is not oriented toward this kind of interaction, so what we have is a special fiber-optics connection between the IBM 4381 and the 20 terminals dedicated to the course. The existence of such a dedicated fiber-optics connection is just one example of the fact that not all the communication will be on the network, although most of it on the campus now is.

The second problem is that if one wanted to do system backup on a computer from a remote site, it is not really going to be feasible, apart from the fact that the software for doing such backups does not exist. The network would soon be overloaded if backups on very many systems were done in this fashion. This is because after protocols are taken account of, the effective maximum rate on the network is approximately 2 megabits, although even this number is probably somewhat high.

Although there are problems with the network, it is clear that it is by and large quite successful and is meeting an important requirement for computing on the Stanford campus. The overview I have given is from a technical standpoint superficial, but I hope I have given a broad sense of how the network looks from the user's standpoint.

It is Yundt's estimate that Stanford currently runs the largest high-speed network of any university in the world. He forecasts the following developments over the next few years. "During the period 1985—88, we will gradually saturate the current broad-band network, including the new physical capabilities for handling video as well as computer communication. After 1988, there will probably be, over a 4- or 5-year period, a widespread installation of fiber optics to provide at least 100 megabits of communication capability".

3. Survey of Instructional Uses of Computers at Stanford

This survey will necessarily be superficial and not in any sense statistical. The widespread different uses of computers are so extensive in nature that I can only describe them in a general way. I have also excluded any attempt to describe the research use of computers which, it seems to me, is in any case much better known from the scientific literature. To a fair extent, the survey will be based upon uses that are being made of the extensive equipment grant made by IBM to Stanford, but there is also extensive use of other computer equipment. In fact, some of the uses described commingle equipment from various manufacturers. In any case, my central point is to stress the instructional applications.

I have organized this survey in terms of the various schools at Stanford, which constitute the main administrative organization of the university for instructional purposes. I have organized the presentation in terms of decreasing enrollment; the largest school, the School of Humanities and Sciences, comprises 27 academic departments and 26 separate programs.

The School of Humanities and Sciences

I begin with the Economics Department which has under way an intensive development program for the use of computers in large enrollment undergraduate courses. Most of the work consists of quantitative analysis including use of simulations. There are also a number of linear programming and other econometric statistical packages used by students in the analysis of data. The Economics Department and its students use essentially 100% capacity of the IBM 4381, although there are other users on the system. I mean that 100% of the cycles are being used 24 hours a day, 7 days a week. The Departments of Political Science and Sociology have a similar large-scale use. Students are doing studies of various social phenomena based upon large-scale data files available from the U.S. Census and other sources. In contrast, the Department of Communications is using computer facilities to improve video-editing techniques and also has an extensive use of microcomputers by students for electronics story board programs for film and television and for data analysis. The Department of Psychology has an extensive use of computers for individualized instruction, especially for demonstration and simulation of well-known psychological phenomena.

It should also be mentioned that for all of these departments, the use of microcomputers for word processing is important for large numbers of students, both undergraduate and graduate.

I turn now to some sample uses from the natural science departments. In Physics, personal computers are being used in a theoretical astrophysics course for new course development. Extensive use by students for both purposes of simulation and numerical computation represent a central role for instructional use of computers in physics. In broad terms the uses are similar in the Department of Chemistry.

The uses by graduate students include calculation of molecular processes, infrared absorption processes, and energy transfer in solids. In the Department of Biology, priority has been given to providing workstations for graduate students in the research labs and to make personal computers available in the undergraduate teaching labs for use by students in the core biology curriculum. The Department of Statistics has placed a current priority on graduate students and faculty doing computing related to the ideas of shrinkage estimation in the computationally intensive problems of smoothing and processing of noisy images. The statistical techniques involved here have extensive applications in a number of areas ranging from satellite pictures to CAT scans in medicine.

In the School of Humanities and Sciences there are 14 departments within the Humanities division. The most extensive use up to date of computers has been in work processing. At the present time about 170 of Stanford's 190 faculty in the Humanities use a personal computer for such purposes. There are a number of other different uses; for example, individuals teaching and doing research in different languages want to be able to manipulate these languages on the screen and at the keyboard. The most extensive teaching applications of computers in this respect have been developed in the Department of Slavic Language where extensive drill-and-practice routines in Russian and other Slavic languages have been developed. Because of the very small number of students taking any of the Slavic languages except Russian, the Department of Slavic Language is especially anxious to develop a computer-based course in Polish and some of the other Slavic languages.

The Department of Music at Stanford is well-known for its extensive work in computer-generated music. At the instructional level, there is also concern to make music printing available to students for use in composing and scholarly writing. There is also use of personal computers to support the performance faculty and their teaching duties. And it goes without saying a number of graduate students are involved in the extensive work in computer-generated music.

School of Engineering

Here is a summary statement of the various ways in which the Engineering faculty are using personal computers for instructional purposes :

- Develop homework problems
- Prepare and give demonstrations in class
- Prepare lectures
- Evaluate student computer programs
- Keep class records
- Supplement activities in the laboratory
- Perform calculations in the laboratory

More generally, the School of Engineering has an intensive effort now to spread the use of computing facilities throughout the faculty and student population. The current rate of change is very high. Even five years ago there was a fairly limited use of computers for instructional purposes in Engineering; ten years from now it will be found everywhere in the curriculum. Here are a few topics either that have been developed or planned for the immediate future by various faculty :

- Classroom demonstration of microwave circuit design
- Lecture demonstration of fractures of materials
- Interpretation of mass spectra
- Interactive use of computers for decision making
- Demonstrations of energy-policy models
- Simulation of shock-tube experiments
- Control laboratory experiments related to composite structures
- Interfacing of computers to the operation of advanced sensors
- Providing simulation in thermal-science laboratory courses
- Developing a computer-aided design facility for VLSI chips

School of Business

The Shool of Busines at Stanford is a Graduate School of Business. There are no undergraduate students. The bulk of the students take an M.B.A. but there is also a significant Ph. D. program. Here are some sample instructional uses that have been developed or are being developed by faculty :

- Development of case studies of decision-making under uncertainty
- Use of LOTUS 1—2—3 for simulation studies of pricing
- Use of LOTUS 1—2—3 and other statistical routines to analyze personnel data
- Introduction to Electronic Financial Reporting (to replace paper reports)
- Use of LOTUS 1—2—3 to model corporate cash flow
- Use of various programs for nonlinear time series analysis
- Statistical analysis of future prices and, in particular, applications to multi-asset hedging strategies

School of Medicine

There is already extensive use of computers as mentioned above for research in the School of Medicine. The current rapid change is in the use of computers also for instructional purposes. There are over 400 medical students currently enrolled, an additional 160 advanced-degree candidates, and more than 450 post-doctoral scholars, as well as the regular faculty. As in the case of previous schools, I list here a number of different projects by brief descriptive titles :

- Use of personal computers in biostatistical analysis
- Use of large-scale medical data bases now on line
- Teaching pharmacokinetics and pharmacodynamics by computer modeling

- Use in cardiology of a three-dimensional, computer-based model of the heart's depolarization, and repolarization sequence, based on real data rather than simulated data
- Analysis of extensive data on geriatric preventive health care
- Use of a relational data base system in radiology for establishing a clinical data base and teaching file

School of Education

Currently, of the regular faculty of the school, more than 80% have regular access to microcomputers, but not that high percentage as yet are using computers in instruction. Some sample instructional projects are the following :

- Graduate training in interactive education technology
- Career simulation project
- Computer-based models for educational planning and management
- Simulation of exemplary teaching
- Development of teacher profiles

School of Earth Sciences

The School of Earth Sciences is a small but active group dedicated to the extensive use of computers in both research and teaching. As in previous cases, I list here some typical teaching projects :

- Modeling of geochemical thermodynamics
- Simulation and management of groundwater
- Techniques of satellite and aircraft image processing
- Dynamic simulation of geologic processes

4. My Own Teaching Experience with CAI

I turn now to a more detailed and personal statement about my own experiences with using computers for instruction (for details see Suppes, 1981). This experience is largely based on two courses developed over many years at Stanford, and also with extensive experience in developing courses for elementary and secondary schools. I shall concentrate on the university experience but begin by saying a word about the school experience. In 1963, we began our first work in computer-assisted instruction by developing courses for elementary-school mathematics and reading. These courses were meant to be supplementary to the regular curriculum ; they were aimed at providing a regime of drill, practice and review. In the more than 20 years since those courses began, they have come to be used as a model for a variety of work. I think that such supplementary use of computers also plays an important role at the university level. Many of the activities I have mentioned in the preceding section would fall under this description.

On the other hand, there is also a more radical use of computers for instruction and it is this use that I want to discuss here. Since 1972, I have offered the regular course entitled "Introduction to Logic" entirely as a course taught by computers. There are no lectures or quiz sections, and all information is given to the student at a computer terminal. The course is offered each term three times a year. We now have experience with thousands of students and I will try to give you some comments about the course based on this experience. First, the students reach a pass level with on-the-average of 80 hours at the terminal, that is, each student has about 80 hours of connect time, but the standard deviation on this mean is very high. Secondly, the students take another 20 hours or so to do all of the work for an honor's grade. From the standpoint of the use of computers, there are important features about a course like logic. The most important is that we have great flexibility in handling student responses. For example, when the students give logical arguments, derivations or proofs, their work is not matched against a stored ideal result. The program is organized to accept any valid argument or proof on the part of the student. Anyone with any experience on these matters knows that it is a mistake to have one single format of response when logical arguments are being given — nothing can be more stifling to the imagination and inventiveness of students. We want to encourage problem-solving as an individualized activity in which many variant answers are all deemed correct.

Another feature of great importance in the teaching of a course like logic is that the work is highly interactive. The screen of the terminal is not used as a page display on which endless amounts of exposition without any exercises to be done by the student are shown. The course emphasizes a high level of interaction and makes available to the student a simple, easily used control language for making inferences. Here is an example where the student's input is underlined.

(5) If $x > 2z + z^3$ then $y > z^2 + 10$

....

....

(8) $x > 2z + z^2$

5,8 AA (9) $y > z^2 + 10$

Let me mention some additional features. Errors on the part of the student are corrected immediately with a message as to why the error is indeed an error. It is easy to generate individual messages again tied to applications of specific rules of inference.

Among the exercises in the logic course I like best the exercises on the strategy of selecting axioms. It is often easy for students to derive desired conclusions from given premises or theorems from given axioms, but it is another matter to understand how one should select axioms to do a certain job. We have a number of exercises labeled "finding-axioms exercises". Here the student is given a list of elementary statements; for example, let us say 15 statements about the elementary geometrical relation of betweenness among points. His problem is to select no more than five of the statements as axioms and then to derive the rest in a sequence of theorems. What is important about this kind of exercise is giving the student experience in thinging through the strategy of what constitutes an appropriate system for a given set of statements. In the case of the geometrical betweenness, almost certainly the student cannot do this exercise by a purely syntactical approach. He must look at the geometrical meaning and sketch some elementary geometrical relations in order to organize his selection of axioms.

I also want to stress the human aspects of the teaching that are important; this comes in the form of teaching assistants. Teaching assistants do not give lectures or quiz sections and do not have the task of grading endless exercises; for example, the rather tedious-to-correct exercises on finding axioms. But the teaching assistants are available for students to ask questions and to give help as appropriate on the various kinds of administrative and other concerns that continually occur as students make their way through the course. It may be that in 20 or 50 years we shall have such completely intelligent programs that we will not need teaching assistants, but I am skeptical that we will be able to entirely do away with teaching assistance for a long time where they can be available. On the other hand, courses such as the logic course are sufficiently self-contained that, for example, in distant learning or in many kinds of adult learning which would take place in off-campus settings, for example, in the home, teaching assistants could be dispensed with if necessary. I want to be clear on this point. It is clearly advantageous to have teaching assistants and even in the case of distant learning, it may be desirable to have a telephone hotline for the student to get assistance when it is absolutely needed. All the same, the courses are sufficiently self-contained that if circumstances required it the student could make his way on his own.

A natural question that arises in a course of the kind I am describing is how students feel about it in comparison to lecture courses. Fortunately in the case of the logic course, I have some interesting and significant data. The Department of Philosophy regularly offers a parallel lecture course given by a junior member of the staff. I have looked at data recently for 15 terms and the comparative enrollments were as follows: 1,477 students in the computer-based course versus 262 in the course being taught in the standard lecture format. This is a ratio of approximately 5.6:1 and testifies to the clear acceptability of this kind of computer-based teaching for standard undergraduate courses.

Axiomatic Set Theory

Let me now turn to the second course that I have taught in a similar fashion. The course in set theory has been offered on the same basis every term since 1974. The general features are the same as the logic course. I mention just those special features that differentiate it. First of all, it is a more advanced course and has a much smaller enrollment. Ordinarily, the enrollment is about an order of magnitude less than of the logic course. This means that the enrollment will run from 6 to 15 students a term. In fact, my own view is that it is really courses of this kind that we should especially concentrate on teaching by computer because it is expensive to have a regular faculty member offer a course to only six students. On the other hand, the stand-up lecturer, looked at purely from a economic standpoint, is a cheap technology when the number of students is well over 100.

The set theory courses are organized into a series of 650 theorems Because of the small enrollment, each student is given an individual set of theorems to prove and, of course, just as in the case of the logic, each student's proofs will be found to be different from any other students. Indeed, at this level of complexity, we would naturally be deeply suspicious of any two students offering exactly the same proofs for many of the theorems.

Of course, as I have emphasized, the proofs are much more complicated in set theory because of its more advanced nature. The biggest intellectual effort has been put into developing a usable interactive theorem prover. We are able to prove the standard classical theorems in set theory now, but there are ways in which we can certainly continue to improve. I do think that our interactive theorem prover is probably the most sophisticated one in the world being used on a regular basis by students who are not programmers to prove non-trivial theorems.

One of the things to have a sense of is the enormous variability in the kinds of proofs that students offer. Here is a small sample of 1,000 proofs. I show the average length of proofs and number of lines in the left-hand column, the average of the minimum proofs, that is, we take the shortest proof given by any student for a given theorem and now average those data across theorems, and finally the corresponding average maximum proof.

MEAN	AVG MIN	AVG MAX
15.0	3.5	54.7

Notice that the difference between the average minimum and the average maximum is more than an order of magnitude.

I should mention that we make regular use of a resolution theorem prover, which the student can call to go from one step to another. The student is given [illegible] seconds of machine time to run this theorem prover, so one of the things that he must learn is what it can and cannot do. For example, it is not of any interest that the resolution theorem prover is in principle complete, that is, given enough time, it could prove any first-order logic inference that is valid. What is important is to get a sense of what can be done in a limited amount of time and with limited resources of the computer. Students become fairly good at calibrating what to expect.

Differential and Integral Calculus

In spite of my statement that we should concentrate on courses with small enrollment, for a reason to be explained in a moment, our current effort is to produce a computer-based course in the differential and integral calculus, the mathematics course most widely taught to undergraduates in American universities. The reason that we are developing this, however, is to place it in high schools where there are small numbers of very bright students who are prepared to take a substantial course in calculus, but there is not an appropriate teaching faculty. In the United States more than in Europe, I should comment, the teaching of calculus is still currently mainly done at the undergraduate level in the universities rather than in high schools. The main topic that we are addressing in the development of this course is exactly the feature stressed in the logic and set theory courses, namely, a stress on offering a rich interactive structure to the student to do all the standard deductive work.

In the case of the calculus course, there are special problems of finding the right internal formalization for the informal language and inferences customarily used in the course. I will not try to survey here the particular technical problems we are now wrestling with. I do want to say that our objective, however, is to change the traditional notation as little as possible and to offer a course that is standard in appearance as far as the mathematical expressions go and the inference rules are close to what is to be found in a standard textbook.

One important feature is the extensive use of symbolic calculations of an algebraic and calculus sort. There are now extensive programs, e.g. REDUCE and MACSYMA, for making such computations for engineers and scientists; our problem is to build a highly interactive symbolic calculator that students can use effectively in this course. The stress on the interaction and the stress on the use by students mean that we must do a lot of things in a way that is different from the way things are done in REDUCE or MACSYMA, but I shall not enter into the details here.

I do want to mention that the striking difference found in the calculus course, when compared to the logic and set theory courses, is the extensive use of graphics. Fortunately, we are preparing this course at a time when good graphics are available at a reasonable price compared to a decade and a half ago, when we first began teaching logic by computer. At that time, it would have been prohibitively expensive to offer students substantial graphic facilities.

Future Progress Needed

Let me close by mentioning three areas in which self-contained courses at the university level need richer and better facilities.

First is the important problem of the processing of natural language. It is in certain ways a bit of a scandal that we still are so awkward in the processing of natural language in the use of computers. The problem is subtle and complicated, but within various limited contexts we are certainly on the verge of making real progress, even if we do not solve the full range of processing difficulties.

Second, we need better and richer theorem provers and better and richer symbolic calculators. Here we can take a more optimistic view — the problem is a much more constrained one than that of processing natural language. We can anticipate having rich and powerful software technology available for the teaching of a wide range of courses in mathematics and science in the decade ahead, but progress is needed all the same. The work must be done. I am optimistic that it will be.

Third, I mention the psychological problem of having better models of the student at work proving a theorem, solving a problem, or writing a coherent and clear essay. Here the software technology is much more primitive but there is reason to be hopeful that progress can be made in ways that will be helpful, even if deeper problems of understanding the relevant cognitive structures, will elude us for some time to come.

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THE USE OF THE PERSONAL COMPUTER IN EDUCATION AT THE UNIVERSITY OF BUCKINGHAM

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Introduction

This paper describes the use of the personal computer in undergraduate education at the University of Buckingham, England. The main part of the paper is concerned with its use in Computer Science, the author's subject, but other parts of the paper deal with its use in other disciplines.

Background

To set the scene, perhaps some information about the University is in order. Buckingham is the only university in the United Kingdom receiving no direct funding from government sources. The University receives its income from fee-paying students, and from donations and gifts from various persons, companies and charitable foundations.

Another feature unique to Buckingham is the length of the degree programme. This is two years and not the usual (in the case of the United Kingdom, at least) three or four years. This is achieved by having four ten week terms per year. The Computer Science course comprises two thirds Computer Science and one third an option chosen from Accountancy, Business Studies, Economics, Biology, Mathematics or French.

The Use of Personal Computers

The Computer Science course at Buckingham makes full use of the personal computer, recognising the fact that the modern computer scientist needs to be equally at home with both small and large computer systems — the smallest and largest businesses are using personal computers.

Moreover, the wealth of software implemented and being implemented on personal computers has opened the door to a wide-ranging number of packages and programming languages for student access in a way which was not possible in the days of mainframe computing. Not only are the traditional software packages and languages being implemented on personal computers but also newer systems are being implemented, in some cases long before appearing on the larger computers. This is a decided plus in our opinion. There are number of courses in our degree programme which would not have been realistic, at least the practical part, without this availability of software.

Another advantage of the personal computer, particularly for Buckingham with its novel funding situation, is the cost factor. A small institution is able to provide a quite acceptable level of computing resources via the personal computer costing a few hundreds of pounds instead of having to invest in the traditional and costly mainframe computer.

However, there are a few areas of concern with the use of the personal computer. One problem arises from their popularity, usefulness and portability. There needs to be some kind of security system which prevents the personal computers migrating from the laboratory. Another problem is the provision of a back-up system for the personal computer's filestore. We have several personal computers which have individual 20 Mbyte hard disk units. Students are encouraged to take copies of their own software on floppy disks as a precaution against the loss of the hard disk filestore. With hindsight, a network of personal computers with a central file server and tape streamer may have been more convenient.

Computing Resources

The computing facility at Buckingham presently comprises a Computer Science computer laboratory and computer laboratory for the School of Accountancy, Business and Economics.

The Computer Science laboratory was set up in January 1986 for the first intake of Computer Science students. It houses a growing range of computer equipment — a *High Level Hardware Orion* [1] super-mini-computer, an *ICL Perq* [2] minicomputer, seven *Olivetti M24* [3] PC compatibles with hard disks, five *Atari 1040ST* [4] microcomputer, an *Acorn Master* [5] microcomputer, a *Commodore Amiga II* [6] microcomputer and an *Apple Macintosh Plus* [7] microcomputer. All of the microcomputers are linked by serial RS232 connections to the Orion minicomputer, which is the University's *Unix* [8] facility. So, the microcomputers may be used as ordinary terminals linked to the Orion (using the *Kermit* [9] terminal emulation package) or as stand-alone intelligent terminals, as required. This, then, is another attraction of the personal computer — it fulfills a dual role.

The Computer Science staff at Buckingham believe that the student should have exposure not to just one type of computer but also to several of the more popular makes — not only in terms of hardware, but also the software environment. This standpoint, of course, means constantly upgrading the resources as new computers are brought on to the market. So, the Computer Science staff are currently evaluating the new *IBM PS/2* [10] series and the *Acorn Archimedes (RISC* architecture) personal computers with a view of adding them to the collection.

Apart from the microcomputers, there are several portable printers and plotters available in the laboratory for the students to prepare a hard copy listing. Such devices are attractively priced for the personal computer market. Students are encouraged to produce solutions to prescribed work, including essays, on the personal computers. This service is, again, only available because of the attractive cost factors which accrue with personal computers. In addition, the Macintosh provides a word processing facility *par excellence*. The Macintosh runs the *TEX* [11] text processing package and a laser printer is available for the production of high quality documents.

Of the personal computers in the Computer Science laboratory, the Olivetti PCs, running *MS-DOS*, [12] are, by far, the most widely used in the Computer Science degree programme. Their usefulness to our course and, even, our dependency on them, will be amply illustrated later in this paper. Some use is made of the other types of personal computer in other parts of the degree programme.

The School of Accountancy, Business and Economics computer laboratory was set up in 1983 and comprises two *Comart CP500* [13] microcomputers, running Comart's version of multiuser *CP/M* [14]. The CP500s each support five terminals and a printer.

Personal Computers in the Computer Science Course

The first term at Buckingham involves the teaching of *Structured Programming* and *Introduction to Operating Systems*. Both these courses use the Olivetti PCs. The programming course utilises *Turbo-Pascal* [15]. This package has proved to be a very popular and usable system which is well-suited to the beginner, although it does have various inadequacies, mainly due to its non-ISO Pascal nature.

The operating systems course uses MS-DOS as its basis and the structure and facilities of an operating system are described with this as a model, at least initially. The student thus learns the details of an operating system which he/she will use for the rest of the degree programme. Moreover, by using the operating system of a personal computer as a test-bed, the student is unable to harm other students if he/she crashes the system whilst investigating the inner workings. Imagine the result on a mainframe computer ! The study of an operating system on a personal computer is likely to be extended with the more sophisticated operating systems such as *Xinu* [16] or *Minix*, [17] now available for PCs. These packages were specifically designed for the teaching environment and allow the inner workings of operating systems to be closely investigated.

The following term carries on from the programming course with a *Data Structures* course. This course again makes full use of Turbo-Pascal.

The third term includes courses on *Software Engineering* and *A Survey of Programming Languages.* The software engineering course is taught using the programming language *Modula-2* as a specification and implementation language. The availability of Modula-2 compilers for personal computers (in our case, we use the *Logitech* [18] version) really facilitates the practical aspects of the course. The students are able to practice what the lecturer preaches ! The recent availability of software packages for PCs which allow the production of *dataflow diagrams* and *structure charts* will greatly enhance courses such as this.

The programming language course includes a discussion of *LISP* and *Ada* — two very important languages for different reasons. In the case of Ada, mainframe implementations are very few and far between, and very expensive. However, a subset Ada compiler, called *Janus,* [19] exists for the Olivetti PC at a very reasonable price. So our students are able to gain first-hand experience with this increasingly important language. For LISP practicals, a version in the public domain in used. True, not much documentation or technical help is available, but, as the course is only a survey, this is enough.

The next term has the courses *Databases, Human Computer Interface (HCI), Assembly Language and Machine Architecture (ALACA) and Occam and the Transputer* [19]. The database course introduces the theory and practice of databases via the *dBASE-II* [21] database management package, before progressing to more sophisticated database packages on *Unix*.

The HCI course uses many of the microcomputers available in the laboratory. The colour graphics of the Olivettis and Amiga, WIMP interfaces on the Ataris, and the smooth professionalism of the Macintosh interface are just some of the environments available for teaching. Indeed, another big plus in favour of the personal computer not mentioned above is the graphics facility which many possess. Such a feature would previously only be found on an expensive mainframe graphics workstation.

The ALACA course, at present, uses the personal computers to prepare *NS32000* assembly language programs to down load to a *National Semiconductor* [22] NSV32016 development system. However, plans are afoot to upgrade the Olivetti PCs with *National Semiconductor SYS32/20* add-boards to run Unix. This package contains assemblers and compilers which means that all the software development can be performed on the Olivetti PC, making full use of its filestore, and then a binary program file can be loaded into the add-on board's *NS32032* processor for execution.

The Occam and the Transputer course is a new one. The Transputer is an exciting new development in computer architecture. It will give the students insight into concurrency and tightly-coupled computer communication. We are intending to base this course around *Inmos's IMS D701* add-on board for the Olivetti PC. This is a full transputer development system and contains the necessary editor and compiler to produce Occam code and run it on the add-on board's Transputer. The course will also make use of an Occam emulation package for the Olivetti PC developed at Buckingham as a final-year undergraduate project [23]. This software package will compile and emulate a large subset of the Occam II language on the personal computer.

The eighth term includes a course on *Artificial Intelligence and Expert Systems*. The course proposes to use demonstration shells, such as *Experteach* [24], available for personal computers to demostrate forward and backward-chaining principles in the construction of expert systems.

The mathematical orientated courses in the Computer Science programme such as *Discrete Mathematics, Analysis of Algorithms, Mathematical Models of Computation and Information Theory,* do not, at present, make use of the personal computer, but there are plans to do so in the near future. For example, the Discrete Mathematics course may introduce a package for the plotting of functions whilst a *Turing* machine simulation is being thought about for the Mathematical Foundations of Programming course.

Personal Computers in Other Courses

Besides Computer Science, the other degree programmes which make most use of the personal computer are Accountancy, Business, Economics and Biology.

Students in all of these programmes have a *Statistical Methods* course in which the practical aspects of statistics are taught on the Olivetti PCs using the *Minitab* [25] statistical package. Thus the students are able to investigate such statistical ideas and techniques as means, standard deviations, histograms, regressions, t-tests, correlations and analyses of variances.

Besides the statistics course, the Business students have a number of other courses in which computing plays a prominent role. Thus, *Introduction to Computing* uses the *Wordstar* [26] word processing package and the dBASE-II database package, *Introduction to Business* uses the *Lotus 1-2-3* [27] spreadsheet package, *Business Modelling* uses the *Supercalc* [28] spreadsheet package and, *Operations Research* uses the *Xpress-LP* [29] linear modelling package.

The students in Accountancy, Business and Economics also make use of various study guides available on the Olivetti PCs. Thus, the students have revision practice available in *Contemporary Management* [30], *Management Applications* [31] and *Economics* [32].

Professional bodies are learning the importance of graduates being competent in the use of computers. A recent report in the *Times Higher Educational Supplement* (14.8.87) commented that the Chartered Institute of Management Accountants were worried that, within the United Kingdom, accountancy graduates were not receiving enough computing education. We hope at Buckingham to redress this imbalance.

Biology students have an *Introduction to Computing* course in which they use the *BASIC* language to study various biological models.

They may optionally go on to take a *Computational Biology* course again based on the personal computer.

Other subject areas are becoming increasingly aware of the power and utility of the available personal computer. For example, the *English as a Foreign Language (EFL)* programme runs a word processing class as part of the introduction to technological English, whilst the French programme makes use of a *Computer Assisted Language Learning (CALL)* package on the Acorn Master.

Conclusion

The paper has shown how the advent of the personal computer has helped the undergraduate degree programme at the University of Buckingham. Personal computers are used in a number of courses and this trend will continue. Some thought is being given to a *Computer Literacy* course which would be available to any student in the University. Buckingham realises the importance of every graduate being *computer literate*. Suffice it to say, this course will be based around the personal computer.

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END USER COMPUTING — A CHALLENGE FOR UNIVERSITY ORGANIZATION

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1. Introduction

By means of this case study, concerning computer introduction in our own institution, we want to look into a number of questions of special interest in the context of the introduction and use of information technologies :

— The conditions for decentralized use of computer technology ;
— The social and organizational impacts of computer introduction ;
— The role and methods of training.

Being based on experiences and discussions on the subject of computer introduction as well as on a research on computer training, the case study is a practical approach to the key question whether the use of computers opens possibilities for less centralized decision making.

2. The Structure on the IFF

2.1. Goals and Tasks

The IFF [1] was founded in 1979 by initiative of the Austrian Ministry of Science and Research. Its creation met the interests of parts of the Austrian universities confronted with new problems, such as :

a) more contact with social prblems and therefore the need for corresponding new didactics ;

b) facilitati ; university access to realize equality of opportunities as an aim of social-democratic politics.

The basic idea of the IFF is to promote the universities' activities in the field of scientific adult education. The development of pedagogics matching the specific situation and experience of adults is its constant

[1] Interuniversitäres Forschungsinstitut für Fernstudien ; Research Institute for Distance Education.

concern. The IFF can be best described by its methodological and didactic innovative efforts in teaching and research, such as :

— social learning
— problem-oriented learning
— interdisciplinary learning and research
— combination of education and research

(HEINTEL, 1980 ; cf. also *Perspektiven* 1, 1980)

The specific objects and conceptions explain the particular organizational structures of the IFF (Fig. 1 : Structure of the IFF). They can hardly be compared with traditional university organization mainly oriented on the realization of regular studies and supplementary research. The IFF is largely independent in its administration and research activities. It is a relatively small university institution, employing not more than about 40 persons altogether, but highly diversified under at least three aspects : geographical, functional, and personal.

2.2. The Geographical Aspect

The IFF is a decentralized institution consisting of seven relatively autonomous units all over Austria and a head office in Klagenfurt (Carinthia) Its institutional form was chosen to guarantee proximity and cooperation with the universities, eight of which are members of the IFF and represented in its board.

The research departments and study centres are thus spread from the very east to literally the western border (Fig. 2 : Map of Austria with IFF units). In a small country such as Austria, distances do not seem to matter much, yet the time needed for transport, especially crossing the Alps, makes any meeting an effort cutting deeply into the disponibility of the participants for their work at home. In this situation, the wish for more efficient communication by new technologies seems natural enough.

2.3. The Functional Aspects

From the beginning, the IFF has been active in research as well as in education (cf. BUCHINGER et al., 1987). The permanent tasks in the field of education are :

- Implementation of the regular distance studies of German Federal Fernuniversität Hagen in Austria. Three of the departments are — at various degrees — involved in these study schemes ;

— Implementation of programmes of further education especially for teachers (didactics of different subjects, didactics of political education) developed by the institute.

Research activities concern, on the one hand, evaluation and improvement of these programmes and, on the other hand, the development of new programmes for further education. These programmes aim at new target groups as well as at new didactic conceptions, mostly taking up topics of acute social interest, for example :

— Health education
— Peace and ecology research and education
— Social conditions of technological development
— Role of education in the development of peripheral regions.

The different activities are neither clearly attributed to the various departments nor distributed equally among them. Therefore, each unit has its own priorities and its own specific character — from the (almost) pure study centre to the (almost) pure research centre.

2.4. The Personal Aspect

This multitude of activities, including the whole range of organizational tasks, is taken in charge by a relatively small staff. The main distinction among staff members is of course the distinction between scientific staff and administrative staff.

The diversification of activities means that hardly two persons in the whole institution have the same tasks and competences. The work of the scientists combines various management tasks and research activities with very different priorities.

3. The Process of Computer Introduction

3.1. The Setting of the Scene

The wish for the introduction of computer technology had been put forward for over a year by several persons and groups with various intensity and intentions. Several departments or even individuals had tried to get computers on their own. The task of finding a way through the vast and confusing hardware and software markets turned out to be too demanding for people confronted for the first time with new developments in computer technology — general experiences with data processing (e.g. with big university computer centres) were of practically no use when negotiating about personal computers. Besides, organizational requirements and effects as well as the need for training were not taken into account. The responsible ministry thus demanded a reasonable and consistent plan for computer introduction to grant the necessary budget.

3.2. The Conception of Computer Introduction

The plan for computer introduction is based on the idea that the transition into the "age of the computer" should be carried out step by step :

1. Simple personal computers for training and first practice which will finally be used mainly in education and study programmes.

2. Performant personal computers (workstations) for administrative and research work, together with MODEMs (cf. fig. 2).

3. Networks, first on a local level (LAN = Local Area Networks) with a gateway for future connection to public networks as offered by the Austrian Post and Telecommunication Authorities (WAN = Wide Area Network) (BAUMGARTNER, 1986, p. 6 ff.).

In the first stage, computer application is thus concentrated on local use and local requirements. The implementation of integrating technologies (i.e. communication by public services, use of public or university data bases, local area networks LAN) is postponed until the moment where the isolate PC can be considered as well integrated in the department's structure and the organizational complexity of new systems can be mastered by the staff. Only the individual use of university computers by telephone service (MODEM) is taken into account, but this application concerns exclusively individual research workers and has no effect on the department's or the institute's organization.

The conception of computer introduction is thus not based on technical feasibility, but on actual requirements. Therefore, each phase is variable : new requirements can be satisfied by improvement of the technical equipment, but the plan can also be stopped at each stage.

3.3. Expectations and Conflicts

The conception was, in its rough outlines, welcomed by most of the staff as a useful instrument to get computers immediately. However, the background of the wish for computers turned out to be extremely varied. Multiple different — and conflicting — expectations were associated with one and the same technical equipment, for instance :

— Implementation of courses in programming and of introductory computer courses in the framework of different curricula and research programmes. This priority is put forward mainly by the study centres.

— More efficient administration. This is a priority formulated by all the groups involved, yet with quite different intentions : while the scientific personnel have in mind the future extension of their activities, the secretaries hope to accomplish more efficiently their already extensive work load, and the government authorities welcome the possibility of important economies (e.g. jobs in administration, cost of publications).

— Statistics for social research (e.g. SPSS). In this case, the wish of individual scientists for a literally "personal" computer may be in contradiction with the idea of a "workstation" (cf. MEISSNER, 1985) integrated in a scheme of organizational development.

— Financial management and control, e.g. of research programmes. This point is stressed by the central administration, but equally by the ministry supervising the IFF. The possible conflict resides in the contradiction between the wish for improved supervision and control and the wish to safeguard autonomy.

— Telecommunication from data transfer to teleconferences. The head office considers computer technology as an instrument for improving communication between the departments and the head office in order to increase integration — or prevent disintegration. Most of the departments remain indifferent or even sceptical towards telecommunication, regarded more as a kind of "high-tech plaything" than as a useful instrument.

In general, the expectations could not be defined very clearly before computers were really available. The introduction of computer technology is a process where, with increasing practical experience, realistic requirements have to be developed out of exaggerated wishes and other new requirements turn up.

4. The Challenge of End User Computing

4.1. The Concept of End User Computing (EUC)

The basic idea of organizational development in the context of computer application is the effort to put into practice a viable concept of End User Computing.

The introduction of independent, highly performant workstations and the possibility to combine them on the local level (LAN) and to connect them by the use of public lines for data transfer creates completely new structures of information flow, communication, and decision making.

End User Computing is already technically possible and a realistic idea from the economic point of view, given the constantly falling prices of hardware. However, its consequences for organizational structures are hardly explored even by high-tech firms. The fact that IBM finances a 2 million $ research programme entitled "Management in the 90ies — New Responsibilities in a Modified Context" to find out more about these changes shows well enough the interest of the question (Fig. 3: Management in the 90ies).

4.2. New Competences versus Traditional Hierarchies

4.2.1. I/S Management

End User Computing is based on the idea that new information technologies transfer information and competences of decision making to the end users. Communication and exchange of information will be possible among them and with all other levels, making possible new forms of cooperation, such as team work, coaching, or job rotation (cf. BAUMGARTNER/MORITZ/WORLICZEK, 1986). Thus, the traditional role of management hierarchies functioning as information filters and canals is radically called into question, while end user computing requires specific management structures: the so-called information system (I/S) management (RUHSERT, 1986).

The role of the I/S management is to promote labour organization, information flow, and decision making based on information technologies, to guide line management in its new tasks, to plan the acquisition of hard- and software, its integration in the organization, and training.

4.2.2. Possible Changes in Labour Division

The shift of competences and the change of organizational structures start almost from the moment the computer is put to work.

Text processing, for instance, seems to be the most inconspicuous application of the computer : it is nothing but — so we think — a modernized form of typewriting. However, complex text processing software offers possibilities far beyond the tasks of the mere typist : footnotes, table of contents, registers, and bibliography can be created and managed while editing and formatting the text. Does this mean that fully trained secretaries can take over the whole task of creating the layout for e.g. a scientific publication, or that scientific workers edit their articles themselves ? It is obvious that usual forms of labour division will have to be discussed and modified.

There is a second level on which the changes brought about by text processing have to be considered. The more recent development of software for desktop publishing makes it possible for the administrative personnel to perform work processes formerly transfered to external publishers, typesetters and printing shops. By subsuming the more demanding and more qualified work under the same name of "typing", it becomes possible for the management to maximize economies — to the disadvantage of the secretaries.

4.2.3. The Master Users

The new function of the "master users" is another example for the radical change of organizational structures, entailed by the introduction of computer technology. The master users are responsible for data security and data protection, documentation and information, e.g. with regard to new software or the organization of hard disks and multi user systems, and they often provide technical assistance, too. In bigger firms and data processing centres, these new functions lead to the creation of new professions (e.g. operators). This implies that end user depend strongly on the availability of the computer experts and that the execution of work is frequently distuhbed by the necessity to wait for the master user in any case of trouble. Empirical studies reveal that interruptions and malfunctions play an important role in the low degree of acceptance of information technologies (MÜLLER-BÖLING, 1987).

In the case of the IFF, the master users are designed among the administrative staff — the end users. It is important to add that they start, at the beginning of computer implementation, from the same level as the rest of the personnel : as (almost) absolute beginners. Gradually, they should assume the responsibility for all organizational matters concerning the computer, acting as a link between the head office and their department, whereas external assistance is available for technical problems.

The idea of transferring the qualification and function of the master users to the end users is an experiment. Its results are as yet not wholly satisfying. The introduction of the concept of master user therefore means the creation of a completely new qualification. It causes fears as well as competition: the role of master user is perceived as a new level in hierarchy eventually concentrating information and power. On the other hand, the taking over of these new tasks was refused as supplementary work.

This resistance underlines the problems rigid organizations such as universities will meet inevitably when new qualifications and competences grow out of the application of new technologies. They are — at least in Austria — not reflected by corresponding rise in position and pay, the salary of administrative workers being strictly bound to school certificates. The fatal consequence of these traditional schemes could be that qualified administrative workers leave university for better paid jobs [2]. It seems important to stress this point, because the question of remuneration is often understimated as a factor of acceptance of new technologies.

The problems mentioned above are only a small part of the controversies in the context of computer introduction. Not all of the problems are raised directly by the presence of the computer, but originate in the organization structure of the IFF in particular and of universities in general.

The fact that these questions are brought up now as deriving from the computer shows that the new technology serves as a catalyst for organizational problems.

4.3. A Forum for Conflicts

For some years, sociological studies have already pointed out that, if different interests are to be considered and the conflicts inevitably arising from them are to be settled, it is necessary to create appropriate platforms.

Kubicek calls this the necessity of a "dialogue free of domination" (KUBICEK, 1979, p. 38 ff.), replacing the "technocratic solution". While, in the technocratic solution, a team of experts design a system, defining the interest acting for the persons concerned, the "discoursive" or "dialogic" solution gives the persons concerned the possiblity to put forward their interests themselves, either directly or by delegates.

The IFF has established internal democratic bodies where all groups of staff — professors, lecturers, and secretaries — are represented.

[2] This problem is somewhat similar to the difficulties universities have to keep experts highly demanded and well paid by industry, e.g. graduate engineers. However, academic personnel have many more possibilities of supplementary income (consulting etc.) to compensate the salaries granted by universities, than secretaries.

These bodies are effective platforms for formulating and settling conflicts of interests, even if it cannot be denied that the possiblities of communication and hence of forming a homogenous group of interest are far greater on the side of the academic personnel. However, these bodies are not officially recognized by the authorities. The gap between "official" and "inofficial" representation is, in itself, a source of conflicts.

Universities, just like any bureaucratic organization, do not dispose of the platforms needed for this dialogue. The road to discoursive solutions is barred unless major changes in university organization (modification of laws, dissolution of hierarchic structures) are made.

4.4. The Need for New Training Concepts

After what has been said about the competences of users in the framework of end user computing, it seems logical that training not only plays a very important role but has to be adapted to the new concept in its contents as well as in its methods (cf. PAYR, 1986).

Training must not be limited — as it is quite too often — to the application of one or more software packages for special uses e.g. text processing, mailing, or data input. This type of training transfers only the competence of executing efficiently the traditionally isolated activities to the office workers, reserving all decisions concerning the organization of computing to the management and to consultants, programmers etc.

Training for End User Computing, however, has to transfer knowledge traditionally concentrated in special departments to the users. The following example of data base management will illustrate the training concepts developed and tested in the framework of a research programme carried out by the IFF and put into practice — among others — in the institute itself [3].

4.4.1. Making Software Transparent

The use of dBase III, a data base management software equipped with a performant higher programming language, made it possible to put forward the question whether and to what degree office workers without special computing knowledge are able to solve practical data processing problems using standard software, and what forms of training can help them to perceive, understand, and, if necessary, modify the structure of the software (in cooperation with experts).

The development of data base structures according to the specific needs of the enterprise or institution serves as a practical experience for learning about organizational and social impacts of the computer. The knowledge of data base and programme structures gives a feeling of dominating the computer instead of being dominated by the machine.

[3] The research programme "Users Programming Data base Management" is carried out by a team of 3 scientists (Walter Kacirek, Wilhelm Linder, Sabine Payr) and coached by Peter Baumgartner (IFF/University of Klagenfurt). It is part of an international research programme entitled "Learning of Critical Computer Competences".

The vast empiric studies carried out by Müller-Böling (MÜLLER-BÖLING, 1986, p. 153—166) show that the restricted margin of decision, complicated handling, and the representation of data on the screen not relevant for the actual task, are important factors reducing acceptance. The users know better than any expert what sort of information they need. These are precisely the points where the courses can offer improvements.

Of course, the courses do not have the purpose to make fully trained programmers and system analyzers out of secretaries, but they should help users to:

a) define their standards for good programmes, and not to accept available software passively and without criticizing it. (In one of the institutes supervised by the research programme, the training made it possible for the them to formulate very specific software requirements for the creation of a data base of Austrian emigrants during fascism carried out by a professional programmer);

b) make them less dependent on experts and data processing centres. (Another institution is now able to manage its stock of about 5000 addresses itself, making important economies as compared to the previous contract with a computer centre: 300 000 — ÖS per year vs. 100 000. — ÖS once for the course and the hardware, with no need for additional personnel;

c) get a qualification highly superior to the handling of a specialized programme. These qualifications are better demanded on the labour market and make it possible to improve job position. This is especially important because the value of first education (school, university) is constantly diminished by the accelerated technological development;

d) acquire competences not limited to the handling of a machine (and thus only of small use), but including knowledge about the organizational impacts of the computer. The necessity of formalization and standardization of data structures, being thoroughly discussed and experienced is not perceived as a constraint imposed from outside and thus better accepted, also because users learn how to modify them if need should be.

At present, we are already able to say that the training scheme developed in the framework of the research programme is especially useful for the implementation of personal computers in small and medium-size enterprises as well as in decentralized institutions [4]. It could be interesting to add that the positive effects did not fully show in the case of the IFF itself. We suppose that there are mainly two reasons for this phenomenon:

1. The expectation of users' participation must not be exaggerated (cf. Müller-Böling's results: only less than half of the users really wish to participate) (MÜLLER-BÖLING, 1986, p. 156—157).

[4] At the time of this revised edition of the article, the research project mentioned above is terminated. A number of final reflections on this concept of computer training are summarized in PAYR/BAUMGARTNER, 1987.

2. The close connection between training and consulting calls for the authority of an external team of trainers.

4.5. The Technological Traps and Handicaps

The question of submission to or domination of the new technologies has to be asked not only on the level of individuals, but also for the whole institution. It is, basically, the question which principles and which social interests influence the technological development.

Mainframes and centralized data processing still prevail in larger institutions and enterprises, mainly out of the simple reason that automation there started before the age of performant personal computers. The age of the mainframes is sometimes compared with the beginning of industrialisation, when all machines of a factory were branched to the same power supply by complicated but not very efficient transmision (cf. BUSCH, 1986). Just as the central power plant was replaced by decentralized engines, central data processing could be substituted by End User Computing on the level of departments or even individual workers. Of course, this process could lead to radical changes of power structures in enterprises. Therefore transnational corporations try to hinder a possible democratizing influence of decentralized computer use promoted by the price revolution of hardware (cf. IBM's conservative price policy with high prices per software unit instead of licences for enterprises) (BOHNHORST, 1987).

Data communication software, for instance, was first developed and used to link terminals to a mainframe. The software adapted for personal computers still reflects centralized and hierarchic data processing structures to such degree that the very concept of "communication" appears as a euphemism : the partners have to take the roles of "masters" and "slaves", where the "master" is able to use the "slave's" computer as if it were his own.

There are as yet no experiences and no standard software packages corresponding to the new requirements of communication on an equal level. On the other hand, not all that is technically possible should be done : in the case of wide area networks (WAN), the question "What do we have to tell each other" must be asked before the question "how to tell it".

For the time being, the use of a public mailbox service by the different departments is preferable to the direct communication, last not least because of the facilities offered for their public relations activities (e.g. press releases by telex).

5. Conclusions

Although the introduction of computer technology at the IFF is a small project from the point of view of the hardware, its organizational and software aspects turn thus out to be all but negligible.

Resuming the case study, a series of general conditions can be formulated for democratic use of computer technology :

— New technologies do not have, in themselves, a decentralizing or democratizing effect. Indeed, the actual development of new software and hardware and the market-situation rather point to the opposite direction.

— The introduction of new technologies is a gradual process requiring a high degree of organizational flexibility and appropriate platforms for dialogue and conflict settlement.

— Personnel policy and labour organization have to be flexible enough to follow the changes in qualification, communication structures, and competences brought on by End User Computing.

— New concepts of training have to be developed, enabling users to handle not just a machine, but also its organizational and social impacts.

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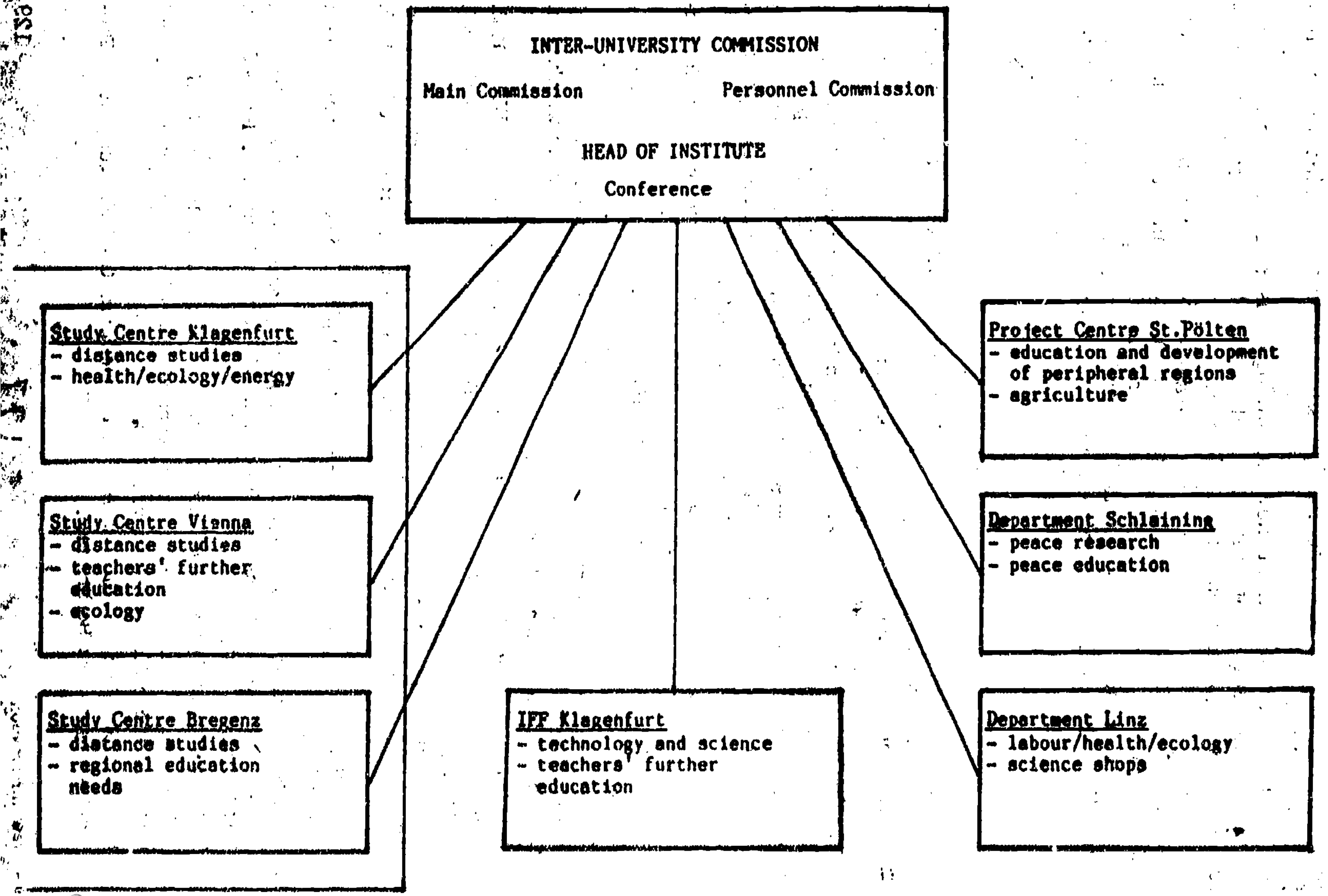

Fig. 1 : STRUCTURE of IFF

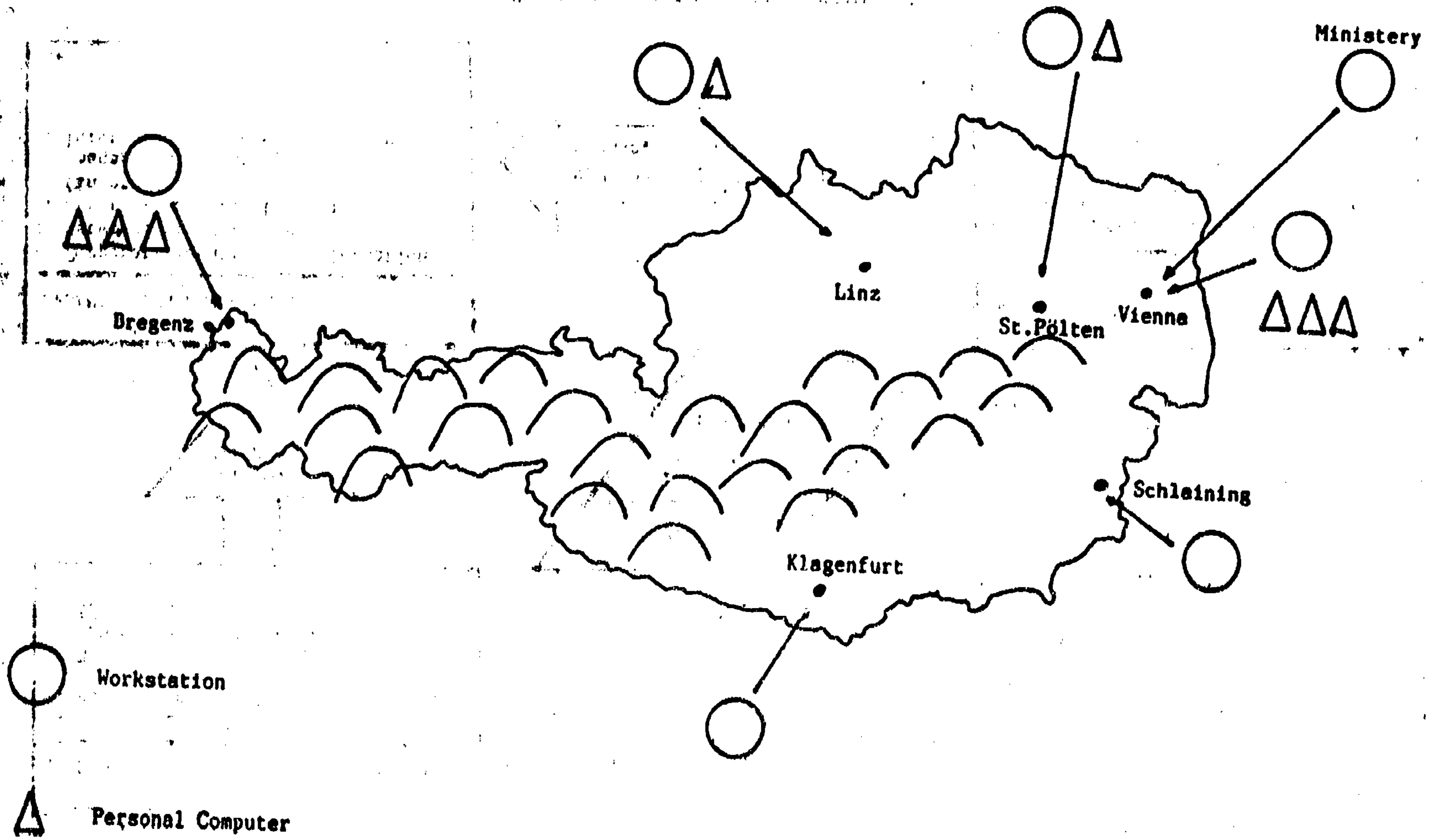

Fig. 2 : GEOGRAPHICAL DISTRIBUTION of IFF units and hardware equipment.

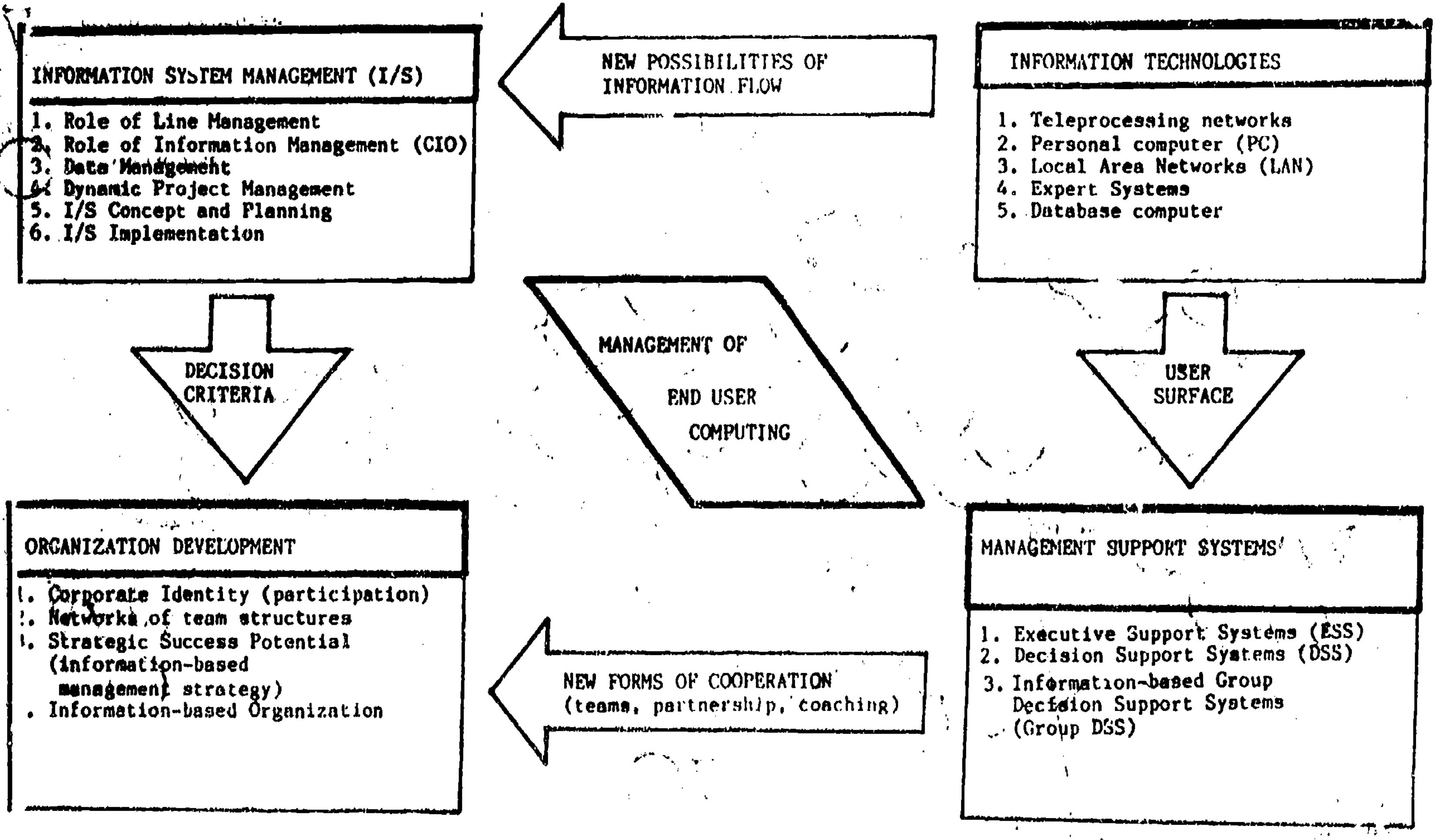

Fig. 3 : MANAGEMENT IN THE 90-ies
New Responsibilities in a Modified Context

THE INFLUENCE OF INFORMATICS AND THE USE OF COMPUTERS IN THE CONTENT AND METHODOLOGY OF HIGHER EDUCATION

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Basic Conditions Governing the Introduction of Informatics and the Use of Computers

The aims of the German Democratic Republic and the tasks facing it require "the guarantee of stable and dynamic economic and social development based on the most up-to-date achievements in science and technology" (1, p. 4). If the GDR wishes to take its place among the leading industrial nations of the world, it must continue the comprehensive intensification of the national economy. Through a strengthening of the interrelationship between science and production and the accelerated broad application of key technologies.

Given the high growth rate of microelectronics, the number of personal and office computers in use in the national economy had risen to 35,000 by the end of 1986. In the same period, the number of CAD/CAM work stations increased to 24,000. As there are now some 69,000 robots in use in the national economy, the automation rate of equipment and production has exceeded 50 per cent.

In the next 10 to 15 years this development should lead to a steadily increasing number of flexibly automated factories.

These achievements will be accomplished not only with the aid of working people but also for them, in so far as their working conditions and living standards will be improved. Closely connected with this evolution, is a continuous comprehensive process of qualification. Up to 86 per cent of all working people have successfully completed vocational training, and 1,7 million professional workers (20.5 per cent) are graduates of universities and colleges. "With a view to social requirements and the development of science up to the year 200 and beyond, levels of qualification are to be determined and the most effective ways of acquiring knowledge, realized" (1, p. 8). The GDR demands of its universities and other higher education establishments that they shape all their programmes: initial education, and further training, and their scientific, intellectual and cultural life in such ways that graduates can respond successively to the demands made on them by society throughout their lives. Thus, "the growing complexity of educational content, its mutual interweaving, the further development of interdisciplinary methods for working in the areas of microelectronics and of computer technology, of CAD/CAM, of more flexible automation, of biotechnology, as well of further key and high technologies" are leading to "changes in the spectrum of fields of study". "Scientific methods of working and training under conditions of production must be better shaped and more mutually interrelated" (1, p. 8).

With these guidelines in mind, this article will discuss the influence of informatics and the application of computers on initial and further tertiary education in the GDR and on the shaping of content and methodology.

Changes in the Content of the Initial and Further Education Programmes Offered by Universities

Modern informatics and the wide-spread use of computers have had far-reaching effects on initial and further education in the universities and colleges of the GDR.

With the *expansion of informatics as a science* dealing with the systematic processing of information, with basic processes of automated acquisition, including the processing, storing, retrieving, and transferring of information, decisive changes in the basic fields of study (Grundstudienrichtungen) have been brought about. In addition, the integration of informatics into existing basic fields of study and postgraduate study is being stimulated.

Thus the new *basic field of study* entitled *informatics* was created in order to train specialists in informatics. At the same time, all students will eventually receive *continuous training in informatics within the framework of their basic fields of study,* particularly in the case of mathematics and natural sciences, technology, economics, and agriculture. Students in medicine and in dentistry will begin to receive basic training in informatics during the 1987—1988 academic year.

To take the *basic field of mathematics* as an example, all students are given a foundation course in informatics during their 1st, 2nd, and 3rd semesters. This course includes an introduction to digital information processing including practical work computers, the basic terminology of mathematics, the bases of formal logic, the basic concepts of the theories of automata and of algorithms, and the learning of programming and of programming languages through practical exercises.

Those students who show special interest, are enabled to specialise in informatics from the 3rd to the 10th and final semester. Their in-depth training includes numerical mathematics, logic, the algebraic bases of information processing, programming language and computer algebra. These students also undertake practical work. A four-year distance education course in information processing is available for those professionally interested in it.

One of the best ways to grasp how training in informatics is affecting the whole restructuring of higher education in the GDR is to examine closely the role of training in informatics in the *basic course in economics* (Cf. 2, p. 198 ff. and 3, p. 38 ff).

1. The intention now is to introduce *user-oriented training* in informatics for all students. The courses in question are designed to correspond to the needs of graduate economists, particularly to cover those aspects of informatics which are necessary for the elaboration of computer-based systems for applied economics. They will cover hardware, software, and organizational aspects.

2. At the same time, *differentiated training* in informatics is necessary. Therefore, a three-stage programme in informatics is being developed for economists.

During the final stage, all students will receive a computer-based foundation course in informatics, the aim of which is to transmit fundamental theoretical knowledge on informatics, to develop computational skills for the dialogue between man and machine, and to give instruction on how to work out programmes with a small range of functions. Computer-based practical work in laboratories will also be carried out.

For some 15 per cent of the students who will be enrolled in different economics disciplines, a more in-depth training in informatics will be provided as a *second stage*. Students will be expected to learn to develop, to implement, and to use consumer software with limited ranges of function intended for desk information processing technology. A concern of this programme will be the active role of students and future graduates in the introduction and the processing of computer-aided solutions (CAD, CAM, CAP).

Finally, a *third stage* of training is to begin with informatics, i.e. the training of specialists in economic informatics. These specialists will be trained to undertake processing using complex computer-based systems, requiring demanding software. Included in this stage are the analysis, the modelling and the simulation of economic processes. Students will be expected to contribute to the processing and the realization of complete CAD/CAM systems.

3. A characteristic of training in informatics is its *interdisciplinary nature*. Thus new interrelationships have arisen between sciences and their disciplines (such as mathematics, cybernetics, general statistics, and the technical disciplines, for example microelectronics) and informatics itself. These above—mentioned disciplines form the theoretical and technological bases of informatics. For its part, informatics is largely integrated into the disciplines concerned with economics. Particularly close relationships exist with the management sciences, the industrial sciences (Betriebswirtschaft), accountancy and statistics, national macro-economics, and foreign trade.

The *basic fields in the natural sciences* are being reshaped in an analogous fashion. Here we should like to point out that microcomputers have been used successfully for many years in laboratory practical work in physics and in chemistry (4, p. 250 and 5, p. 239). The computers that have been used up until now are going to be replaced by more powerful ones. Since both of these basic fields of study are going to be oriented, experimental questions concerning the flexible coupling of computers in experiments are very important for the direction and control of experiments. Therefore, students must have knowledge of what a computer is capable of doing with regard to the measuring system and of the interrelationship between the measuring process and the experiment itself.

Students begin their training in programming languages by using BASIC to work out measuring data processing programs and to represent the results. Here the question is also one of integrating practical work with computers into the basic course of study as early as possible in order to be able to deal profoundly with questions concerning the link between profession-related studies and experimental automation. The organization of student work groups which solve programs independently has proved to be very successful. These groups interpret programs for their felow-students who in turn make use of them.

Informatics and computer use are important subjects in the *further education* programmes offered to teaching staff members and to those working in practical spheres of economics who are able to participate over several semesters in postgraduate studies or in short courses.

A representative example of such a postgraduate programme is *computer-based plant automation* (6, p. 273). Since a fundamental change in automation technology took place with the transition to microcomputer-based regulators and storage programming connected with hierarchically structured process direction systems for the automation of whole production complexes, the demand for specially trained engineers has grown rapidly. Such engineers must be specialized in computer-based automation.

Because of the complexity of the problems confronting the GDR, post-graduate studies can correspond to such newly developed scientific and technological demands as in the case of mechanical engineering, one of the major supporting branches of industry. The two-year postgraduate course (organized as distance education) enables participants to select microcomputer-based automation for a given sphere of work, to programme, and to use it. The practical work related to theoretical further training is carried out at computer terminals in the university or in the factories of industrial partners. A final dissertation the subject of which is of equal importance to the university and to the firm, is written and defended. The additional vocational title of "engineer (Fachingenieur) for automation technology" is awarded to participants. Considerable emphasis is also placed on the *further education of management personnel in the fields of economics* (cf. 7, p. 210). It is always a matter of importance to familiarize managers with the very latest developments in management science and to train them to use the latest management techniques. Acquisition of this additional qualification generally takes the form of 5-week courses for company directors at Institutes for Socialist Economic Management. The use of mathematical and economics-inspired methods and of computer technology in management are integrated into the course. A complex management exercise, in which computing dialogue is used to support decision-making preparation, marks the high-point.

At present, *special courses on informatics* have been made available within the framework of cyclical further education, *to specialist teachers of mathematics and physics* who are involved in the teaching of optional courses in the ninth and tenth grades of the General Polytechnic Secondary Schools of the GDR and in optional courses for the A-level (Abitur) level grades (classes 11th and 12th grades). These courses include an introduction to the fundamental problems of informatics, including algorithmic structures and solutions to problems. The courses also require the learning of suitable programming languages and the acquisition of micro-computer skills.

It is now well understood that the General Polytechnic Secondary Schools should include informatics and computer operation as part of their general education programmes and as a prerequisite for university and college education. Specialist teachers in these areas require further training. A suitable *technological basis* in higher education must be provided for the initial and further training of the teachers of such subjects. The equipment needed to provide this training should include decentralized personal desk computers of the PC 1715 type and BC A7100 office computers (belonging to the 8-and 16-bit class). Another model of courses, which should be made available is the central macro-computer (ESER).

Didactic and Methodological Changes in Tertiary Level Initial and Further Education

With the wide-spread introduction of informatics and of dependent computer-based working methods among full-time and distance students and those enrolled in further education courses which are characterized by the effective man-machine dialogue, certain consequences have arisen for the reshaping of the university pedagogical process. Some of these consequences will be discussed here, in agreement with other authors (8, p. 26lf and 9, p. viff.).

1. Our assumption is that the elements of work of future scientists and engineers will not undergo major change up to the year 2000 with regard to expected scientific and technological progress. What future scientists will require is *knowledge based on theories which are applicable to praxis.*

More and more the scientist as well as the engineer require an "internal, imaginative model for their specific work as the basis for their orientation and for the execution of their work". This model should include a clearly defined sequence of steps relevant to the problem or task in which a structured series of mental operations is involved. These steps should be consciously made and well understood, developed, and strengthened. The real processes of nature, technology, society, and thinking should be deeply and methodologically penetrated if they are to be successfully and effectively employed in connection with informatics and computers. An engineer, who cannot recognize a technical or a technological problem and break it down into its constituent components, who cannot think competently in abstract and concrete terms, who is not sufficiently capable of mastering the mental processes of induction, deduction, and logical conclusion will not be able to work successfully with computers.

2. Only *in connection with scientific or technical and technological content* is it feasible to train students *to develop ways of working based on computers.* An "ability in itself" is not possible. Thus, the point at which this particular aptitude is identified should come as early as possible in the educational cycle. General education at the level of the General Polytechnic Secondary School should include information processing by means of micro-computers. Informatics and computer operation as they relate to specific fields of study should be introduced at the beginning of the period of study.

3. As much as the *growing complexity of the problems and tasks* facing us correspond to real processes, they *can be overcome by using* the full potential of applied *computer-based methods* of working.

Doing so fully corresponds to growing social demands and favours the transmission of such results to typically complex work processes. The complexity of problems and tasks increases from the phase of initial to the phase of further education.

4. The types of *methodical and methodological training* which we rightly stress as being characteristic of our higher education system, and which increases the flexibility of graduates, is subject to significant *expansion through the teaching of* students to work using *computer-aided methods* based on informatics. The principal aim of this training is to enable students — future scientists and engineers —, to decide how to combine individual creative work with the automated recording, processing, and storing of informations on computers, as well as how to relate them to one another. Thus more scope for creative work can be made available whilst routine work can be gradually reduced and man hours saved.

5. Through the use of computer-based methods adapted to one's work places, it is possible, depending upon the differing abilities of students, to guarantee them the necessary personal scope *to further develop their individuality* and to promote their creativity. They themselves can determine the style and the rate at which they work. Such forms of individual work, should however, be combined with collective co-operation.

6. It is often necessary in initial education to simulate a real process of nature, society, and thought on the basis of a mathematical model, and to process it using computer technology. We increasingly prefer *to place our students directly into the process of the social scientific and*

technological revolution. Thus they are involved in research. The same also happens in the field of informatics and computer technology. Frequently postgraduate students in further education contribute to the scientific and technological revolution through their theses and their research as well as through their specialist subject-related results much of which has involved the use of informatics and computer technology. Thus the pedagogical study process in initial and further education becomes a genuine work process.

7. Even the *didactic forms of realization* in the teaching and studying process undergo certain *changes* in the course of initial and further education when computers are involved. Traditional forms of realization, such as lectures and seminars, are enriched by work forms with a marked training character, for example computer-based case studies and projects (Planspiele), and such practical sessions and complex computer-management exercises as are relevant to decision-making. Students work in computer cabinets, at CAD/CAM stations, and with management computers which are equipped with corresponding hardware and software.

Personal and office computers which are initially used as teaching aids and are often complemented with graphic apparatus and printers become means whereby students may make real contributions to the scientific work process.

8. Using the psychological knowledge that *motivational and cognitive processes form a unit,* the question becomes one of *motivating full-time and further education students* to work with informatics and computers. This task can be accomplished most efficiently through the solution of problems which are socially, scientifically and technologically significant. It is equally important that there be signifiant motivation for permanent further education with regard to informatics and computer technology.

9. The fact that *teaching staff members can provide a constant objective assessment* of the level of activity of their full-time and further education students when the latter make use of computers to complete their scientific and technological work also needs to be stressed.

10. In order to increase the effectiveness of the use of office computers, an *"information headquarters for office computer programmes" has been set up* to avoid duplication of efforts while at the same time to encourage rapid development.

In order to guarantee a high and effective level in the didactic and methodological training offered in informatics and computer use in initial and further education training programmes at the tertiary level, the *university pedagogical qualification of all the young scientists and academics* in the GDR has been expanded by means of a one-year postgraduate course entailing the above-mentioned ten points. It has thus been possibile to create preconditions for the accelerated integration of informatics and computer-based methods of working into initial and further education in every field of study.

International Co-operation

The GDR welcomes the fact that the European Network on Higher Education set up by Unesco has received an initial impetus in terms of content and that experience gained at the EARDHE Congress has stimulated co-operation among certain countries and universities wishing to work together in the fields of informatics and computer operation linked to university pedagogics. In the same spirit, coordination with the International Network of Centres for Computer Application (INCCA), also initiated by Unesco, must be ensured.

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INFORMATICS IN HIGHER EDUCATION IN SWITZERLAND*

The aim of this report is to survey the progress made in the introduction of informatics in higher education institutions in Switzerland.

The federal structure of Switzerland, which has a particular influence on education, is no doubt the reason that evolution in the field of informatics has been greatly marked by personal initiatives. In general and in comparison with the education systems of other countries, most of which have long been investing heavily both in terms of finance and of personnel in informatics, the record of the Swiss education system in this respect is uneven and has been subject to delay. As needs are obviously not the same at all levels, the various degrees of implementation are not necessarily comparable.

If one considers specific training sectors, one will note that various aspects of informatics are thoroughly implemented at least in some of the cantons. Although there are still important regional differences and numerous gaps to bridge, one can no longer speak of a considerable lag in any of the sectors of training. The task nowadays is to achieve a comparatively equal level everywhere, to reinforce the existing situation, and, wherever necessary and advisable, to adapt rapidly to the new developments which seem to be appearing and advancing at the speed of light. Thus, for the future, it will be particularly important to step up the intercantonal and Swiss coordination which, one has to admit, already works well.

Informatics is being or has already been introduced into a number of domains in compulsory schooling, especially at the level of higher education. The rate of evolution has not been equal. In particular, at the cantonal level it was first necessary to develop guidelines and common objectives.

Although the guidelines and objectives in question were approved by the CDIP in October 1986, they had already been adopted by several cantons. In order to achieve a certain harmony in the domains both of hardware and of software, it is now necessary to devise common criteria for factum acquisition.

In the field of basic professional training, development is under way. Alterations of training guidelines have also sped up the integration of informatics in the compulsory study courses of all the professions

* Excerpt from a Report on Informatics in Education in Switzerland issued by the Federal Ministry for Education and Science.

involved. In 1986, basic objectives had already been enacted for 121 professions requiring a period of apprenticeship, thus covering 56 per cent of all apprenticeships. This evolution is going to be enhanced, while in parallel the further training of teachers will be intensified. The setting up of a Swiss documentation and research centre for professional education, one which could prove to be a valuable support for the domain of informatics itself, is an objective for the future. Informatics is part and parcel of the educational programmes of the higher institutes of technology (ETS's), of the higher education institutions for economics and administration, and of other specialized schools.

1. The Origins of Informatics in Switzerland

Swiss higher education entered the age of informatics in the 1950's in a very promising way. At that time, the Zürich Federal Institute of Technology (EPFZ) became the owner of one of the first computers to function in a higher education institution in Europe.

A decade later, the growing needs of research in higher education institutions in the field of computer sciences and the rapidly increasing demands for services of a mathematical nature resulted in the setting up of university computer centres. Between 1958 and 1962, adequate centres were opened at the two Federal Institutes of Technology and in most of the cantonal universities.

The setting up of university computer centres was followed by the creation of specialized informatics institutes. Since then, informatics has become an autonomous science with its own corpus of knowledge and problems which collectively exceed the limits of the various basic areas of instruction in this field and call for an appropriate institutional form. In 1967, a section of computer sciences was set up at the Zürich EPF.

Three years later, the Institute of Electronic Information Treatment was founded at the University of Zürich, while in 1976, the University Informatics Centre was set up in Geneva. In situations in which the size of the university, or the subjects traditionally emphasized have precluded the establishment of autonomous informatics institutes, isolated informatics chairs have been created. The full professors of these chairs have had to create specific infrastructures from the bottom up as well as assuming public relations tasks.

At this beginning stage, research proper was only possible within certain limits, a situation also holding true in the cases of the larger institutes.

As of the beginning of the 1980's, all the Swiss higher education institutions, with the exception of the University of Basel, offer basic training in informatics. Both at Gneva and at Zürich, as well as at the two Federal Institutes of Technology, one can choose informatics as a major course of study. Thus, informatics as a scientific subject and auxiliary science has acquired a solid basis in Switzerland, but with a delay of ten years relative to the international scene.

2. The Present Situation

2.1. Training

Between the 1980—1981 and the 1984—1985 academic years, the number of students in Swiss higher education institutions having chosen informatics as their major object increased radically. Their number increased more than 50%, reaching 1800 units, between the 1983—1984 and the 1984—1985 academic years. During this same five-year period, the number of chairs more-or-less doubled, even though the expansion of the teaching staff as a whole was less than half of that. At the end of this period, there were fewer than thirty full-time teachers available for teaching informatics. At the same time, the number of auxiliary staff membres who could assume certain pedagogical tasks was greately restricted. No other university discipline has registered such a high growth rate in these last years and has been so characterized by admission and training conditions that have deteriorated so severely.

Because stimulation and suggestions from outside were lacking during an earlier planning phase, potential users underestimated for a long time the need for engineers specialized in informatics. But there was also the respective influence of an internal factor within the higher education institutions: the new disciplines have had difficulties in establishing themselves when confronted with traditional courses of study which defend their established positions. The Swiss higher education institutions were overwhelmed by the dynamism of this new rapidly developing university subject. All higher education institutions have been affected, moreover, in addition to the students who have chosen informatics as their major course of study, an ever growing number of students are taking up informatics as secondary courses of study or would like to receive a certain amount of basic training in this discipline.

Except at the University of Basel, one can study informatics as a major course of study in all the Swiss universities. However, a distinction is made between studies in general informatics as applied to mathematics and to technical sciences and the cycle of studies in informatics as applied to economics and management.

The goal of studies in informatics per se is the training of university teachers who are able to pursue the development of informatics and its applications to new specialized domains and at the same time to enrich their knowledge of the automatic processing of information. Today this goal is compromised because of staff shortages. The lack of personnel not only leads to deficiencies in the training of students, it can even stop or delay the indispensible development of informatics as a secondary discipline and as an auxiliary science. Today, nevertheless, one can choose informatics as a secondary branch of study in every higher education institution. However, the existing possibilities for combining it with various main disciplines are still far from being satisfactory. Indeed, the particularly interdisciplinary character of informatics, its vast field of application, and the fact that the methods and means used by this new discipline influence, to a decisive extent, the ways of thinking and working in a great number of fields of knowledge, call for a reform of education. In numerous specialized disciplines, other than the basic disciplines of informatics, in medicine, in law, in history, in archeology, and in linguistics, for instance, this essential adaptation of study curricula has still not been accomplished. Moreover, the basic training offered in informatics in most higher education institutions is not yet satisfactory, even though since the autumn term 1985 it exists everywhere. And yet, only one third of the 15,000 students who began their higher education studies in the winter term of 1984—1985 have received basic training in informatics. The latter should be made compulsory for the majority of students and branches of studies, the most important task being the acquisition of a minimum knowledge of the structure, the way of functioning, and the applications of the computer in the discipline that is being studied as well as an initiation to systematic programming.

Thus, the fact that additional efforts in the areas of retraining and continuing education in informatics should be made in parallel with priority efforts directed at basic training in informatics itself and in its application to other principal branches should surprise no one. Very few adequate continuing education programmes are available. In this respect, the first persons affected are not only the potential users of the services offered by the higher education institutions but also the academic staffs of these establishments. In numerous universities, the various collaborators do not have the required knowledge which would enable them to make judicious and purposeful use of the data processing means already existing in their specialities.

2.2. Research

Since the beginning of computer science the centre of gravity of research in the subject at an international scale has moved from the higher education institutions to the laboratoires of the manufacturers who are developing computers intended to be sold in large quantities. The intense research activity being undertaken by the computer industry does not, however, exempt the Swiss higher education institutions from the duty of doing research themselves, quite on the contrary. To begin with, industrial research, which aims primarily at the development of products, needs to be complemented by research in the fundamental sciences. There also independent research activity tends to reduce the already very strong Swiss dependence on knowledge and products coming from abroad and offers Swiss enterprises the chance to collaborate with universities throughout the country. Finally, if teaching is to be successful, it must be based largely on the independent research undertaken by the teacher. In a field of knowledge like informatics, in which developments occur with great rapidity, too great a distance from the research field signifies a delay in the curriculum when measured against international standards of development. Despite the evident importance of university research in informatics, relative to the economic and university environments, the volume of research which is being currently untertaken is totally insufficient. At present, the two Federal Institutes of Technology (EPF) and the University of Geneva are the only institutions which are devoting themselves to sustained research. One has only to analyse the work under way in Switzerlan in order to realize that, in comparison with the situation in other countries, Swiss researchers limit themselves to cover certain research sectors. Aside from research in informatics itself, the situation with regard to the use of informatics as a research tool and as a means for supporting research in other disciplines requires improvement. At present simulation based on informatics is the third pillar of research along with theory and traditional experimentation. Indeed, informatics permits a broadening of the experimental classical method in almost all disciplines. However, many researchers are still insufficiently aquainted with methods based on informatics: research projects of this kind are relatively rare in the Swiss higher education institutions.

That this situation is unsatisfactory is obvious, the staff shortage requires a concentration of forces. A university researcher is first and foremost a teacher. The difficult tasks of teaching as well as that of supervising of students and of introducing the new discipline — a particularly essential activity — all of these are accomplished at the expense of wide ranging major research programmes. In addition to the shortage of staff there are also deficiencies in the research infrastructures.

Not long ago, the Swiss universities lacked a high performance computer, and today they are faced with the need for a "super-computer" of the next generation.

In the past, Swiss research in informatics made some very advanced contributions. The Zürich Federal Institute of Technology (EPFZ) made major contributions to the development of programming languages (ALGOL and PASCAL).

Nevertheless, it seems doubtful today that specialized universities of Switzerland would be able to carry out fruitful research activities at the international level.

This situation will only change for the better when the current phase of educational restructuring produces a degree of structural stability.

2.3. Services Offered — Infrastructures

The computer centres, equipped with medium capacity computers, of which Swiss higher education institutions dispose at the present moment, are generally sufficient to meet the demands placed on them. The existing computers correspond to present levels of development and are adapted to the sizes of the different universities. However, a goodly number of the systems are having difficulties in adapting to the ever increasing tendency in favour of the decentralization of services offered by the computer. This development comes as a consequence of the new technological possibilities and meets the requirements both of teaching and of the rationalization of tasks. The man-machine relationship is shifting more and more in favour of man and doing so both in a concrete, and a figurative sense. The highly centralized computer centre has lost its monopoly and has become the kernel of a vast and highly efficient university network. Such a network offers both important services in data treatment and storage capacities in data banks (high performance computers have been developed for such banks) and special functions requiring numerous entrance and exit units (peripheral units with terminals and printers).

The services and the extremely varied categories of users are linked to a network which, once it is completed, will include almost all the domains of higher education. Tasks of small and medium scale are accomplished by personal computers placed at workstations. For the outlining of procedures and the accomplishment of on-line work of larger scale the university institutes which are close to informatics make additional use of small computers. Thus, each and every individual will have directly at his disposal, at his working place, an ever increasing number of processing functions and services. In a working environment adapted to his specific type of activity, he can conduct a dialogue with the computer in the simplest of ways. In addition to informatics, students who do most of their exercises and practical work assignments with the assistance of small personal computers, students and researchers from other specialized domains also benefit from this progress, particularly the interdisciplinary teams working in the areas of advanced teaching and research. Members of a team, who are often placed in different buildings, are in serious need of a means to communicate. Therefore, a university informatics network enables the establishment of direct communication among the collaborators in a given project (dialogue or "electronic mail") and access for the needs of the project to intermediary or final results stored in the common data bank.

Thus, the traditional organization of a computer centre should develop into a data processing service capable of anchoring a decentralized system as well as of counselling a heterogeneous group of users linked to it. Such a service should also ensure links to interuniversity, national, and international networks. Although at present most higher education institutions have only taken the first steps towards the organization of the sort of large university network as the one previously described, a serious shortage of specialists able to plan such systems, to make use of the software and hardware necessary for the storing of data, and to advise and to help the users of the former, is evident everywhere.

Another need of the higher education institutions which is far from being satisfied is that for microprocessor-based personal and collective computers, permitting both the direct and the autonomous processing of data and texts and linkages with more powerful computers.

2.4. Interuniversity Collaboration—Coordination

The importance of informatics for all or for most of domains of education is so great that no higher education institution would consider not making its own efforts so far as teaching in the field and offering services is concerned. Thus, coordination of efforts does not mean the concentration of training in informatics in certain universities but collaboration and distribution of tasks so as to obtain a maximum benefit from the staff and the material means at their disposal. From this point of view, the existing collaboration and the present structure of coordination may be considered to be good. Indeed, no university in Switzerland has isolated itself, so far as informatics is concerned, or has refused to cooperate in this domain. Particularly close collaboration exists, of course, between the University of Zürich and of Lausanne and the Federal Institutes of Technology (EPF) in both towns. The same is true of the two federal institutes of technology. At the regional level, one should make particular mention of the 3-rd cycle programme in informatics, organized by the French-speaking cantons, which constitutes one of the strong points of the coordination initiated by the Conference of Universities of the French-speaking cantons created in 1968. The courses and seminars offered to doctoral candidates and university researchers coming from a wide variety of fields has stimulated great interest. At the national level, the collaboration of the higher education institutions is furthered by the university planning commission, as well as by the informatics commission of the Swiss University Conference (CICUS). The first mentioned of the two commissions ensures the availability and the exchange of information on the conception, the available means, and the development perspectives of higher education institutions within the framework of the federal aid offered to the universities. Its activities in this context are also assisted by CICUS which, from its side, formulates suggestions concerning possible areas of collaboration and also gives its opinion on technical problems in connection with federal grants for informatics, this by virtue of the mandate conferred on it by the Swiss University Conference (CUS).

3. Evolution in the Future

Switzerland is beset by a severe shortage of engineers proficient in the present peak technologies. In this respect, informatics, as we have tried to show, raises a special problem. In the last years, the Swiss higher education institutions have certainly tried hard to develop informatics and to adapt the technical sciences to contemporary requirements. But the measures taken were taken too late, with regard to international developments and have not yet enabled the Swiss institutions to fully catch up. Considering the tremendous effort of the other industrialized nations, the gap may even get wider, particularly in the domain of research. This is why the Confederation and the cantons have taken steps to cater to the future needs of the country by training engineers and by developing research and training in informatics.

3.1. The Commitment of the Confederation

In order to accomplish its tasks, the Confederation has at its disposal a number of resources and means of action : with its regular budget it finances the two EPF (1985 : 613 million francs including subventions for their affiliates) ; it grants financial support to the university cantons according to the 1968 federal law on support to the universities (1985 : 237 million francs for basic financial grants and 67 million francs, for financial grants for investments) ; and by means of financial grants and other contributions it supports research in higher education institutions and in other non-profit research institutes. Other important funding channels also exist like the Swiss National Fund for Scientific Research (1985 : 169 million francs) and the Commission for the Furthering of Scientific Research, of the Federal Department of Public Economy (1985 : 19 million francs). Moreover, the federal law of 1983 on research (art. 16) permits the government to assume responsibility for some of the basic funding of certain research institutions, the first one benefitting being the Swiss Electronic and Microtechnique Centre of Neuchâtel (1985 : 10 million francs). Finally, in view of the law on vocational training, the Conference grants financial support to the higher technical schools (ETS) (1985 : 35 million francs). Already today a part of these resources are spent on the development of informatics.

But these means of action and resources have not been sufficient for doing away with the bottlenecks and the deficiencies described above. Since then, during the summer session of 1986, the federal Chambers adopted special measures to be taken in favour of informatics and engineering and approved credits amounting to 207 million francs (150 million to be administered at the federal level and 57 million to be allotted to the cantons).

By the pursuit of these measures, the Confederation is determined to contribute to overcoming the present difficulties in the informatics sciences and engineering. The special measures have been conceived of as a one-time shot intended to provide a necessary stimulus. The first goal of these measures is to cover the needs of the federal institutes of technology, and then to help in the realization of projects of a national interest. The latter include the efforts of the cantons to develop informatics in their higher education institutions and their advanced-level schools. In this resepct, the Confederation only offers partial financing, the amount being dependent on the matching grants offered by the cantons requesting aid.

— At the heart of these special measures is the financing of the employment of part time teaching personnel. Although such a measure will improve teaching conditions, the number of students will continue to increase. It will ease the task of professors and other members of the teaching staff who will then be able to concentrate more on research and on ensuring the future reserve of teaching staff members by the provision of further training possibilities in Switzerland and abroad. A second crucial aspect of these special measures concerns the work stations and the employment possibilities necessary for training in informatics and for the use of informatics as an auxiliary discipline in the other university domains. In this connection, the cantons will be given financial support only for the acquisition of the equipment necessary for training in informatics proper. Two other measures need to be taken with regard to the strengthening of the research infrastructure at the national level: acquisition of a supercomputer capable of bridging the gap in comparison with what is being done in other countries, the lack of which could have serious consequences for future research projects, and the elaboration of a national network capable both of ensuring the transmission of data among the different higher education institutions and of connecting our national network to those of other countries.

3.2. The Commitment of the Cantons

Over the last years, the cantonal higher education institutions have increased their efforts with regard to the development of informatics. At the present time it is possible to study informatics as a principal or a secondary discipline in each of the Swiss higher education institutions. It took only a few years to develop basic and introductory courses in informatics as parts of the core curricula. In order to provide for the need to catch up the various university organs have stressed the importance of informatics as a scientific discipline and an auxiliary science. The hope was that by the end of 1987, it would be possible to create 26 new chairs and a great number of posts for mid-level personnel. In additon, various cantons hape created additional posts or have raised loans for the acquisition of equipment so as to overcome the most serious difficulties and shortages with regard both to personnel and to equipment and to improve both employment and working conditions that are currently unbearable.

However, the cantons have realized that even these additional efforts are not sufficient to improve the situation decisively. In a letter dated September 15, 1985 addressed to the Head of the Federal Department of the Interior, the Swiss University Conference (CIS) declared itself, without any restrictions, in favour of the special measures to be taken by the Confederation.

The same letter clearly states that in this emergency situation the eight university cantons are ready to offer special services and along with the Confederation to further the development of informatics is Swiss higher education institutions.

This declaration of intention of the eight university cantons is a guarantee that the special measures which were conceived as stimuli will not vanish like smoke in the air, but on the contrary, will give rise, at the cantonal level, to additional measures and will be continued, not only in the strict university domain but also at the lower levels of schooling as well as in the tertiary non-university sector. Here too, in the last few years, the cantons have clearly manifested their firm intention to further the development of informatics. In this respect, the current increase of training possibilities in informatics within the higher level secondary schools is playing a decisive role. In the 1990's students who enter higher education institutions will have a better knowledge of informatics than is the case today.

4. Efforts in Other Domains

Within this context, one cannot obviously offer a complete overview of all the efforts which are being made in the furtherance of informatics beyond the traditional domains of training. We are going to randomly select some of these efforts which, we are convinced, are exerting, at least indirectly, a strong influence on training in informatics. Mention is also made of private initiatives which are being taken in the domain of training and further training.

It seems appropiate to begin by mentioning the support which the Swiss National Fund (FNS) is giving to research projects. It manifests itself primarily via the general framework of encouragement and to a lesser extent through the normal operation of the national research programmes (PNR). The technical sciences and informatics occupy an important place within these national programmes; for instance in PNR 7, "Problems of raw materials and other materials", in PNR 13, "Micro-electronics and opto-electronics", in the PNR 18, "Bio-chemical techniques", in PNR 19, "Materials for the requirements of tomorrow" and finally, in PNR 23, "Uses of artificial intelligence, especially in robotics". In addition, they have obtained the place they deserve in the priority order adopted by the allotment plan of the FNS. The corresponding credits increased from 2,9 million francs in 1984 to 10 million francs in 1987. In 1986, the technical sciences and informatics received the equivalent of 13% of the resources allotted to the exact, natural, and technical sciences, and this proportion rose to more than 16% in 1987. According to the opinion o fthe FNS, it is desirable to continue to strengthen these two domains during the next financial granting period to run from 1988 to 1991. Within this context, it is appropriate to mention that the fundamental sciences like mathematics, physics, and chemistry also play an important role.

During these last years, informatics has acquired increased importance in the general conception adopted by the Federal Commission for the Furthering of Scientific Research (CERS). If the extent of this encouragement has remained relatively insignificant, it is mainly because of the precarious situation of training and research in the higher education institutions and the higher technical schools (ETS) as described above. Indeed, the resources of which the Federal Office for Economic Change (Office fédéral des question conjoncturelles — OFQC) disposes can only be invested in a given project, if its encouragement implies close collaboration on one hand, between a university institute, a research institute of the respective branch, or an ETS or similar institution with an enterprise or a consortium of enterprises on the other. As a general rule, the industrial partner or partners who use the results pay half the cost of the project. In the past, a number of projects failed or could not be extended to the lomain of informatics because of insufficient research means in a given higher education institution or ETS. In addition, the industrial partners can have their own bottlenecks.

As part of the planning which the OFQC undertakes several times a year, it has clearly stated its intention to increase its financial commitment in favour of informatics. Will this declaration of intention give rise to concrete results ? The answer will depend to a great extent on the rhythm at which it will be possible to supply the higher education institutions and the ETS's wih indispensable research capacities and equipment.

At the international level, it is necessary to emphasize the efforts which Switzerland has been making in order to participate in various projects of the European Community. Of particular importance in this context are the projects known as ESPRIT and RACE which are attempting to establish close intra-European collaboration with the aim of recapturing the ground lost vis-a-vis the United States of America and Japan. Two other projects, COST, in the context of European cooperation in scientific and technical research, and the recent one EUREKA, which originated in a French initiative, are aiming at the same goal. Here too, the Confederation will strive to create general conditions which are favourable to collaboration between interested Swiss higher education institutions and enterprises and European partners.

So far as the numerous private initiatives are concerned, it is particularly germane to mention the research being carried out by the private sector. In some domains of the technical sciences, private research exceeds by more than three-quarters the average contributions made by the private sector to the total volume of research in Switzerland. Unlike the situation prevailing in most of the OECD countries, applied research and development in Switzerland are only moderately supported by the public authorities. The relatively large proportion of R and D expenses in the Swiss gross national product is largely absorbed by ten or so large enterprises. The strong interest that Swiss industry is manifesting in the major European projects that are being devised demonstrated that it has understood the need for additional efforts and that it is motivated by the firm intention to regain the lost ground.

Chapter III

SCIENCE : TEACHING AND RESEARCH

This chapter gives an account of the role of the new educational technologies from the point of view of several science disciplines, either as teaching subjects or as fields of university research.

The selection includes chemistry, medicine, statistics, graphics, biology, economic and demographic processes. The fact that today medicine is making the most extensive use of computers and the building of expert systems accounts for the fact that two of the studies are on this topic.

In the first article, Aleksandra Kornhauser of Kardelj University, Ljubliana, Yugoslavia, provides an overview of the use of NIT's in teaching and research in the field of chemistry. One problem that must be faced here stems from the vast amount of data that have to be manipulated. To solve at least part of this problem, the author has prepared a hierarchy of possible uses for computers, a hiererchy which ranges from the organization of bibliographical information to basic factual data, which are then structured, culminating with expert systems. The main idea common to science — education and the introduction of new technologies resides in the gradual structuring of data into systems, structures, and patterns of recognition.

In his study, David Ingram of the Department of Medicine of the Medical College of St. Bartholomew's Hospital in London offers a survey of the results and the literature on the use of computers in medical education and training. The author emphasizes the close link between medical information applied in medical praxis, on the one hand, and medical education, assisted by computers, on the other, as well as the sheer pace of change in these domains which has made some experiments obsolete, while validating others. The extremely extensive area covered by the potential role of computers in medicine, such as case simulations to illustrate diagnosis and treatment, statistical modest for guiding clinical decision and expert systems of artificial intelligence, is highly relevant for the huge efforts required to devise methods with a wide scale applicability.

In the following article, Professor Dr. Hugo A. Verbeek presents a computer assisted system of simulation and education devised and developed by the Leiden Medical Faculty. The system presented is a valuable aid both from the point of view of the medical students who learn to diagnose through dealing with computer patients and from that of teachers who learn how to become authors of cases. The scoring system is only one aspect of the students-teacher relationship, which the system stimulates. It also brings forth comments, arguments, and explanations. The most important expansion of the computer assisted simulation and education system described above is the addition of visual images, by means of video discs and video laser discs. Both are very valuable to medical education.

In the fourth article, Eddie Shoesmith describes some of the experiences at the University of Buckingham in using computers to support the teaching of statistics. This course, which has been introduced into all the schools of the university, is either compulsory or optional. In the beginning, computers were used only for demonstrations; next it was introduced into student and staff research work and now it is used as a teaching tool for all types of current methods, such as regression, analysis of variance, and multivariate techniques.

Josef Novák's article presents the experiences of technical higher education institutions in Czechoslovakia with respect to the importance of computer graphics in connection with computer-aided design. Special mention is made of Constructive Mathematics (particulary of Constructive Geometry) which is fundamental to the endeavour. Within the same context, mention should also be made of recent concerns with regard to Constructive Mathematics (e. g. D. Bridges, F. Richman, *Varieties of Constructive Mathematics*, Cambridge University Press, 1987).

Tuula Kinnunen's study of the behaviour of a system is aimed at reconstructing a dynamic law whereby the observed time series of a given system is produced and the occurrence of oscillations of a chaotic nature is explained. The author describes a way to reveal the complex behaviour of systems by computational experiments made by computers. By this mean, the article analyses 14 growth models which have been used for the solution of economic problems (innovation diffusion, the forecasting of energy consumption, car production), of biological problems (growth of an organism, growth of a population) and of demographic problems (e.g. the study of demographic strategies).

SEARCHING FOR PATTERNS OF KNOWLEDGE IN SCIENCE EDUCATION *

Aleksandra KORNHAUSER

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Faces of Science

There are two main reasons for good science education and further life-long education :

— in the industrial, and even more in the post-industrial era of man's development, every career, even every day-to-day activity, involves science and technology, supported increasingly by mathematics and informatics ;

— growing dmocratization processes involve an increasing part of the population in decision making.

Science, this achievement of research, has many faces, depending on the individual approaching it.

For a researcher, science means the results of objective observation, supported by powerful methods and techniques, with an analytical treatment of the data collected and a search for interrelationships between them, followed by a synthesis of these data enabling explanation of processes and recognition of patterns, which thus lay the foundation for hypothetical predictions to be checked by further research.

For the engineer and technician, scientific information is the starting point for developmental efforts, giving a fundamental orientation and stimulating creativity in searching for the useful applications of scientific achievements.

To a manager, science offers a basis for predicting several possible solutions of real problems which help him to understand the nature and implications of different possibilities needed in his efforts to optimize processes.

The quality of sciehce and thus also of science education increases from the level of objective observation supported by efficient techniques, via organizing data and expressing interrelationships with diagrams, leading to the formulation of the interrelationships recognized in the form of abstract mathematical equations. These express relationships in the shortest, most accurate and logical way.

* Paper presented at the Nordic Conference on Science and Technology Education : The Challenge of the Future : May 1985, Karlslunde Strand, Denmark.

Entering the Information Era

The little silicon chip with its increasing capacity belongs to the discoveries which are bringing fundamental changes to education also. In 1971 a thousand bits of information could be housed on a single chip, in 1978 sixty four thousand, while by 1990 a million-bit chip is expected. Fibre optics and satellite communication promise great contributions to the world system of communication.

These techniques are urgently needed since scientific and technical informtion is growing in most disciplines exponentially. In chemistry (1), for example, over four hundred thousand papers and a hundred thousand patents are published annually. Over six million compounds are registered in the Chemical Abstracts Service Registry and about three hundred thousand new compounds are added each year, i.e. about one thousand a day. The only solution is the construction and use of computer-supported data bases.

The construction of the first data bases supported by the computer started in the sixties. They were at first designed for local use and constructed in national languages.

In the seventies it became clear that for scientific and technical information too a critical mass is needed to enable quality and efficiency in use: a critical quantity of data, finance, equipment and specialized staff.

The results of this awareness were efforts to combine small data bases into larger ones, which implied standardization of the input and modes of retrieval. The next step was logical: an interlinking of computerized data bases into networks and large information systems of an international character. In the eighties we can speak about the development of an information industry. We are entering the information era.

Over two thousand computerized data bases of an international character exist today. Chemical Abstracts Search (CASEARCH) data base houses information on over six million compounds and over five million papers. AGRICOLA offers about two million data on agricultural publications, COMPENDEX one million on engineering. INSPEC covers over two million electrical engineering publications, MEDLARS has about five million data on publications in medicine and veterine. The multidisciplinary BIOSIS houses four million data on biology, medicine and veterine, TOXLINE two million on pharmacy and pharmacology. The strongest, International Patent Documentation INPADOC, offers information on over ten million patents from 49 countries plus two international patent organizations. A number of these and other data bases are parts of large systems such as DIALOG, DARC etc.

From Fragments to Systems

Computerized technology is opening up rapid access to scientific data. Yet not only the layman, but often also the researcher, does not know what to do with large sets of data. Systems-thinking is missing, i.e. an organized way of linking bits of information into networks, trees, modular systems, showing the interrelationships between large sets of data.

How much systems-thinking is needed can best be illustrated by how poorly data bases are used. Even in the most developed circumstances, data banks report that only 5—10 per cent of the data stored has ever been asked for. This is the reason why some call data bases "scientific cemeteries". Another proof is the fact that the market is flooded with sophisticated hardware with relatively scarce, often also poor, software.

The development of good software does not require only ability and patience, but also organized thinking, typical of good researchers, yet obviously a rare gift of nature. We have to learn how to structure data into systems, how to organize data into knowledge. Students should not be taught the content. They should be encouraged to define real problems, to collect and analyze data, to search for common parts and variables, to define the hierarchical order of variables, to structure the hypothetical system and to try to validate it — in short: to use the method of structuring data and pattern recognition.

Towards Expert Systems

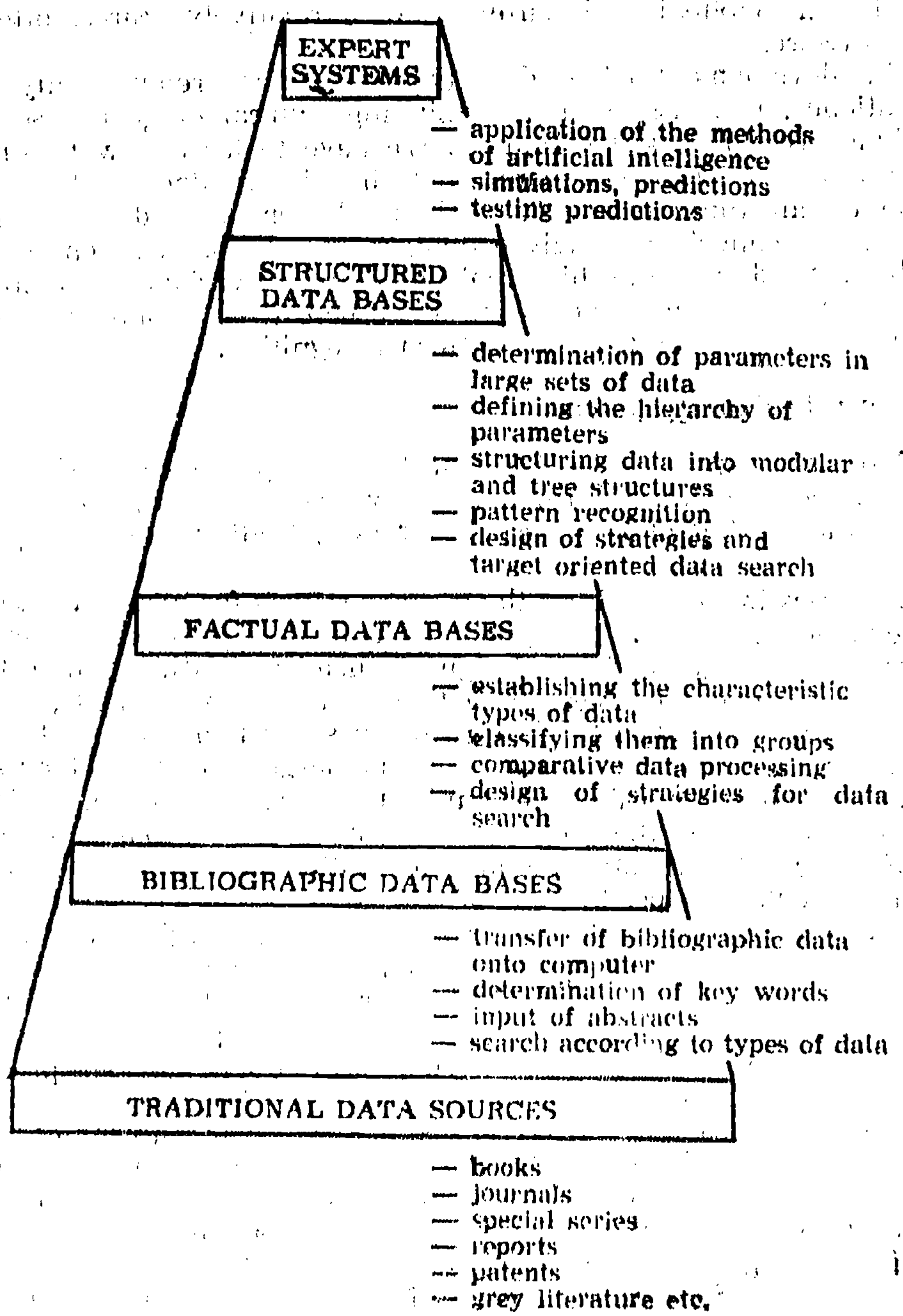
Expert systems are considered to be the top of computerized scientific and technological information. They are complete programs which support the linking of large groups of facts leading to expert problem solving.

Examples in this field are the expert systems for diagnostic purposes in medicine, design of computer system configurations, search for minerals, natural gas and oil, design of chemical syntheses, detection of failures in electronic devices, prediction in market movements, etc.

The main characteristic feature of these systems is that they take into account a number of parameters and larger amounts of data than possible by human brains. Although they cannot compete with the logic of a researcher, they are significantly better in comparative analysis of large sets of data and in combination of parameters, in scope and in particular in speed.

It could be said that a kind of knowledge engineering is being developed, which is still in its initial stages, but will undoubtedly greatly influence the processes in research and education, as well as solving problems in production and decision making.

A secondary, but no less important, consequence of the process of development of expert systems is the fact that knowledge engineering catalyzes the efforts in collecting, coding, exchange and application of human knowledge on a world wide scale. This means that knowledge engineering leads to the development of larger systems of knowledge, and along with this also supports the development of understanding and efficient target-oriented acquisition of knowledge. Instead of acquiring tiny pieces of information, masses of information will be introduced in science education in future. They will be organised into systems, which will on one hand show the already defined relations and hypothetically forecast new relationships on the other. Instead of a disordered search for the new, it will be possible, by the use of these systems, to design research hypotheses and with a target oriented research to approach more quickly to the solutions. Intuition and chance will of course still have their role in research. But it is also true that systems will aid in finding knowledge much more quickly than it was possible up till now, in particular knowledge which has already been discovered,



From data sources to expert systems

but which is hidden. Strategic and technological secrets will become less inaccessible. This will also give a totally new impetus to education.

The higher we go up this diagram, the narrower the field, since expert systems are as a rule designed for solving a specific type of problem, whereas structured data bases can be built on less narrow areas of a field and are only afterwards interlinked to larger systems. Factual data bases also have their limitations, above all in the possibilities for input of and search for data. Bibliographic data bases, however, cover usually broad areas. The traditional data sources — journals, books, special series, patents, grey literature — constitute the broadest basis of the whole system.

The following phases are characteristic of expert system design :

Phase	Characteristics
1. Definition of a problem	recognition of characteristics of the problem
2. Conceptualization	search for laws and rules or at least for the relationships in knowledge necessary for the solution of a problem
3. Formalization	structuring data into systems
4. Implementation	formulation of rules for the knowledge concerned
5. Testing	checking of rules on problems captured in the expert system

Development of Methods of Structuring Data into Systems

The main reasons for lagging behind in use and design of data bases, as well as in the development of expert systems, lie in education. Traditional schooling is too often oriented towards memorizing data (lower level), or to development of reasoning based on a relatively small amount of data (higher level). Deductions of rules and laws based on large sets of data are still unknown in our education. Without such an approach we of course do not educate for the use and design of computerized data bases. Therefore no wonder that what "little Johnny has not learnt, John does not know and also does not do".

Let me give an example for structuring data into systems at secondary level : *lipids*. Traditional study of lipids at secondary level includes the description of fats and waxes, phospholipids and glycolipids. In dealing with this subject matter, emphasis is placed mainly on their component parts — on alcohols and acids in the former, whereas the more complicated components of the latter are only briefly mentioned, if at all. Due to the complexity of these compounds students learn only simple formulae, and the more complicated are usually not considered. Consequently, it is very difficult to deduce rules on the basis of such a limited amount of data, and knowledge remains mainly on the lowest level — memorizing.

In structuring chemical data :

— students use textbooks and find the formulae for different lipids : fats and waxes, phospholipids, glycolipids. They construct a file with simple formulae, and the more complicated are usually not considered.

— this is followed by the search for common part(s) in the formulae of these lipids. They will find glycerol, monohydroxy-alcohols and sphingosine, as well as a number of carbocyclic acids bound in the lipids; they will also find phosphoric acid; amino-alcohols and carbohydrates;

— this could be followed by a discussion of what the criterion of higher hierarchical order is, e.g. alcohol or acid? Students should try to build a tree givind first the higher order to alcohol, and next giving it to the acid part. What are the differences between the two systems?

— they can try to use the data available to construct an overview, e.g. Table 1.

It is not the system produced, but the effort of structuring data into systems which really counts. The student is put into a situation in which he does not only learn from one source, but searches for new data in different sources. He does not only memorize chemical data, he is using them to search for interrelationships. In this way he develops higher cognitive levels, i.e. an analytical mind, meaning the ability to synthesize data, to recognize the interrelationships and to evaluate both — data and systems.

A number of other examples for secondary level could be given, e.g. attempts to build a system of acids and bases, hydrocarbons, oxidations and reductions, types of organic reactions, etc. Thus, a system could be constructed around the structural parts of a certain group of compounds, around types of reactions, different properties, spectral data, isolation procedures etc. The basic condition — a sufficient amount of data — has, however, always to be fulfilled.

An example at the university level is illustrated by efforts to search for a system of optical brighteners. In this case, the student had first to study phenomena like the relationship between colour, absorbtion and emission with fluorescence as the special case. This was followed by the collection of data on optical brighteners, using traditional sources of information, as well as computerized chemical and patent data bases. By analysis of the structure of optical brighteners it was found that stilbene derivatives are present in sufficient number to fulfill the condition of a critical amount of data for or the use of structuring data and the pattern recognition method. The structures of these compounds were then analysed in detail, commond parts and variables were recognized and their hierarchical order determined. The following fragment (table 2) of the system produced offers an illustration.

The work on the system of optical brighteners is being continued by taking fluorescence as the crucial criterion with the intention of searching for a pattern in these compounds of dependence of fluorescence on their structure. Thus, the teaching and learning aspects are combined with research directed towards the understanding of fluorescence in relation to chemical structure, and including an industrial interest in the synthesis of optical brighteners — stilbene derivatives.

An example of structuring at secondary level : LIPIDS

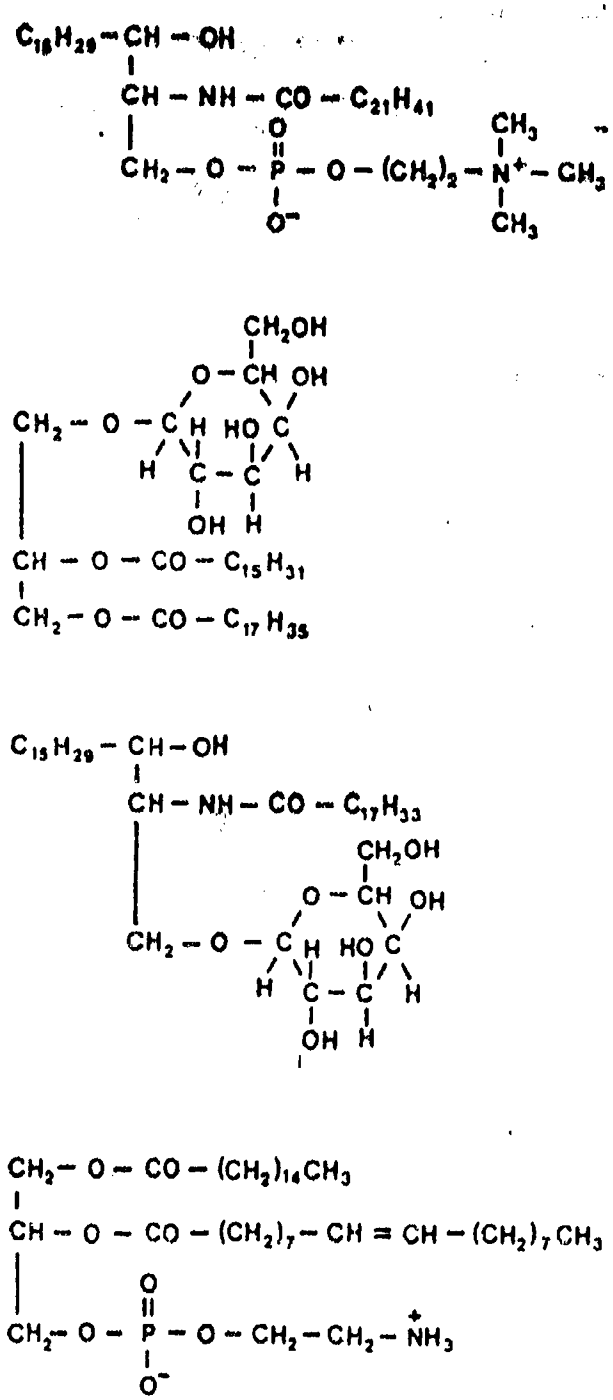


Table 1

Examples of formulae of lipids — learning by heart would give only short-term success.

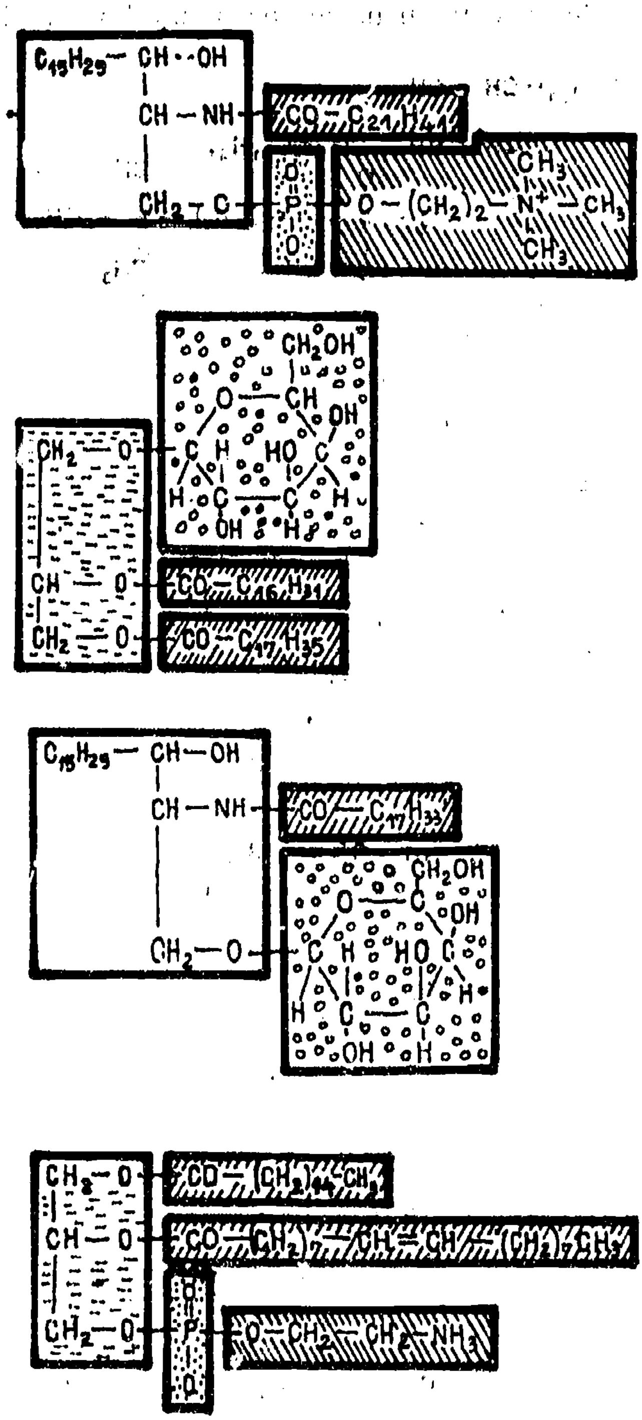


Table 2

Recognition of constituents in the formulae of lipids — students observe and recognize parameters and establish their hierarchy.

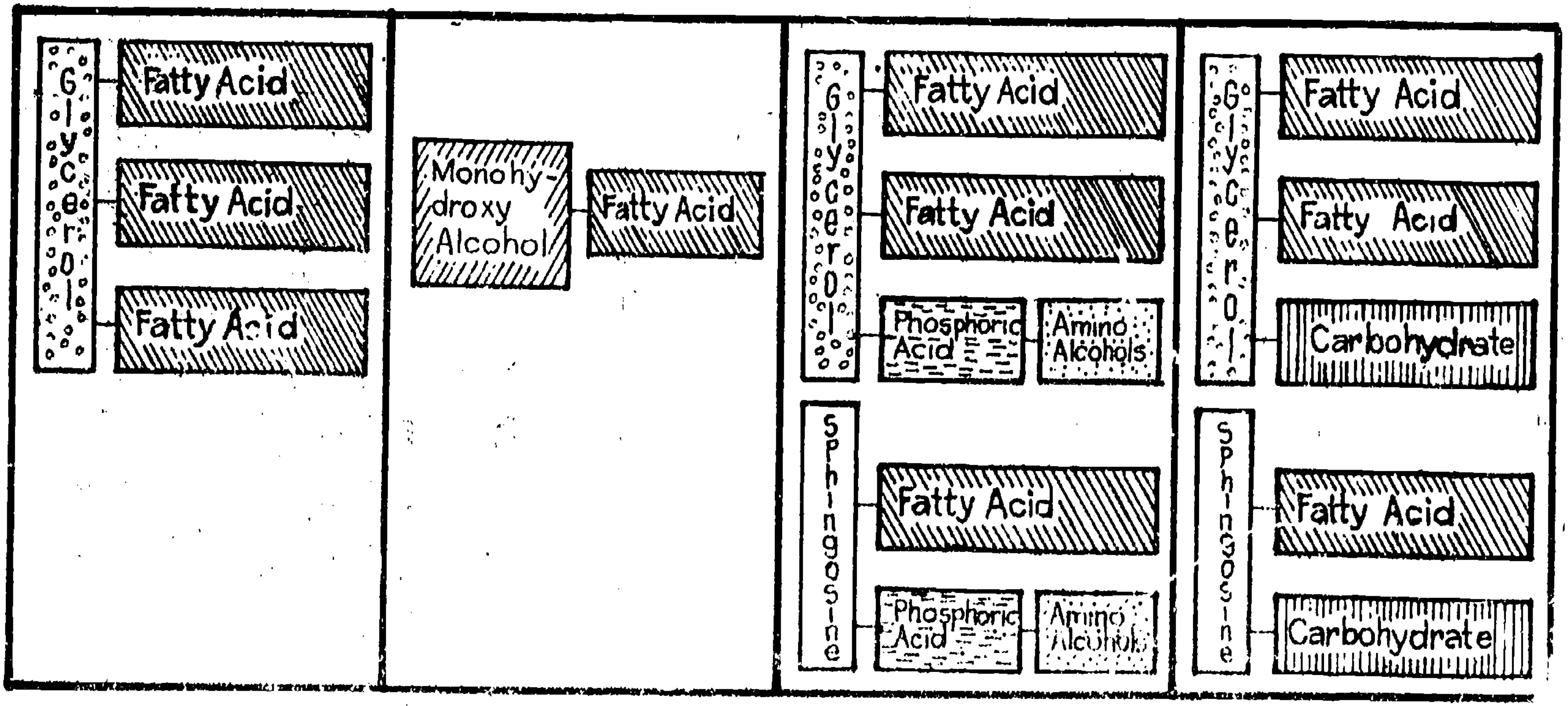
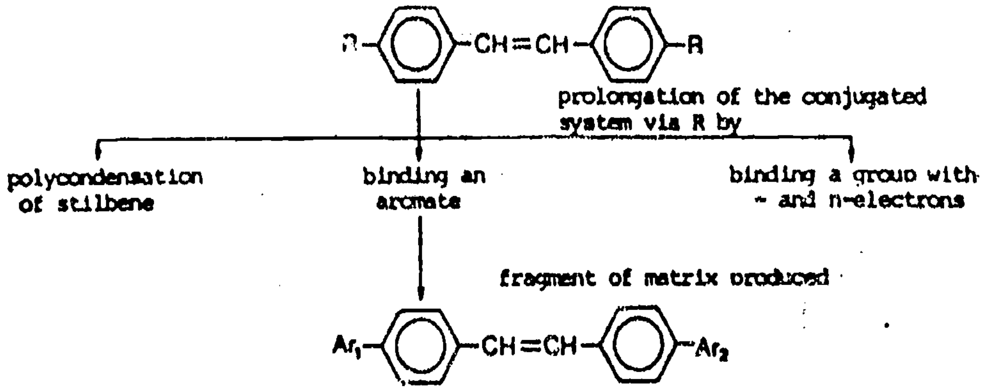
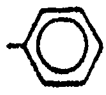
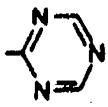
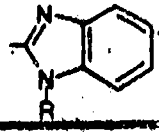
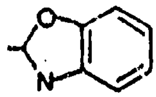
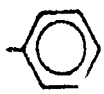
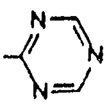
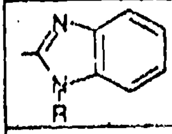
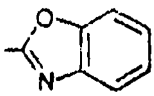


Table 3

The modular system at secondary level showing interrelationships between individual parameters.



Ar1 / Ar2				
	o	•	o	•
	•	o ı	o	o
	o	o	•	o
	•	o	o	•

• found in chemical and/or patent literature
o prediction
oı found after prediction

Table 4

System of optical brighteners on the basis of stilbene (fragment)

University-Industry Cooperation

The method of structuring data into systems and pattern recognition is essential in the developmental efforts of industry. There is a flood of patent and scientific information, among which there are also data which can be misguiding and may lead one in a wrong direction. In recent years the publication of strategic, both technological and economic data is increasingly limited. Therefore methods enabling hypothetical predictions are becoming more and more necessary.

An example in university-industry cooperation is the search for the backbone of the technological process in microencapsulation of a new technology for which in recent years alone more than two thousand patents have been issued. It is of course impossible to deduce the essence of the whole procedure from single patents or small groups of them, since patents deal only with parts of the process, and even here the key information is hidden to the greatest possible extent.

In the search for patterns we started with the largest number of patents which were accessible. This was followed by an analysis of subsets of data from about a hundred patents. Each procedure was structured into a hypothetical "backbone" of the successive technological operations.

In the direct vertical line there are four phases, for which it was first supposed on the basis of data analysis to be unavoidable parts of the backbone of the process. Which are the other parts of the "backbone" ?

By superimposing those four diagrams, the phases which occur several times can be recognized. The greater the fit of processes for an individual phase, and the higher the number of patents studied, the more probable the "hypothetical backbone" of the process which is deduced from the parts of the diagram obtained by superimposing the different patent structures.

The same applies also to defining the probability of a value of an individual parameter within one phase, e.g. temperature.

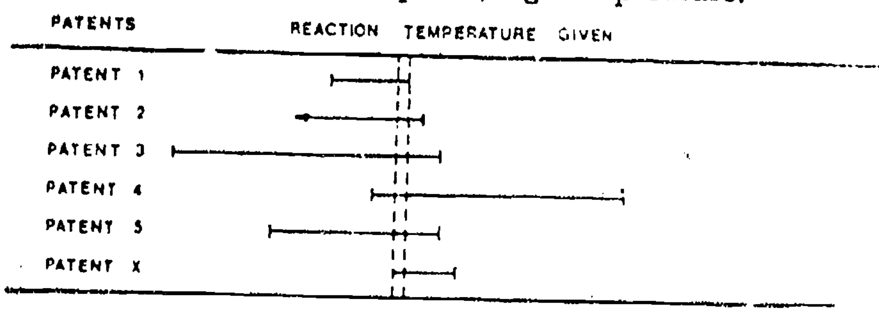


Table 5

The vertical dotter lines show the temperature interval where all the procedures meet, i.e. the most probable value.

Backbone of the Method

In general, the following stages can be defined in the method of structuring data into systems and recognition of relationships and patterns :

1. Definition of the problem and subproblems
e.g. : How to improve the existing technology ?
The subproblems are :
Which variants for this technology exist ?
What are the alternative technologies ?
Which producers use those technologies ?
What are patents, offers of licences like ?
Etc.
In short, we should formulate such questions as would lead us to the sources of suitable data.

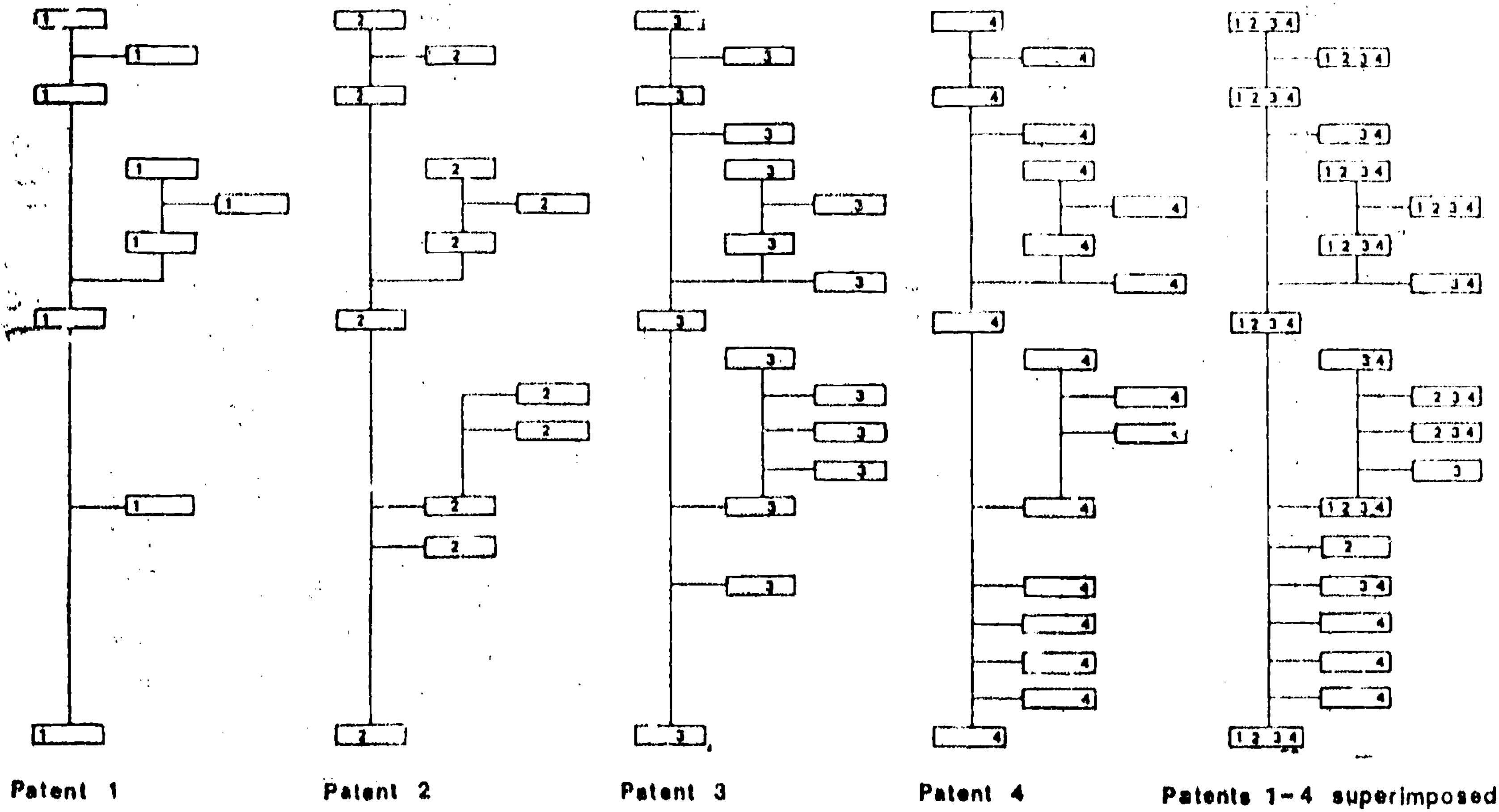


Table 6

Superimposing of patents : each square denotes one technological operation

2. Collecting data
Use of special publications, journals, patents, industrial offers, etc. ; profile design, search through scientific patent and marked data bases ;

3. Analysis of the collected documents
Search for the structure of each process, definition of parameters ;

4. Comparative study of each parameter and its relations ;

5. Search for common characteristics, building up hypothetical patterns ;

6. Stating hypothetical predictions on the basis of patterns and their check by experimental work.

Design of Computerized Data Bases as a Component of Education

The method of structuring mentioned above always requires a large amount of data if it is to be efficient in research or in development. This means that along with each approach to the use of such methods, we actually also become involved with the design of specialised data bases.

Therefore it is necessary to start constructing and using computerized data bases in school, e.g. for data on energy, metals, non-metals, reaction processes, rise and fall of prices, etc. Only on condition that both, the teacher and the student, are exposed to such data bases which offer the required data and comparisons between them within a few seconds, can we expect them to turn to higher levels of knowledge, i.e. to the understanding of data and their interrelatedness, as well as the use, analysis, combination and evaluation of data.

On the level of higher education, the building of data bases is an imperative. These are of course specialized data bases for problem-oriented tasks, for which the bibliographic data base is only the first step to a factographic and further to a structured data base, leading finally to the development and incorporation of at least some elements of expert systems.

Education for the use of data bases is therefore not only learning how to find information quickly on what has already been discovered. Such an approach would soon convert the initial enthusiasm to lack of interest, due to the disillusionment caused by badly designed searching, which leads to a costly and excessive number of hits with little value.

Data bases in education become an indispensable part only if they are not just a collection of data, but the first step towards higher levels, presented in the diagram on page 166.

This however requires a different way of thinking and therefore also a different kind of education. We have to establish a transition :

— from dealing with separate data to dealing with sets of data,

— from putting together small numbers of variables to building systems with large numbers of variables, as well as,

— from insufficiently organized searching for new knowledge to a long-term, carefully planned collection, arrangement and combination of data into systems which are directed towards well defined disciplines or developmental problems.

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MEDICAL EDUCATIONAL COMPUTING *

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The literature of the last twenty years has described many projects which have explored the applications of information technology to medical education and training. A variety of different approaches and techniques have been developed, reflecting diverse educational objectives. The projects have ranged from little more than the computerisation of 'page-turning' of a text-book and the presentation and marking of MCQ tests, to complex mathematical simulations of body mechanisms and clinical treatments. Formal evaluations of such systems have been reported, including often very positive accounts of favourable responses from users. However, few of them have been used far beyond their places of origin and few have survived long in use.

This rather unhappy situation can be attributed, to some extent, to the sheer pace of change in computer technology itself, and to the computer users' changing perceptions of what constitutes an acceptable device or manner of operation. Technical developments in microcomputers, computer graphics, databases, interactive video and techniques of artificial intelligence have driven the field forward, leaving a trail of now obsolete systems. Many educational software developers — some simply enthusiastic individuals, others members of large teams — have found themselves unable or unwilling to devote the time and energy necessary to keep pace. The products of their labours have thus gradually become remote and unusable, being now either technically obsolete, or outdated in content or educational approach. But the early demise of such products may also be considered, in part, an implicit 'evaluation', in the market place, of the educational benefits derived, ease of use and value for money when compared with traditional teaching methods and other priorities for educational research and development.

It is interesting to note that the same general picture of widescale experimental development of software, limited success in its dissemination and short useful lifetimes, is found in the wider literature of

* Based on the keynote lecture delivered to the 5th EARDE Congress, April 1987, University of Utrecht.

medical applications of information technology. For educational developments, there are, of course, somes special considerations. An important one is the means available to publish software and to communicate knowledge both of its content and of the changes in organisation and approach to teaching which may be needed if teachers are to use it effectively. Without sharing of this knowledge, effective development of educational software is not possible, proving prohibitively expensive for individual institutions to contemplate alone. Such aspects will not be considered further here.

A useful account of early developments, mainly in the United States, was that edited by Deland (Deland, 1978). A recent publication (Association of American Medical Colleges, 1986) considered the implications for medical education of wider developments in the field of Medical Informatics. This review will consider areas where important contributions have been made in exploring potentially distinctive roles of the computer in medical education. It uses examples of pioneering work in the field. Some of the systems described have since been recreated in the form of new hardware and software implementations, with little revision to the content, but taking advantage of new opportunities to improve the visual impact and ease and pleasantness of use. In some cases such enhancement may, indeed, make the difference between an acceptable and an unacceptable system. The review seeks to highlight lessons which have been learned and to suggest where limitations on further progress may lie.

There is a relationship between progress in research in medical informatics, which impinges on everyday problems of medical practice (in such areas as clinical decision analysis, biological signal processing, database systems, imaging, simulation of body mechanisms and clinical procedures, and artificial intelligence), and the potential for useful applications of information technology in medical education. There have been interesting examples of systems which fulfill a dual role in medical practice and medical education ; such systems, having gained acceptance in medical practice, may, more readily, be accepted as relevant to medical education, because they are seen to complement and enhance human capabilities.

Case Simulations to Illustrate Procedures in Diagnosis and Treatment

Systems of this kind aim to simulate a clinical encounter, with the student assuming the role of the physician and the computer programmed to respond with information about the patient. Several extensive projects have been reported ; the most general and elaborate early systems were those of Harless, Drennon, Marxer et al. (1971) (the 'CASE' system) and of Friedman, Korst, Shultz et al. (1978), both based on 'mainframe' computers. The implications of this work for the assessment of clinical skills have been well summarised by Senior (1976), describing the CBX project, and in the report of the Office of Technology Assessment of the U. S. Congress on 'Computer Technology in Medical Education and Assessment' (U. S. Congress, 1979). In recent years many similar systems have been implemented on micro-computers.

Accessing the 'CASE' system through a computer terminal, the student progressed through various stages to determine the clinical history, physical findings and laboratory test results and, when ready, entered a diagnosis and suggested treatment. The complete 'encounter' was scored by the program, using criteria provided by the author of the individual case. This score reflected success in eliciting the important information and the efficiency with which it was achieved (avoidance of irrelevant questions).

The CASE system was notable for its use of sentence parsing methods, which allowed the student to respond freely, without being cued, to choose from a range of possible responses. This was not wholly successful, partly because of the extreme difficulty of devising natural language parsing algorithms (on which work continues still) able to correctly identify the essence of the student's questions, which might be expressed in such a variety of equivalent forms. The computer devoted much processing-time to this aspect. The emphasis required on accurate typing and spelling also diminishes the perceived "friendliness" of such systems for many users.

The system of Murray, Cupples, Barber et al. (1976), in common with that of Friedman et al. (1978), included a simulated clock which was used to help represent time-dependent constraints; for example, how long it would take to perform and report on an investigation. It was also used to effect gradual changes in the condition of simulated subjects, albeit in a rather simplistic manner.

The systems considered thus far have all required a detailed database to be constructed to describe each simulated case. A rather simpler approach is illustrated by problems designed to teach specific clinical techniques and procedures; an early example being the work of Hoffer, Barnett and Farquhar (1972) on the principles of cardio-pulmonary resuscitation. This took the user through the events following a cardiac arrest and gave extensive guidance on the correct procedures for clinical management. Six possible ECG rhythm disorders were discussed with reference to traces contained in an accompanying handbook. Similar exercises were developed for problems in general medicine (Farquhar, Hoffer, and Barnett, 1978), general practice (Murray, Cupples, Barber and Hannay, 1976), as part of the United Kingdom National Development Programme in Computer-Assisted Learning, and in anaesthesia (Kenny and Schmulian, 1979).

Both published and informal reports on these systems indicate that computer-assisted learning software of this kind can be a stimulating resource for students at many levels. It has been used for individual study and self-assessment and in small group teaching, and has useful potential where qualified teachers are in short supply. However, the actual contribution made to most medical curricula has been quite limited. The range of information which can be represented realistically in the 'encounter' has often been clearly deficient and can, of course, never encompass the full experience of talking to and finding out about the problems of real people. The use of associated work-books, computer-controlled slide projectors, and interactive video techniques have gradually made a more complete presentation of the case possible, at the price, however, of introducing more technically complex equipment, which is sometimes not easily operated and maintained for routine use.

An early application of the interactive videodisc was for teaching cardiopulmonary resuscitation (Hon, 1982), in this case linked to a patient mannikin. Other pioneering work of note has been at the United States National Library of Medicine and the Georgia School of Medicine (Abdullah, Watkins and Henke, 1984). The recent development in videodisc and compact disc technologies lend themselves to the design of much richer computer-assisted learning materials, for a wider range of applications. It is becoming increasingly possible to provide immediate access to large amounts of information and, with more flexible software systems, to allow the student considerably more freedom to find his or her own pathway through this material, free also to make mistakes in dealing with situations encountered and to cope with the consequences of such mistakes.

It would be premature to comment on the extent to which this enhanced technical and educational potential may prove effective in practice, although significant benefits have been claimed in well defined areas of industrial training. A number of experimental videodisc projects, including resource discs devoted to collections of medical slides, and discs combining still or animated images, filmed procedures, case presentations and background resource material, are being developed and evaluated in use. Enthusiasts have often held that the 'next foreseeable', technological feat will provide the key that unlocks effective educational applications of information technology, but past experience justifies caution! Such equipment is expensive and, for successful marketing, much will depend on the richness and variety of resources to which the purchaser gains access; often the cost cannot be justified for a single application alone. This is a strong reason for seeking to foster mutual compatibility in medical educational software developments.

The evaluation of new educational methods is recognised to be a very difficult task. Medicine presents the added complication that the assessment of clinical skills is not in itself a well formalised process; thus it has been found extremely difficult to construct reliable objective tests and scoring methods. Friedman et al. (1978) could not correlate assessments of students based on use of their system with traditional methods of assessment. Much effort has been expended in trying to develop acceptable objective methods of clinical assessment. With progress in such areas, computer-based case simulations may be expected to find an increasing role in medical education.

Statistical Models for Guiding Clinical Decisions

The application of statistical models to the analysis of complex medical decisions has been widely investigated (Skene, 1984). Clinical trials have been conducted to study the efficacy of such techniques in everyday practice. Spiegelhalter (1983) provided a useful account of approaches to evaluation of clinical decision aids.

An early example of the application of these ideas in medical education was the work of Warner, Wooley and Kane (1974). Their program incorporated a database with conditional probability information relating observed symptoms and signs to diagnoses. A disease was selected at random from the database and a representative simulated case generated. The student was given the patient's age and sex presenting complaint relating to the highest probability symptom in the disease. He or she was then asked to select from a list of possible diagnoses using the given information, and subsequently to choose among questions which might be asked or tests which might be requested according to their relative discriminating power. This cycle of operations was repeated until a definitive choice of diagnosis could be made. The system cues the student's responses to a degree found unacceptable by some teachers.

Research into the use of mathematical approaches in clinical decision-making may be expected to impinge on teaching only to the extent that the methods gain acceptance in clinical practice. While a considerable literature exists in this area, again few systems have been transported far beyond their places of origin. Formal evaluations of such methods are an important means of assessing their value but, as with clinical trials, can be difficult to design and to interpret.

The evaluation published by Warner et al. (1978) concluded that, by the methods of assessment chosen, the students did not gain significantly from use of the computer system, in comparison with other traditional ways of developing the problem solving skills concerned. On the other hand, a multi-centre trail of the methods developed by De Dombal for assisting the differential diagnosis of the causes of acute abdominal pain (Computer-Aided Diagnosis of Acute Abdominal Pain, Final Report of Multi-Centre Trial, DHSS, 1985) showed well substantiated benefits associated with their use in clinical practice. These were quantified in terms of diagnostic accuracy, avoidance of serious errrors of diagnosis and management, and economy in use of resources. There was also a clear indication that staff using the system gradually improved their own independent skills in this area.

The work cited here appears to demonstrate a potentially valuable educational role for clinical decision aids. But it should be appreciated that the long-term inter-disciplinary effort and pioneering commitment required to develop and validate these methods has been considerable. It appears to have been more fruitful to concentrate on solutions to specific problems, rather than on the development of general purpose tools.

Dynamic Models of Pathophysiological Systems to Assist Understanding of Overall Function and Control

The use of dynamic models has developed at many levels of medical teaching. Models used range from very simple descriptions involving perhaps just one differential equation, to extremely large and complex non-linear models. Typical examples with very specific treatment objectives were the management of diabetic keto-acidosis (Inoue, Kajiya, Inada et al., 1976), control of anticoagulant therapy (Sheiner, 1969) and the control of digitalis therapy (Aida, Minamikawa, Takai et al., 1977). The most wide-ranging single program developed for teaching in physiology and pharmacology is the model 'Human' developed by Coleman (1978).

The task of building an accurate model of a system as complex as, for example, the human circulatory system is extremely formidable and limited in many crucial respects by lack of knowledge as well as by mathematical complexity and intractibility. With fundamental knowledge of such systems still lacking, models must be treated as hypothetical.

A classic early example of the modelling of circulatory system control mechanisms was that of Guyton, Coleman and Granger (1972). One of the earliest and still, perhaps, the most sophisticated mathematical models developed for medical educational purposes is the 'Fluidmod' (Deland, Winters, Dell and Zuckerman, 1972) describing equilibrium of fluids and electrolytes in the body and disorders of metabolism and excretion. This has at its core a simulation of the biophysical equilibria concerned with the distribution of fluids and electrolytes in the plasma, red cells and interstitial and intracellular fluid. The system has an elaborate interface for describing treatments and any losses of fluid and electrolytes not modelled by the system. Thus quite elaborate simulated subjects can be generated and the student challenged to provide appropriate therapy over many days.

Models of circulation, respiration, body fluids and electrolytes and clinical pharmacokinetics have been developed at St. Bartholomew's Medical College and McMaster University Health Science Centre over the past sixteen years (Dickinson, Ingram and Ahmed, 1986). These have found a wide range of medical applications, in preclinical and clinical teaching, postgraduate courses, and more widely in the teaching of the life sciences. Perhaps the best known of these is 'MacPuf' (Dickinson, 1977) which simulates lungs and airways, pulmonary circulation, and gas exchange based on a Riley 3-compartment model. Gases are transferred to arterial blood, and passed round to the tissues, where oxygen is extracted and carbon dioxide produced, after which the blood returns to the lungs. The carriage of gases in the blood is governed by mathematical expressions describing the oxygen and carbon dioxide dissociation curves, taking account of temperature, haemoglobin, packed cell volume, and acid-base status. The storage of gases in the tissues is based on the best available estimates of the mean tissue dissociation curves. Ventilation can either be 'artificial', in which case rate and tidal volume can be specified, or 'natural', i.e. controlled by known influences upon ventilation of PaO_2 and $PaCO_2$. There is also an additional central neurogenic drive, normally proportional to tissue oxygen consumption, which can be increased to simulate increased reflex drives from the lungs, or reduced to simulate narcosis or anaesthesia. If the tissues acquire an oxygen debt, proportional anaerobic respiration results in generation of lactic acid and carbon dioxide at appropriate rates.

Extensive teaching materials in respiratory physiology, anaesthesia and intensive care have been developed using the program, which has been linked with an author system ('MacAid'). This work has been described in a number of publications, including Hinds, Ingram and Dickinson (1982) and Skinner, Knowles, Armstrong and Ingram (1983). Microcomputer versions of the 'Mac-series' programs, incorporating graphic display and other revisions and enhancements have been developed over the past three years. The author system enables output from simulations, videodisc images and other information in text or graphic form to be combined on the screen.

Whereas one must accept that no model can be regarded as a perfect representation of the biological reality, nonetheless the structure and function of many biological systems is usually taught in terms of idealised quantitative representations (or models) which usefully encapsulate and convey aspects of the function of the system with adequate quantitative precision and rigour. Quite simple models can be used to illuminate aspects of drug kinetics, haemodynamics and respiration. Such models have been found helpful by many students, particularly those used to the quantitative approaches of the physical sciences, when first coming to grips with these subjects. Randall (1980) documented a useful collection of models of this kind. Their role and power is in helping to bring to life the underlying idealised concepts, usually by setting problems for the student to explore, in a setting similar to laboratory practical work.

Once these concepts are understood, models can only fulfill a useful continuing role in clinical teaching, it they provide something of direct relevance to clinical practice. Hoffer (1973) proposed four criteria which he felt should be satisfied by simulation models if they were to be of educational value. These were :

(i) The clinical situation modelled must be amenable to simplification and modelling on readily available computers.

(ii) Poorly quantified areas of medicine should be avoided.

(iii) The subject area must have enough clinical importance to warrant the effort involved.

(iv) The subject area must be rich enough in variable parameters to provide students with a wide range of decision-making choices and hold their interest.

This pragmatic advice provides a useful counter to over-enthusiastic mathematical modelling of body systems and attempts to use such models to enrich teaching. Readily available computer systems can now run quite elaborate simulation programs at a speed acceptable for interactive use by a student working at a terminal, and at a fraction of the cost of the much larger computers which would have been required before, to achieve the same performence. However, complex models tend to be difficult to use.

Nomograms and Algorithms to Teach and Assist Diagnosis of Specific Clinical Disorders

In well quantified aspects of medical practice, the computer may be used as a tool to guide interpretation of measurements and choice of treatments. A typical example in this area is that of diagnosis of acid-base disorders. The program of Goldberg, Green, Moss Marbach and Garfinkel (1974) used blood pH and carbon dioxide content or partial pressure — to define the position of sampled blood in one of 30 discrete areas on the pH — PCO_2 plane. They defined regions of acute or chronic respiratory acidosis and alkalosis and metabolic acidosis or alkalosis. Supplementary clinical measurements were then requested, for example serum electrolytes or blood glucose. The management of fluid and electrolyte disorders and specific problems in drug prescribing have been tackled using similar techniques. The system of Bleich (1972) provided an interesting exemple of an approach wich employed complex reasoning about measured data and guided the user to elicit and enter new information to reach a logical assessment of the patient's condition, a forerunner of today's expert system but not developed with the general purpose software tools now available.

Such systems have relevance both for the practising clinical and for the trainee learning the techniques. Bleich's system could be turned round to operate in a problem-solving mode where a particular example of a disordered state was presented and the student guided through the procedures for identifying and treating it.

Artificial Intelligence

Research into "artificial intelligence" in the area of inferential reasoning has led to progress in developing systems which make systematic use of predefined rules to draw conclusions on diagnosis and treatment (Schoolman and Bernstein, 1978). Pionnering examples of such approaches were the 'Mycin' system for guiding choice and prescription of antimicrobial drugs (Shortliffe, 1978) and the more general purpose 'Internist (Caduceus)' program (Pople, Myers and Miller, 1975) designed to assist diagnosis of a wide range of clinical conditions. A potential educational value of such systems is the possibility to make manifest the reasoning process employed in each case.

Such systems would, if adopted, have wide-ranging implications for clinical education and practice; many would oppose them in principle as potentially damaging to human relationships and to the development of human expertise. Thoughtful discussion of such matters may be found in an issue of the Journal of Medicine and Philosophy devoted to the topic, edited by McMullin (McMullin, 1983). At present, the techniques available find their most persuasive use in well defined problem areas. Some impressive examples of performance of such systems have been reported in a variety of areas, some in medicine, but the general level of performance has been slow to improve and potential practical applications in tutoring in medicine remain to be explored in detail.

Some Reasons why Computing Innovations Have not Succeeded

In an editorial review published in 1977 (Computers and Biomedical Research, number 10, 1977), results of a survey of medical computing projects reported in the literature over the preceeding years were described. This revealed that only 19% of these had advanced to routine use and 51% were no longer funded. The main reasons for failure to prosper were summarised as follows :

(i) The system had poor facilities for interaction with the user. It did not exceed the user's own capabilities and therefore had only novelty value.

(ii) There was no direct impact on patient care.

(iii) The system was poorly designed from the point of view of maintainance and portability.

(iv) The design made subsequent change and updating of the system too difficult.

(v) The designers had failed to learn from their own and other people's mistakes.

Such criticisms reflect unclear or inappropriate objectives, inappropriate or poorly managed technology and partly simply human failing. Along with the difficulty of disseminating educational materials, where inter-compatibility among different hardware and software systems has been practically impossible to achieve, we have some of the fundamental reasons for the slow progress in use of computers as a resource in education and training.

Conclusions

In seeking to be objective, and realistic, this review may have strayed into an overly pessimistic portrayal of the prospects for medical educational computing. The potential is clear and exciting but achieving that potential will continue to demand skill, perseverence and powers of persuasion of the highest order. Some areas of continuing development in the field can be clearly foreseen — for example use of new audio-visual media (such as the videodisc) in case studies, to provide an opportunity for more realistic representation of relevant clinical information and as a rich archival resource of a wide variety of images, film, and databases, readily available for interrogation. Others cannot be foreseen as they will arise from progress in other fields — progress on techniques of three-dimensional reconstruction and display of medical images would find valuable applications in medical education but will not come about through efforts in medical education.

In summary, whether the whole of higher education will be revolutionized by information technology within 10 years, as has been suggested by some, or whether at the other end of the scale, the impact will be slight and slow to develop still seems impossible to judge with any certainty. Some medical schools (notably Harvard in the 'New Pathways Programme') are persuaded of the importance of information technology in meeting the educational needs of the next decade and are actively developing ideas for a new curriculum to explore and use it to the full. It does seem inevitable that all students will, through various avenues, have access to large amounts of computer-based educational material of varying quality (as with books or any other educational resource). Thus, the importance of good standards of program design, documentation and portability cannot be over-stressed.

Finally, the achievement of the educational potential of information technology will depend most of all on the attitudes and actions of teachers, and teaching methods, as with many professional disciplines and for some good reasons, are not lightly or quickly changed. It seems likely, therefore, that growth in effective educational use will be slower than in other more clearcut areas, such as in business training applications. In medicine, the emphasis placed on such new approaches will develop hand in hand with information technology securing an accepted role in everyday medical practice.

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PATIENT SIMULATION BY COMPUTER C.A.S.E.S., SOFTWARE FOR THE CONSTRUCTION OF 'COMPUTER PATIENTS'

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1. Introduction

The form of instruction best described as discovery by trial and error is often recognized as the best way to learn, certainly when skills are involved.

'Trial and error' cannot, however, always be applied when the student is actually at work, as many skills do not allow of errors. Just one is fatal. Pilots learning to fly Jumbo-jets won't have much chance of getting up and dusting themselves off and starting all over again if they happen to commit an error at 35,000 feet.

Much the same objection applies to training medical students in healing skills, the difference being that when they commit an error, the patient is the one who has little chance of getting up and walking away unharmed. The use of cockpit simulators to train pilots led to the idea of creating a simulation program for future doctors.

Various forms of simulation can be conceived. We are all familiar with the practice of using a doll in obstetrics. Other examples of simulation are PMP (Patient Management Problem) and the simulated patient. The arrival of the computer has brought us an aid opening whole new vistas for simulation. Computer technology will undoubtedly continue to develop. Computers which listen and talk lie just over the horizon, but even if their development did not progress any further the opportunities offered by the present generation are more than enough to allow of many applications in medical studies. In short, present-day hardware offers us more than sufficient opportunity but the lack of software forms a bottleneck preventing us from making anything more than a very partial use of the potential offered by educational computers.

Various people have thought of writing paient simulation programs before, writing such programs involves *a lot of time*, which has proved to be a difficult obstacle when trying to build up a well assorted archive of a variety of disorders. If we wish to offer students an opportunity to train in diagnosis and treatment, then we must have a good selection of 'computer patients' at our disposal from every field of medical specialization. All those disorders appearing regularly in each field must be represented, and even, as far as is possible, a number of different patients displaying the symptoms of one particular disorder. If this condition is to be fulfilled, a Faculty of Medicine must have many hundreds of cases at its disposal if it wishes to build up a well-assorted file of computer patients.

Writing one case as a computer program takes, in our experience, 200 to 300 hours. At this rate one would have to invest tens of man-years to build up a file of several hundred cases. The Department of General Surgery of the Leiden Faculty of Medicine has attempted to solve this problem by switching from 'bespoke tailored' work -- writing a separate computer program for each patient — to a system one might call 'ready-made' production. We have had to accept that some of the qualities of the 'tailored' product would have to be sacrificed for the benefit of being able to produce a case in a considerably shorter period.

The following conditions for the development of this system of computer simulated patients were drawn up :

1. A clinical teacher must be able to write a case in a short time.
2. The author needs to have no previous knowledge of computer languages.
3. Departments and medical schools should be able to enlarge their files of computer patients by arranging *exchanges*.
4. When exchanging computer patients it should be easy for each teacher to *adapt* a program originating elsewhere to fit his or her personal ideas and insight.
5. Programs should be 'user-friendly' and easy to use in IBM compatible Personal Computers.

The system has been named C.A.S.E.S. This is an acronym for Computer Assisted Simulation and Education System. In our opinion, C.A.S.E.S. will be a valuable aid for teachers who will, in a relatively simple manner, by using the program Editor, be enabled to produce a case themselves in order to simulate a patient with a particular disorder. Medical students will be able to practice solving all kinds of problems taken from a varied assortment of computer patients. Consequently, they will be able to acquire a certain degree of skill without running the risk of harming a real patient. I must emphasize, however, that this form of computer-assisted instruction will never be able to replace bedside instruction, neither may it ever do so.

In the following pages we describe how students must deal with a computer-patient and how a clinical teacher constructs such a patient.

2. The Student as Doctor

After switching on the computer, students make a random choice from the list of patietns. The patient is introduced with some personal details and the most important symptoms. Students then gather as much data from the case history, physical examination, laboratory tests and supplementary tests as they think necessary to be able to diagnose correctly and to prescribe treatment.

Students are told, when gathering data, to pick out those details they consider relevant from a multitude of possibilities. All superfluous laboratory or X-ray tests they request are penalized by negative points on the student's score. The same applies to incorect diagnoses. Students can only proceed further after they have diagnosed correctly. They can then consider what course of treatment the patient should be prescribed. Once they have chosen the correct treatment, they have completed the first section of the computer program. The second section, which follows immediately after, presents detailed comments on each step the student has taken. This then was an overview of the whole program, a more detailed account follows.

Students begin by choosing a patient from the list (Fig. 1). This list can be a selection, only children or only neurological patients for example.

However, it can also a be a random selection such as might be met in a G.P.'s waiting room.

— LIST OF PATIENTS —

0 : End program
1 : Mrs. Jones
2 : Mr. Valera
3 : Mr. Shield
4 : John Branscombe
5 : Mrs. Shortlands
6 : Amanda Firewell

Your choice →

Fig. 1 : List of Patients

As soon as all the data of the patient chosen by the student have been loaded into the computer memory the Main Display Menu (Fig. 2) is displayed on the screen.

— MAIN MENU —

0 : End of this case
2 : Case history
1 : Introduction of the patient
3 : Physical examination
4 : Laboratory tests
5 : Various examinations
6 : Diagnosis and Therapy
7 : Report

Your choice →

Fig. 2 : Main Menu

When the number 1 has been typed in, a text introducing the patient is displayed on the screen. This introduction includes information on the patient's age, sex, profession and any social aspects which may be of importance. This is followed by the patient's symptoms.

The display also informs students of their role as 'doctor' for example, a G.P. during surgery hours or a houseman/intern on duty at the First Aid Post. (Fig. 3).

INTRODUCTION 1/1

Mr. Shield, 42, married, 3 children, insurance agent.
Referred by G.P. to Outpatients' Surgery Ward, for blood in faeces.

You are seeing the patient as a resident at the Surgery Outpatients

0 — 0 — 0

(Press the spacebar to continue)

Fig. 3 : Introduction of a patient

When students have read the introduction, they then recall the Main Menu by pressing any one key, and continue by typing in a 2, thereupon the case history section appears. The case history section comprises a mixture of relevant and irrelevant questions. All the questions are of course typical of what might b asked when taking a medical case history, however some of them are of no interest for this case in the circumstances known to the student at that moment. Just as may happen in actual practice, students can always return to the case history section at a later stage, if they realize that questions initially thought irrelevant may well be relevant after all.

The case history section will include some tens of questions for most computer patients. Eight questions are all that can be displayed at one time (in one frame) however. Consequently, a number of lists will be needed to get through all of the questions. These lists can be worked through in consecutive order or called up separately (Fig. 4).

If students consider a certain question to be relevant, then they must press the corresponding number. The patient's answer appears at the bottom. If, for example, the student had wished to find out the nature of the pain, then he would have chosen question 6 from Fig. 4.

The student may select as many or as few questions from each page as he pleases. The numbers of asked questions appear underlined. If no further questions are to be asked from this page then the following page can be called up by typing the letter F. This process goes on until the student has been through all the pages. The screen then requests the student to think of a provisional list of possible diagnoses (hypotheses).

— QUESTIONNAIRE 1 — 1/3

1. Do you cough a lot ?
2. Have you ever had an operation ?
3. Do you spend much time on sport ?
4. Do any of your relatives suffer from asthma ?
5. Are your parents still alive ?
6. Do you get sudden, severe attacks of pain or is the pain continual and nagging ?
7. When you cough, do you cough anything up ?
8. Have you any problems in urinating ?

Answer to question 6 : It's a biting pain, doctor, it lasts a couple of minutes and then almost goes away again.

Type (choice), F (= Forward), B (= Back) or E (= End of this section) →

Fig. 4 : Example of a list of questions with one question answered.

Before describing the rest of the program it may well be useful to make a few remarks on the teaching aspects of this program. A choice had to be made between two alternatives. Either the students had to be allowed to think up and type in the questions which they thought up themselves, or they could pick their choice from a selection of questions offered by the computer.

The first method (thinking up the questions themselves) might well be the best from the point of view of teaching, but there are three important practical objections to it, namely :

1. Most students are not skilled typists. Consequently, typing in questions would take them a long time and they would quickly loose interest.

2. It would make writing a program much more complicated and take up a lot of the author's time.

3. It would need a relatively large computer memory, one which would be bigger than most micro-computers possess.

For these reasons, we decided to use the alternative, allowing the student to choose from lists of questions. The particular skill in investigating a case history that C.A.S.E.S. attempts to teach students is that needed on confrontation with patients and their immediate complaints. Medical students must certainly also practice taking a detailed *routine* case history but that is a different skill needing other methods of training.

Once a diagnosis has been typed in, the computer can process it in one of four categories: correct, partially correct, wrong, and 'non-recognizable'.

The number of diagnoses placed in the last category can be kept as low as possible by the author's medical and linguistic inventiveness. If students' diagnoses are not wholly correct, then they can be prompted by a 'leading question'. If, for example, they should fill in 'peritonitis' as a diagnosis of the case of acute appendicitis, then the computer, in other words the author, can answer, "So far so good. colleague, but what has caused the peritonitis?" The fact that students need such a prompt will be reflected in their score, but it will encourage them more than if the attempt is met by the cold statement "This is incorrect".

They will, indeed, be told just that if their diagnosis is wide of the mark but has been recognized by the computer because the author has anticipated such a diagnosis and has included it in the program's data.

If students still do not manage to diagnose correctly even after prompting, then a list of diagnoses appears, all of which are relatively plausible, but only one of which, of course, is correct. Fig. 5 gives an example of a list of diagnoses.

Try to select the correct diagnosis from the following list :

1. overtaxing
2. thrombosis of the calf vein
3. torn muscle
4. osteomyelitis of the tibia
5. arterial thrombosis
6. thrombophlebitis
7. entrapment of the popliteal artery
8. crural fracture

Your choice + (return) →

Fig. 5 : Example of a list of diagnoses.

Students indicate their preference for a particular diagnosis by typing in a number. If this is indeed correct, then the following section of the program, 'Treatment', appears on the screen. If it still is not correct then the list of diagnoses reappears. This process is repeated until the correct diagnosis has been found (or guessed !).

The Treatment section follows with the same procedure as for the Diagnosis, two chances to prescribe correctly with or without the computer's assistance and then a list. Students are, of course, penalized for all the incorrect diagnoses and treatments they inflict on their 'patients'.

3. The Author as Teacher

The future doctors have now finished dealing with their patients, but from the teaching point of view the most important part of the program still has to begin. All the choices they have made and decisions they have taken now pass the review accompanied by comments. The screen displays to the students all the case history questions they asked which the author of the program had categorized as irrelevant, accompanied by the author's reasons for regarding them as irrelevant. Then all the relevant questions which the students should have asked are displayed, again with a brief explanation by the teacher why that particular question is important and should have been asked.

The laboratory and then the supplementary tests are dealt with likewise, being submitted to a critical commentary. The incorrect diagnoses and wrongly prescribed treatments are also discussed and an explanation given as to why exactly they are wrong.

The scores marked up for each of the 6 sections are displayed as a bar graph and the program finishes with a mini-lecture on the particular disorder dealt with in the case.

The student has now gone through the case, including the author's comments on the student's performance. At this point students can choose one of two alternatives:

A. they call another patient in from the "waiting-room";

B they decide to pursue the problems involved in the case just dealt with more deeply.

Should they decide on the second, then they can study the teacher's comments on the incorrect decisions that they did *not* take. This could be a good revison exercise for the student. They can, for example, study the full differential diagnosis of the case, or go through the teacher's arguments why certain tests are superfluous and therefore undesirable.

4. The Production of a New Case

By standardizing production the time needed to create a new computer patient can be drastically limited. One of the preconditons this system had to fulfill was that the author of a case need know nothing of computer languages.

This system has speeded up and simplified the production of computer patients. In a short while the clinical teachers gain sufficient experience to create a new computer patient in a few hours work. They need only fill in a C.A.S.E.S. form. A fictitious patient can be created out of thin air, but data can also be taken from the case history of a real patient or from cases described in medical books. When completed, the form can be given to a typist to be typed in on a computer. All further processing needed to create a complete computer patient can be entrusted to the EDITOR of C.A.S.E.S.

The C.A.S.E.S. form consists of about thirty pages each with a text instructing the author how the content of a case should be structured and filled in in the correct spaces. It would be going too far to describe the C.A.S.E.S. form in detail here, we shall suffice by giving one page — marked NL — as an example.

NL stands for 'Non-relevant Laboratory Tests. Authors are asked to write down a number of lab tests on these NL pages which they consider not necessary or even superfluous for that patient in those circumstances. The result (e.g. a number with units) is filled in after the test and, if so desired, the standard values. The 'reasons', teachers comments on why, in their opinion, the test is irrelevant and therefore superfluous in those circumstances, is filed in in the space which follows below.

Teachers indicate, by means of a letter code, in a separate column their assessment of the seriousness of the mistake made. The following code is used :

R = Routine Test. This is a simple test which does not inflict any extra burden on the patient (a blood sample is already available, for example, as it has already been taken for other reasons) and which hardly involves any expense.

B = inflicts suffering on the patient. For example internal examination techniques on other kinds of examination which are lengthy and painful.

K = expensive tests.

B + K = a combination of the two.

The number of negative scoring points (penalties) is ascertained with the aid of these qualifications. Obviously the combination B + K will incur the highest penalty. What we wish to achieve by this is that students do not request whole lists of tests or other research gratuitously, but think carefully about the direction in which they must search beforehand. C.A.S.E.S. might perhaps contribute, albeit modestly, towards an efficient use of the health services' budget as a result.

Figure 6 shows part of one of the NL pages concerning an 8-year-old boy suffering from a greenstick fracture of the right forearm after falling off his bicycle.

Sequence	Irrelevant Laboratory Test	Result Nominal value + units	R, B, K or B + K	Score
	8. Alkaline phosphatase	92 U/1	B	—16
	Reasons : A representative trauma can be found in the case history, so there is no reason to assume that bone pathology already present has caused a spontaneous fracture. Moreover, children always have a higher alkaline phosphatase.			

Fig. 6

As we have already pointed out, the teacher needs know nothing of programming to fill in a C.A.S.E.S. form, but should certainly have plenty of experience in giving clinical instruction to medical students.

Authors should be able to draw on a wide range of experience so that they know or have developed an intuitive feeling for the kind of mistakes that students can make. Students get the opportunity to make them without harming a patient, and the teacher has an opportunity of placing a few well-chosen comments and of explaining why something is wrong and how it should be done.

Experience has shown that the most difficult problem authors have to face when filling in C.A.S.E.S. forms is thinking up the irrelevant items.

Good teachers will do their best not to fill in anything transparently irrelevant, since it will never or hardly ever be requested by the students. Authors should attempt to think of items which, though irrelevant, are still closely related to relevant ones. From their experience of teaching, they know that some students are wrongly inclined to follow a particular train in thought. Should students indeed go off on the wrong track by choosing such an irrelevant item then authors can correct this pattern in their comments.

For example: a 68-year old female presents an increasing constipation and fatigue (caused by a sigmoid carcinoma).

The student is interested in the answer to this question: "Did you ever live in a tropical country?". Asking that question he will receive the patient's answer: "No doctor, I never left this country". The author considers this an irrelevant question and (later) the student will receive the teacher's comment: "This is a relevant question in case of chronic diarrhoea, however there is no known tropical disease which causes constipation".

This manner of teaching students can be applied throughout the program and is not limited to the case history as in the example above. The authors can, for example, point out the difference between an X-ray of the wrist and one of the forearm, or the difference in value for the diagnosis of a disorder of X-rays of the abdomen taken while the patient is lying or while standing.

A basic rule for this type of self-instruction is that the student must learn from every mistake he makes. This means that the author of the case must take great care that the comment on each irrelevant or wrong item *should always contain a positive element.*

The Diagnosis and Treatment sections have their own particular problems for authors. They must fill in the correct diagnosis and a list of as many other diagnoses as possible which, within reason, students must also take into consideration. Each diagnosis in this list of differential diagnoses should be accompanied by the reasons why it cannot be correct. Every conceivable symptom of all the diagnoses listed (both the correct one and the list of DDs) should be filled in by the author. This is necessary because students have to type in the diagnosis which they conclude is correct, themselves. This means that the computer's memory must be programmed so exhaustively that practically anything can be recognized.

For example, a 22-year-old woman has an acute appendicitis. If students type in 'inflammation of the vermiform appendix' then the computer must be capable of recognizing this and react on the screen with: "Well done colleague, acute appendicitis is indeed the correct diagnosis". In the initial phase of developing the system we failed to recognize this problem, and we found that it was an extremely frustrating experience for our students if the computer reacted badly with the comment: "Your diagnosis has not been recognized".

For instance, one of the diagnoses included in the DD list of this example was 'salpingitis', but if the student typed in 'inflamation of a Fallopian tube', this incorrect diagnosis was not accompanied by the comments on why it was wrong which the author had filled in under 'salpingitis'. Thinking of *all the possible synonymous* versions of a diagnosis gives teachers a chance to exercise their imaginations. Since the computer stores everything on the disc we are able, once a computer patient has gone through a trial period, to make a print-out of all the diagnoses the students have made during that period by using the program Utilities option 4: 'Print out of scores' and use them, if necessary, to add to or alter the program. Thus the student can improve on and supplement the author's work.

5. The Scoring System

Experience has shown us that being able to score points adds a sporting element to the system for the students. Most of them attempt to score as highly as possible even when they use this computer-assisted instruction entirely voluntarily. The scoring system allows this form of patient simulation to be used for the following purposes:

a. Self-essessment. Students can assess their knowledge and skills before an exam by running through a few computer patients.

b. As part of an official examination.

We have scored the six sections (number 2 to 6) so the students can see what their strong and weak points are after going through a number of patients. We have scored the *Case History section and physical examination* as follows: all the relevant questions score a total of +100 points. Nuances of importance have been introduced between the relevant questions, the author indicates this by means of a code. All the irrelevant questions score a total of —100 negative points, distributed equally among the questions. Students who cannot decide what is relevant and what is irrelevant will probably ask all the questions in order to gather as much information as possible. Consequently, their score for Case History will probably be nil, or in any case very low. The Physical Examination section is scored likewise.

A slightly different system of scoring is used for the sections *Laboratory Tests and Various Examinations.* All the relevant items (per section) together score +100 points. Here again individual items can be given differing values. The negative score awarded for the irrelevant items is decided by the classification R, B, K, B+K (for definitions, see explanation). An 'R' item is not penalized, but a B+K item is penalized so heavily (e.g. : —60), that the student will most certainly be failed for that section. If no tests are considered necessary for a particular case, then students must indicate this. They are then awarded +100 points.

The sections *Diagnosis and Treatment* are scored in yet another manner. If the correct diagnosis is typed in straight away, then the student is awarded 100 points; a correct diagnosis at the second attempt gets 80. If the students only succeed in diagnosing correctly when the DD list has been displayed, then the score is 60 or lower, depending on how serious the blunders are. The author indicates this on the C.A.S.E.S. form, an F for incorrect and FF for a fatally incorrect diagnosis. The Treatment Section is scored likewise.

The same applies to the scoring system as to all the data. If teachers obtain a case from elsewhere, then the standard score can be altered very simply to what they consider to be correct. When developing C.A.S.E.S. we have always kept our goal firmly in view, namely to develop software which will enable clinical teachers to make their *own* computer patients in a relatively easy manner. If we were to deliver a complete file of patients, then there would be immediate objections to certain details of the content. All teachers cherish their own particular way of seeing things. C.A.S.E.S. offers an opportunity to expand the file of patients fast, by an exchange of case reports between departments and medical schools *without* having to ignore each teacher's personal wishes. For this reason we have developed an important part of the EDITOR of C.A.S.E.S., namely the 'Edit case' program. This allows the text to be changed very quickly and simply. Any secretary can do it, even those who have no word-processing experience. It is so 'user-friendly', that even teachers can edit changes if they wish (see Editor Manual).

6. Feedback from Student to Teacher

The computer can store all the student's reactions in its memory, either per student or per computer-patient. A statistics sub-routine included in the C.A.S.E.S. software allows for the detailed calculation and printing of cumulative data per patient. One can imagine, for example, that the patient with the sigmoid carcinoma has been "treated" by 42 students during the past months. The statistical print-out reveals that 30 of these students, being 70%, asked the question about living in a tropical country. This percentage should alert the teacher to paying closer attention to the subject in the following lectures in order to correct an apparently widespread misunderstanding among the students. (See Utilities Manual).

7. Experience with Clinical Computer-Aided Instruction at the Leiden Faculty of Medicine

Clinical instruction has been given to *first* year students since 1982/83 as part of the new curriculum made necessary by recent reforms in Dutch university education. This clinical instruction can be very useful and help motivate the students particularly when clearly related to the basic subjects (anatomy, physiology, biochemistry etc.).

Knowledge, once acquired, 'stiks' better, however, if it can be applied. It follows, therefore, that clinical instruction for first-year students must lead to application of their freshly acquired theoretical knowledge through contact with patients. There were, however, various reasons making such direct patient-student contact impossible to achieve during the first year of study. The opportunity to simulate patient problems through C.A.S.E.S. was, therefore, a very welcome alternative and no objection whatever was made to its introduction.

A number of computer-patients were created specially oriented to first year students' level knowdelge. Thanks to the availability of a computer room equipped with fifteen micro-computers, the students could follow a compulsory practical. C.A.S.E.S. enabled them to practice their skill in patient management.

The results of a questionnaire filled in by the students showed that the great majority were enthusiastic about this type of CAI. Junior and senior housemen/interns are also given the opportunity to use computer facilities in the study room of the clinic besides the video tapes and audio-visual slide presentations already available. This means they can practice diagnosing and treating disorders which may not occur among the patients admitted while they are studying at the clinic.

Although C.A.S.E.S. was intended in first instance for use on micro-computers it can also be fed into a network.

C.A.S.E.S., which was originally written in BASIC, has been re-written in a PASCAL program.

8. The Use of Computer-Assisted Instruction for Post Graduate Medical Education (PGME)

Where the term 'students' has been mentioned above, it included doctors who wish to test or improve their skill by this type of clinical computer-assisted instruction, as well as medical students in the strict sense of the word. Once computers have become commonplace in doctors' consulting rooms, C.A.S.E.S. and similar computer programs will be able to make a valuable contribution towards PGME. By having a floppy disc sent to them or by connecting up to a telephone line through a modem, doctors will be able to test their skills in the privacy of their own study and, if necessary, supplement their knowledge with information on recent advances and new insights in medical science.

9. The Further Development of C.A.S.E.S.

C.A.S.E.S., as described above, has already been in operation for several years. Further development is continuing, however. The most important expansion of the system is the addition of visual images. Many types of examinations, such as X-ray sonography, computerized tomographic scanning, EEGs, ECGs, etc. produce an image as result. Until now the results of such examinations have been reported to students by means of a text displayed on a screen which gives an expert interpretation of the examination in words. The images can, however, be put onto slides and the micro-computer linked to a projector which is directly controlled by the computer and the students thus shown the results of a piece of research 'in kind'

If they request an ECG, then it is projected as a slide for them. The teachers themselves can decide the extent to which they leave the interpretation of the test — a sonography, a PA microscopic slide or a tomographic scan — to the student. Alternatively, teachers can, of course, offer an expert interpretation and explanation as instruction. For example, "The arrow on this thorax photo points to some fluid in the right-hand pleural sinus".

Besides these static pictures, it may well be prefreable to be able to show filmed sequences. Good examples are the limping of a boy suffering from epiphysiolysis of the ball of the femur, or the radio-paque passage of a substance through the oesophagus shown by cine-radiography, which can much better be seen than described. Recording and showing these on a video tape is a relatively simple matter.

When a student has chosen a test with moving pictures. a message will be shown on the display e.g. "You must play the video tape from number 680 till 1120".

The *ideal* medium for both still and moving pictures is the Video Laser Disc (VLD), which can produce a picture or sequence almost instantaneously. At he moment only a few specialized studios can record images on a VLD, which means teachers will have to be satisfied with what they are offered ready-made on VLD.

On adding up the balance of advantages and disadvantages, the automated slide projector and video recorder can be expected to satisfy needs for the moment. Well selected collections of slides and video recordings can, when the time is ripe, be transferred to VLDs. Quite conceivably, the recording of images on VLD will be within the consumer's reach in the not too distant future, especially if one bears in mind the speed with which audio and video equipment has been developed. In October 1986 a single videodisc with 30,000 medical pictures will be released (see Appendix Meddix Data).

10. Opportunities for the Use of C.A.S.E.S. Outside Medical Facilities

The para-medical professions are the first to spring to mind. The first steps have, in fact, already been taken. Schools for dieticians and physio-therapy schools and speech-training schools have already used C.A.S.E.S. after making a few modifications.

It does not take any great stretch of the imagination to see many uses for C.A.S.E.S. outside the medical world, in particular for technical training programmes. An airplane engine refuses to start, its exhaust gases are an abnormal colour, the search for the cause of the trouble and its repair can easily be compared with diagnosing and treating a disorder. C.A.S.E.S., originally developed for the benefit of medical education needs only slight adaptation to make it suitable for many non-medical training programmes.

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MICROCOMPUTERS IN STATISTICAL EDUCATION: THE BUCKINGHAM EXPERIENCE

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1. Introduction

This article describes some of our experiences at the University of Buckingham, England, in using microcomputer software and hardware in support of statistics teaching. The account is written from a personal perspective, and is to that extent anecdotal. Nevertheless, I have tried to set the account of our Buckingham experiences within the wider context of the microcomputer software and hardware market in the United Kingdom (U.K.), and to make some general remarks about the use of microcomputers in the teaching of statistics.

Sections 2 and 3 give a brief background to the University of Buckingham, the degree programmes it offers, and the statistics courses taught here. This is not intended as an advertisment for the University. It is necessary because Buckingham University is unusual — indeed, in some respects unique — among U.K. universities, as outlined in Section 2 below. One of the consequences of Buckingham's special character has been that microcomputers have played a particularly important part, relative to larger computing machines, in the development of computing support for teaching.

Sections 4 to 6 of the paper give a more or less chronological outline of our experiences with microcomputers between 1978 and the present. The story line is one of how rapid development in microcomputer hardware and software, and the adaptation by software houses of well-established statistical software from main-frame computers to microcomputers, has enabled Buckingham University, like many other teaching institutions, to provide computer support for statistics and other academic programmes at a relatively modest cost. (Rowe (1984a) briefly documents another example). From our point of view, advances in microcomputing, and the associated fall in the costs of hardware and software, came at an opportune time.

2. The University of Buckingham

Buckingham University is unique among chartered U.K. university institutions in being the only one not to receive financial support directly from Government sources. All revenues come from student fees and from private donations. In this respect, it is the U.K.'s only "private" or "independent" University. By "chartered", I refer to the possession of a Royal Charter. The institution opened its doors to students, as the University College at Buckingham, in 1976. It received its Royal Charter, and became the University of Buckingham, in 1983. A sympathetic account of the University's formation and early years is given by Pemberton and Pemberton (1979). A more recent, and more critical perspective is offered by Shaw and Blaug (1987).

Buckingham is a small institution by U.K. university standards. We currently have around 630 students. It has grown from even more modest beginnings, the first student intake of 1976 numbering only 67.

Apart from its financial status and size, there are other features that have contributed to Buckingham's character. The academic year for most students begins in January (rather than the usual academic start in September or October), and the calendar year has four teaching terms, each of 10 weeks duration. Most students complete an honours degree programme in two years : that is, eight terms or 80 teaching weeks. The two-year degree programmes, and their implications for the relative costs of completing a degree at Buckingham compared with other U.K. universities, has made Buckingham an attractive option for some overseas students. Currently, about 36% of our students are from the U.K. The next largest national groupings are Malaysians (19%) and Nigerians (11%). Our student body encompasses 58 nationalities. Mature students too figure more prominently at Buckingham than at U.K. universities in general. Almost half of our present students were aged 21 or over when they entered the University, compared with about 15% in the same age group entering U.K. state universities as undergraduates in 1985/86.

3. Academic Programmes at Buckingham

In terms of student numbers, the School of Law is at present the predominant faculty at Buckingham (around half of all students). The next largest School is Accounting, Business and Economics (between 25% and 30% of all students). The School of Sciences is, as yet, a relatively small component (less than 10% of all students), though has contributed, very substantially to the research activities of the University (Shaw and Blaug 1987). A degree programme in Biological Sciences has existed since 1980, and Computer Science degree programmes since 1986. There are no degree programmes in which students major in either Statistics or Mathematics. The nearest approach to this so far is a programme in Computer Science with Applicable Mathematics, which comprises roughly two-thirds Computer Science and one-third Applicable Mathematics.

However, all students majoring in Biology, Accounting, Business Studies, and most of those in Computer Science, have coursese in applied statistics as part of their degree programmes. Typically, students majoring in Biology or Accounting take two or three terms of statistics. whilst those majoring in Economics, Business Studies or Computer Science have a single term of statistics. There are also a small number of students majoring in other subject areas — Law, History, Politics, European Studies — who chose to take statistics as one of their optional courses. Altogether then, around 125 students (nearly half of our January intake) take statistics courses in any one year. The courses have a very applied flavour, and are geared as much as possible to the subject areas in which the students are majoring.

Given the present-day importance of computing in many branches of statistical science, both at a practical and at a theoretical level, it is desirable that, when statistics is taught, even as an ancillary subject and at an elementary level, the opportunity should be sought of giving students a glimpse of the part computers can play. This is one of the principles that we have tried to adopt in our statistics courses over the last eight or so years.

4. The Early Days of Microcomputers.

Our first plans to develop computing facilities to support teaching and research at Buckingham University were made in 1978. Because of the small scale of our operations at the time, and the scarcity of financial resources, the possibility of acquiring an in-house main-frame computer was never seriously considered. Fortunately, from our point of view, desk-top microcomputers were beginning to reach the U.K. market. The market leaders at the time were Apple, Commodore and Tandy. The availability of these small machines enabled us to make a modest beginning in computing without a massive outlay of funds. Our first purchases were Commodore PET micros. They had calculator-style keyboards, 40-column black-and-white monitors, built-in cassette drives using ordinary audio--cassette tape, 8 kilobytes of random access memory (RAM), and the BASIC programming language in read-only memory (ROM). The price of each machine was around £500 at 1979 prices, roughly £900 at 1987 prices if the re-valuation is done using the U.K. Retail Prices Index. That sum today would buy an IBM XT "clone" with 640 kilobytes of RAM, a floppy disk drive and a 20-megabyte hard disk. (When I last visited the Science Museum in South Kensington, London, a Commodore PET micro was one of the exhibits !)

Our purchase of these machines was not solely, or even mainly, with statistics in mind. We also had to consider the need to support teaching programmes in accounting, economics, mathematics and biology. This has also been the case for the purchase of microcomputers since then. Our computing facilities are considered as University — rather than departmental or faculty — resources.

Software for the Commodore PET micros was relatively limited in its sophistication, when judged either by present-day microcomputer standards, or by the main-frame computer standards of 1979. The restricted scope arose mainly from the size and technical limitations of the machines. Audio-tape as the only form of program and data storage can be a slow and frustrating way of working, as many home computer owners quickly discover! The statistical software we bought, or were given, or wrote ourselves did relatively specific jobs, like producing descriptive statistics for single samples of data, or calculating regression estimates and correlations for bivariate or multivariate samples. Students taking statistics courses, most of whom also had introductory computind courses to familiarise them with the PET micros and the BASIC programming language, had the opportunity of "hands-on" experience with these pieces of software. The micros were used primarily for student project work, for demonstration purposes and to give some limited support in staff research work. Our main objective at that time, framed in light of the resources available to us, was to give students taking statistics courses some notion of the labour-saving potential of even small computing machines.

We also had time-sharing access to a DEC-20 main-frame machine running the conversational statistics package IDA. This was used extensively by staff applying statistical techniques in research work in other discipline (e.g. economics, biology), and we incorporated occasional demonstrations of IDA into statistics lecture classes, to show the power of a "real" general-purpose data analysis package.

It is interesting at this point to look in more generality at the market for microcomputer statistical software, as revealed by the 1980 "Register of software for statistical, survey and general social science computing", compiled by the Study Group on Computers in Survey Analysis SGCSA). SGCSA is an organisation affiliated to the British Computer Society and the Market Research Society, that has published such software registers on seven occasions between 1973 and 1987 (Hall et al., 1973; Rowe et. al., 1975; Rowe and Hall 1978; Rowe 1980; Cable and Rowe 1983; Cable et al., 1985; Rowe and Cable 1987). The SGCSA registers cover statistical software for all types of computing machine, though since 1980 the registers have become increasingly dominated by software for microcomputers. Two lists of statistical software, confined to those programs that would run on miccrocomputers, were published by Neffendorf (1982, 1983) in *The Professional Statistician,* the newsletter of the (U.K.) Institute of Statisticians. As with the interpretation of most registers, there is the problem of assessing the level of completeness, and of whether the adequacy of the coverage has altered substantially over the years. Nevertheless, the SGSCA registers, supplemented by Neffendorf's lists, offer an interesting picture of the changing situation over the years, and the broad trends they suggest are probably fairly reliable. I shall refer to them again in the sections that follow.

The 1980 SGCSA register contained 113 entries, of which only three programs were listed as running on microcomputers (one of the three ran on both main-frame machines and micros). The three programs were each designed for a different machine: one for Commodore, one for Apple and one for Wang.

5. Z80 Micros and CPM

Real progress, for us, came when desk-top machines based on the Z80 microprocessor chip established themselves firmly in the market-place, and the CPM operating system that ran on these machines became something of a *de facto* standard for microcomputers (as we shall see below, the Apple operating system was, as far as available statistical software was concerned, a "competing" standard). Some indication of the growth of the market in statistical software running on Z80 micros under the CPM operating system can be gained from Neffendorf's 1982 and 1983 lists of statistical software for micros, and from the 1983 SGCSA register of statistical software (Neffendorf 1982, 1983; Cable and Rowe 1983).

Neffendorf's 1982 list ran to 26 items. By the following year, the update had grown over two-fold, to 56 items. Of the 26 programs on the 1982 list, nearly half (12) were documented as running under CPM, slightly more than half (14) on Apple machines, 4 on Commodore, and 3 on Tandy micros (some programs were listed as running on more than one type of machine). The figures for all these four categories grew between the 1982 list and the 1983 update, the most substantial increase being for CPM and Apple. The 1983 list had rather more than a third of programs (20 out of the 56) running under CPM, half on Apple, 6 on Commodore, and 5 on Tandy. An important new category of entry to the 1983 list was programs running under PC/MSDOS, the operating system for the recently launched IBM PC and for IBM PC "compatibles". Neffendorf's 1983 list contained 25 items running under PC/MSDOS (45% of the total). I shall comment further on this in the following section.

The 1983 SGCSA register showed a broadly similar picture to Neffendorf's list. The total number of items on the SGCSA register in 1983 (for all types of machines) was 119, only a marginal increase over 1980. However, more significantly in the present context, the number of items listed as running on microcomputers had risen from 3 to 39. Of these, about three-fifths (24) were documented as running under CPM, nearly half (18) under Appledos (the Apple operating system) and only one fewer (17) under PC/MSDOS. Some of the detailed differences between the figures in the SGCSA register as compared with Neffendorf's lists arise, because the latter give information only about the type of machine on which each program runs, often though not always described in terms of th operating system for the machine, whereas the information on the SGCSA register distinguishes hardware and operating system.

Our first purchases of statistical software running under CPM were the S.A.M. and Microstat programs (for reviews of these two programs, see Shoesmith 1982, 1983), at a time when we had only two single-user Z80-based micros running CPM. S.A.M. and Microstat are general-purpose statistical packages, both menu-driven in their style of operation, with data entry, editing and transformation facilities, and a good range of statistical procedures. We used the two programs fairly extensively in student project work and in staff research involving applied statistics, but not as a regular adjunct to teaching. They provided us with a valuable introduction to CPM software.

In early 1983, we bought the CPM micro version of the popular main-frame statistics package Minitab (converted to run under CPM by CLE.COM of Birmingham, England), and mounted it on two Comart Z80 multi-user micros. It was at this point that the incorporation of a computing element into statistics courses at Buckingham began in earnest. Minitab, which had existed on main-frame and mini computers since the mid-1970's, already had an established reputation as a teaching aid in statistics. The CPM version, despite some limitations and problems, ran well on the Comart micros (for a review, see Shoesmith 1984). The package is strong on data manipulation, exploratory data analysis, regression, probability distributions, and generation of random data. It uses a command-driven mode of operation whose syntax seems to be quickly picked up by students. The accompanying documentation is good. All these are excellent ingredients for a package to be used in teaching (some further thoughts on the kind of package needed to support applied statistics teaching can be found below in Section 9). Since the time we began using Minitab on the multi-user Comarts, all students taking statistics courses at Buckingham have been exposed to at least the rudiments of the Minitab command language. This has enabled them to do simple data analyses, and to practise exercises designed to illustrate basic probabilistic and statistical principles. Some students, biology majors in particular, go on to use Minitab extensively in project work.

6. IBM PC-Compatible Micros

In the previous section, I noted the emergence, in Neffendorf's 1983 list and the 1983 SGCSA register, of statistical software running under the PC/MSDOS operating system. It is apparent from these lists that, when the IBM PC was launched, and soon follwed by compatibles and "clones", many of the programs originally marketed for CPM were quickly adapted to run also under PC/MSDOS. A look at the SGCSA registers of 1985 and 1987 shows how dominant PC/MSDOS has become since then as the major microcomputer operating system for statistical software. The 1985 SGCSA register (Cable et al., 1985) included 109 items for micros, of which between two-thirds and three-quarters (77) ran under PC/MSDOS. In 1987, according to the latest SGCSA register, the domination of PC/MSDOS is even more pronounced: of 158 programs for micros on the register, nearly 90% (138) are listed as running under PC/MSDOS.

One very notable trend has been the implementation by major software houses of micro versions of well-established statistical programs that ran previously only on main-frame and mini computers. Relatively few well-known main-frame packages became available under CPM, almost certainly because of the memory restrictions imposed by the operating system and by the machines on which it ran. Minitab and GLIM were two outstanding examples of widely used statistical programs that did migrate to CPM micros. With the larger RAM and hard disks available on the IBM XT/AT and compatibles, the situation under PC/MSDOS is very different. The 1987 SGCSA register contains PC/MSDOS versions of all the well-known "main-frame names" in statistical software: for instance, SPSS, SAS, BMDP, Genstat, TSP, Soritec, P-Stat.

Buckingham's move to IBM XT compatibility took place at the end of 1985, when we equipped a new Computing Laboratory with Olivetti M24 micros. This was part of our preparations for launching new academic programmes in Computer Science. The Olivettis are used also in support of teaching in other academic programs. As far as computing support for statistics teaching was concerned, continuity was provided by Minitab. We now have multiple copies of Release 5.1 of Minitab for IBM PC/XT/AT-compatible micros. Apart from speed of operation, size of worksheet, and graphical capabilities, this is essentially identical to the version of Minitab currently available on main-frame machines, and is an excellent teaching tool. There are now quite a number of introductory statistics texts that incorporate Minitab as a pedagogical aid (e.g. McGhee 1985; Howell 1985; Kvanli et al., 1986).

We have also enhanced our facilities for research work involving applied statistics by buying single copies of SPSS PC+, Soritec and Statgraphics.

7. What Will Follow PC/MSDOS ?

The total number of items listed in the SGCSA registers has grown markedly since 1980, from 113 to 207 in 1987. This growth is accounted for by the increase in the number of programs available on microcomputers, which has gone from 3 in 1980 to 158 in 1987. After a brief period in the early 1980's when CPM and Apple were the most popular microcomputer operating systems for statistical software, the market has become dominated by PC/MSDOS software. The number of items in the SGCSA registers running under CPM and Appledos has remained fairly statistic since 1983 (28 and 19 items respectively in the 1987 list) but they now form a much smaller proportion of the total than previously.

What of the future? What can we expect of the 1989 register? Given the large investment by software houses in PC/MSDOS software, it seems almost inevitable that in the next few years we see a continued presence of this operating system, accompanied by adaptation of software to the newly announced IBM micro operating system, OS/2, that will run on its PS/2 range of micros.

8. Some Practical Problems

A brief mention is worthwhile of two "commercial" problems that we have experienced. So far I have tended to stress the advantages that microcomputers, and the falling costs of hardware and software, have brought to a small institution like Buckingham University. They have enabled us to reach our current position of having a number of "main-frame-quality" statistical packages available and running successfully on desk-top micros, at a considerably lower cost than would have been the case had main-frame computers been the only purchase option. But as a small institution we have encoutered stumbling blocks with pricing policies for multiple copies of software. Though there is no doubt that microcomputer software often offers cost advantages over main-frame software, current pricing policies adopted by software houses for multiple copies of software can cause problems for small organisations.

At the time when Z80 micros and the CPM operating system figured prominently in the market, multiple-copy purchase arrangements varied widely between companies, because the market was new and still settling. Arrangements were often favourable to academic institutions, regadless of size. Some examples, for European and U.S. companies, are given by Rowe (1984b, 1985). The favourable position was almost certainly due in part to the fact that the majority of the software available had been written specially for micros.

Now, on the other hand, as noted above, we have available many sophisticated statistical programs that have been adapted from mainframes to PC/MSDOS micros. In general, their size and relative complexity mean that they command higher prices for single copies, and purchase or licence arrangements for multiple copies tend to be modelled to some extent on licence arrangements for their main-frame forebears. For single-copy purchases, it is not unusual now to find that one piece of complex statistical software can cost as much, or more, than the hardware on which it is designed to run. Licence arrangements tend to be favourable for institutions that need many copies of the software, for example in the fifties or hundreds, but much less favourable for those that need only 5 or 10 copies. Cambridge University, for example, evidently has a licence arrangement for SPSS/PC+ that enables the University to sell copies of the software outright to members of the University for about £ 150. An institution that uses only 5 copies of SPSS/PC + will pay comfortably in excess of this sum each year, per copy, to licence its use of the package.

Large, sophisticated pieces of statistical software for micros tend, for obvious reasons, to be carefully protected from illegal copying. A common system of protection is the "key disk" arrangement, whereby a special diskette must reside in the floppy disk drive of the micro when the program is loaded, and sometimes also at other points during operation, for instance when modules of the program are swapped between RAM and hard disk. Issue and retrieval of multiple key disks in the classroom situation can be an administrative head-ache, and even more of a problem when students wish to pursue exercises and project work outside scheduled class hours. Minitab has now moved to a protection system in which the "key" can be installed on the hard disk. This is a much more convenient arrangement, but in its present form carries with it the danger that the "key" installation can be inadvertently wiped off the hard disk, or otherwise corrupted, by users. Fortunately, the Minitab distributors have been understanding so far in replacing "keys" that we have lost in this way !

9. The Ideal Teaching Package

It is pertinent to ask what our experience over he last eight years or so has led us to expect of an "ideal" package for use on microcomputers in support of statistics teaching. The list below gives ten points which seem to me important. The list is certainly not exhaustive, and no doubt there is a certain amount of personal preference embodied in my choice of items for the list.

(1) A predominantly interactive mode of operation, giving the user quick feedback on the results of his/her actions, so that he/she can react appropriately before the next stage of analysis. Interactive working helps to split the analysis task into manageable pieces, providing the user with positive encouragement in the form of output on the VDU, or warnings and guidance in the form of error messages. This is particularly inportant for inexperienced users, who can find "batch"-style operation very frustrating when mistakes in one section of the command sequence prevent any useful output at all from appearing on the VDU.

(2) Detailed on-screen help, if needed, supplemented by good documentation. I have already remarked on error messages in connection with point (1), but they are worth mentioning here too. Error messages should be explicit and helpful, and should be designed as part of the system of on-screen guidance.

(3) Flexible data entry, editing and manipulation facilities. Ideally, these would include a good full-screen, spreadsheet-type editor. The data entry options should make it easy to import data from other software packages, including text-processors, spreadsheets and database management systems. Export of data to such packages should also be facilitated.

(4) A variety of options for producing summary displays of data. These would include Tukey-type exploratory methods. One of the great merits of using computers to support statistics teaching is that, given the right software facilities, students can relatively easily and quickly subject data sets to careful descriptive examination before attempting formal analyses.

(5) A wide range of built-in statistical procedures for the common types of "formal" analysis, such as regression, analysis of variance, multivariate techniques.

(6) User control over the form and extent of output, but with sensible default values built in if the user chooses not to exert control.

(7) Good graphical output, especially on-screen but also to printer/plotter. Graphical facilities would lend particular support to (4) and (6).

(8) Fast operation. This is, perhaps, a convenience rather than a fundamental necessity, but if practical statistical computing sessions are to be conducted within a reasonable time-scale (e.g. 1-hour or 2-hour sessions), it is desirable that the software should work efficiently. There is also the point that users tend to become discouraged, bored or frustrated if they have to sit for long periods waiting for results to appear.

(9) Flexible facilities for Monte Carlo-type simulation. A good teaching package will allow users to investigate sampling variability, the central limit theorem, and the coverage properties of confidence intervals, for example, in a "pseudo-practical" way (see, e.g., Horgan 1985 ; Saunders 1986 ; Bloom et al., 1986). This will entail options for generating random data, and for calculating probabilities and expected values, from a range of distributional forms.

(10) Extendable by the user, e.g. by means of "macros". The ability to develop and store command sequences will enable the user to produce analyses that are not provided routinely by the package, and will facilitate simulation exercises as envisaged in (9). If the command structure of the package is sufficiently rich, the ability to produce useful macros can be provided by relatively simple control structures.

In drawing up this list, I have focussed on the requirements for a statistics package to be used in support of teaching. Indeed, I have had primarily in mind the needs associated with students who come with little or no experience of statistics, and who do not intend to become statistical experts. The list might well be somewhat different for statistical specialists or researchesr in other disciplines who use sophisticated statistical techniques in their work. For example, statistical specialists may well want relatively sophisticated programming facilities, rather than just an ability to create simple macros. Nevertheless, any package that fulfilled all the criteria implied by the list above would inevitably also be a very useful tool for much of the applied work done by specialists in statistics and in related disciplines.

Release 5.1. of Minitab for PC/MSDOS micros scores well on most of the above points, falling short on only (6) and (7) perhaps. I have recently had the opportunity to review a relatively new package, Instat, produced by the Statistical Services Centre at the University of Reading, England, which is equally impressive as a teaching aid (for a review, see Shoesmith 1987), though leaves something to be desired in repect of (8).

When I drafted the above list, I originally included the item "simple and consistent command syntax", but eventually omitted it because it might seem to pre-empt the choice between command-driven and menu-driven modes of use. Some of the remaining items in my list — (9) and (10), most probably — may still give the impression of doing this. Judging only the basis of statistical packages that I have used, I am inclined to feel that the criteria in my list are more likely to be filled by a command-driven package, like Minitab and Instat, than a menu-driven package. The range of options that can be concisely and quickly dealt with by good command-driven packages seems wider than that of the best menu-driven packages available. Yet, given fast hardware and a well-implemented WIMP environment (windows, icons, mouse, pull-down menus), I see no reason why a menu-driven mode of operation could not be made to work satisfactorily (if not optimally) on all counts, except perhaps (10). The ideal would be a package that gives a genuine choice between command-driven and menu-driven modes of operation, so that users can switch depending on their personal preferences and degree of familiarity with the package. This, too, would give the opportunity to do a real test of the user interface that students prefer. Most experienced statisticians express preferences for command-driven packages, but inexperienced users may think quite differently.

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COURSES IN COMPUTER GRAPHICS IN FACULTIES OF MECHANICAL ENGINEERING IN CZECHOSLOVAKIA

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1. Introduction

The importance of computer graphics, as a scientific discipline dealing with computer aided graphic information processing in the most diverse fields, especially in computer-aided design (CAD) is constantly growing. Parallel to this trend a demand to include mandatory computer graphics in the curricula of Faculties of Mechanical Engineering of Technical Universities in Czechoslovakia has emerged. It was in the school year 1980/81 that these ideas came to fruition and a new subject. namely that of Computer Graphics and Numerical Methods with 2 periods of lectures and 2 periods of seminar per week (2 + 2) came into being. In this intent an autonomous course (1 + 1) in computer graphics was started for the students of Mechanical Engineering Design in their fifth term. The rest of the students, about a third of the total number, could attend optional lectures in computer graphics. By starting these courses our universities joined the ranks of the most prestigious universities world-wide.

The successful introduction of this innovation was based on thorough familiarity with the problems involved and positive results in the work of all those who had been asked to work in this field. In the following we present detailed descriptions of the individual stages of preparatory work before classes started and focus on instruction and experience gained. Finally prospects for courses in computer graphics are assessed.

2. Preparation for Computer Graphics Teaching

At the beginning of 1980 a number of the teaching staff in the Section of Constructive Geometry within the Department of Mathematics and Constructive Geometry in the Faculty of Mechanical Engineering of the Technical University in Prague were given the task to start preparing courses in computer graphics in Faculties of Mechanical Engineering in Czechoslovakia (thre are 6 of them). These were experienced teachers who had been working in this field for a number of years. On the one hand they gained their experience in research work and on the other in organizing optional lectures in computer graphics.

There were four aspects to the preparatory stage :

— formulation of course content and syllabus,

— writing a textbook,

— selection and preparation of software and its implementation on the computers of the the faculties,

— preparation of teachers.

In the first stage the basic course content was agreed on. The aim was to familiarize the students with the fundamentals of computer graphics and their practical application in the field of mechanical engineering, especially in technical drawing, solution of design problems, design and manipulation with curves and graphical surfaces in engineering applications and in CAD. Special emphasis was put on concrete individual solutions to assignments given to the students by means of a computer and a graphical output device. As a starting point, familiarity with the Fortran language was assumed. Students were acquainted with it in their freshman year.

The course syllabus was deduced from the main target areas and linkage to other disciplines, such as programming, numerical mathematics, constructive geometry, descriptive geometry, technical drawing and CAD. The syllabus consists of two elementary parts, which deal with the means of computer graphics and the study of curves and surfaces in computer graphics. In the first part the emphasis is on program systems which the students must master before they can start solving problems assigned to them.

The syllabus in the computer graphics course is made up of the following parts :

- technical and program means of computer graphics,
- mathematical means of computer graphics,
- basic graphics packages,
- software for :
  - elements of engineering drawings,
  - planimetric constructions,
  - stereometric constructions,
- analytical curves and surfaces,
- interpolation and approximation of
  - curves,
  - surfaces,
- CAD and computer graphics.

The designing of the syllabus was followed by writing a textbook (1) which completely covered the syllabus and served as a manual of program systems with which the students were to work. For internal use of the teachers an appendix to the textbook was written comprising solutions to all exercises included in the textbook.

In order to achieve the goal, i.e. to enable the students to solve the tasks on a computer by themselves, it was necessary to take great care in preparing the software. Computer graphics software produced in previous years in the Section of Constructive Geometry were used as a starting point. Identical hardware at the majority of Faculties of Mechanical Engineering enabled to transfer the software and, in cooperation with the staff of computer centres, to implement it on faculty computers.

Selection of program systems was based on the subject syllabus and contained four extensive systems constituted by subroutines in Fortran.

FSIGRAF — basic graphics package,
ELEMENTS — elements of engineering drawings,
PLANI — planimetric constructions,
STEREO — stereometric constructions.

This sophisticated program stage could be completed in such a short time only due to previously produced reliable software that could be used by all faculties without greater problems as soon as computer graphics teaching was introduced.

The final stage belonged to the most important ones as it was devoted to teacher training. Departments of Mathematics and Descriptive Geometry at all Faculties of Mechanical Engineering were charged with teaching computer graphics. For the teachers in these departments, computer graphics was an entirely unknown discipline and they had minimum experience with computers. To get aquainted with the topic, the teachers had been given handouts of individual chapters of the textbook before it was published. Intensive teacher training was organized in two workshops lasting several days where the subject matter was explained in detail and practised. During an excursion to the computer centre, examples of graphical outputs from the computer were demonstrated.

The teachers made every effort to prepare for teaching this new, and in its complexity, highly demanding discipline and were greatly interested in the task.

In the end, it is possible to say that preparation of the teaching of computer graphics was carried out with great pains and in spite of extremely short time available, it was successful. It is necessary to appreciate the assurance of hardware and software for these courses namely the uniformity of this software which enables easy transfer of the programs and thus the exchange of studies in this field among the individual Faculties of Mechanical Engineering.

3. The Run and Analysis of the Courses

The first course of computer graphics was run in the school year 1980/81 in compliance with the binding curricula. Lectures were accompanied by slides projection and two instructive films about graphic peripheries and possiblities of rationalization in machine tool design.

In the lecture related classes simple programs in Fortran with applications of subroutines of graphic systems were created. The students in addition to written accounts dealing with computer geometry were expected to fulfil a given task consisting as a rule in an engineering drawing of a simple machine component by means of a computer with a graphic output. The fulfilment of this task was a precondition for credit obtaining. To prevent overheating of computer centres the credit tasks were organized in groups of 2 to 7 students. Even in the first run of courses such demanding problems as the student's computer tasks in...ing graphic output were successfully solved.

The courses ended up with credit or the exam within the range of examination in numerical methods.

The subject had met with a positive response on the part of the students which resulted in their participation in the Students' Scientific and Technical Optional Activity in the field of computer graphics.

The initial insufficiencies were removed and classes were consolidated in the following years. Technical equipment and software were improved too. The lecturers also could rely on their experience resulting from the previous preparations of the course. Better conditions found their expression in higer level of the results of students' works; to some of them very definite standards could be applied. Work groups jointly involved in credit tasks were reduced to 2—4 students. More students are taking part in the Students' Scientific and Technical Optional Activity in the field of computer graphics and they get very good placing, e.g. students of the Faculty of Mechanical Engineering in Prague advanced once to the all-state, and twice to the international round of this competition.

The seminars aimed at the exchange of experiences among lecturers and at better use of software and teaching aids, are organized every year for the members of the academic staff and they have proved to be very useful. In the related accounts the subject of computer graphics and its curricula are widened and more deeply dealt with, together with its practical application even in connection with the field trips to individual enterprises. These seminars had considerable effects on the consolidation of the courses and helped to reach the objectives of the lectures. The exhibiton of students' works which are up to standard and provoke much interest prove the ability of the students to work individually with the graphic program systems and they inspire lecturers in setting the credit tasks.

On the whole it can be stated that the main objective — to enable the students to get practically aquainted with the possibilities of computer graphics — has been reached. Though the numbers of students participating in the courses are comparatively large (more than 600 in Prague), each student has a definite computational task to solve and is given a graphic document about the result of his work. A number of students can apply the results of the courses to the solution of tasks connected with the Students' Scientific and Technical Optional Activity or with their dissertations.

4. The Outlook for Computer Graphics Teaching

Computer graphics teaching will provide students with the basic knowledge of a discipline which is an important part of a new promising branch — computer — aided design. No reference to CAD is possible as yet since CAD teaching has not been provided for in the syllabus so far. This is partly related to the fact that there is still no technical equipment available that would make it possible to implement the practical part of CAD teaching at the desirable level, i.e. in the interactive mode. Therefore it is necessary that computer graphics classes be supplemented by work with interactive graphic systems to prepare students for interactive work with CAD systems.

This is the reason for the modification of the subject's scope involving expansion by topics dealing with interactive computer graphics and geometry issues in the CAD system on the one hand and reduction in the present-day emphasis on elements of passive computer graphics on the other hand.

Once the difficulties with technical equipment have been solved, a no less serious problem of software for interactive computer graphics will arise. Creation of such software is extremely difficult from all aspects and should be paid great attention to and arranged for in advance. Also teacher training requires special attention and suitable seminars for this purpose will have to be organized. In this respect, things will be simplified by the fact that teachers have gained a great deal of valuable experience with and have overcome their shyness of computer technology.

When universities have been furnished with interactive graphic systems, changes to the syllabus of computer graphics teaching will have to be made accordingly. These changes are hardly compatible with today's minimum extent of teaching units (1 + 1) which should therefore be increased by one unit. It is also desirable that the subject be accorded rating not just by credits, but also graded credits.

The increasing use of computer technology, in problem-solving within various branches of technology and the predictable and inevitable arrival of CAD at design centres of our enterprises has to be taken account of in the preparation of future engineers, a trend which must be reflected in computer graphics teaching as well. At the same time, it should not be forgotten that geometrical means used in computer graphics derive from constructive geometry which thus becomes the first link in the chain taken up by computer graphics and CAD.

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ON THE WAY TO CHAOS — AN ANALYSIS OF A FAMILY OF LOGISTIC MODELS

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1. Introduction

The conventional way to study what is the system behind an observed time series is to use well known standard methods of time series analysis. The main characteristic of standard analysis is that, when an analyst is making a choice of a model for the system he/she is usually not interested in any complex nonlinear features but mainly linearities on nonlinearities only in a narrow region. Possible nonlinearities will usually remain undetected in the noise. In the recent years, complex features of systems and their realizations in time series has got growing interest among researches. The aim of the analysis is to reconstruct such a dynamical law for the system which is able to produce the observed time series and to explain the occurrence of oscillations of chaotic nature.

The law can be presented for instance with the help of difference equations. Some difference equation, even very simple ones, can reveal very complex behaviour in addition to the ordinary fixed point behaviour. This complex behaviour can be either limit cycle or chaotic behaviour. The development of computers has given a new alternative to study these phenomena : Complex behaviour can be powerfully revealed with computationl experiments. Amongst the first ones R.M. May and G.F. Oster made such experiments (see. [10], [11]). E.g. T. Kinnunen and H. Pastijn have continued making these experiments with the same models and also with some other models [4], [5]. In these experiments the chaotic behaviour of some one-dimensional difference equations was studied with the help of computed bifurcation diagrams and Lyapunov characteristic exponents. These difference equations define growth models, some of which are often encountered in economic literature and some of which are derived from the other models. The analysis is continued in this paper.

The models that will be studied in this paper form a family of logistic equations ; all of them have some connection to the logistic equation. When these models are used for modelling real dynamical systerms, parameter setting and estimation has a great importance, because even small changes in the parameter values can introduce quantitative and qualitative changes in the behaviour of the system. These changes in turn effect to the results when these models are used for forecasting. In this paper some of the critical parameter values concerning the models are gathered together in one table and comparisons between models are made.

2. The Family of the Models

The one-dimensional growth models treated in this study have a connection with the most often analysed growth model, the logistic model:

(1) $$x_{t+1} = rx_t(1 - x_t)$$

or with one variation of it, the exponential form

(2) $$x_{t+1} = x_t \exp(r(1 - x_t)).$$

(For the origin of the models that are found in the literature see [2], [7], [10], [11], and for the models that are derived from the other models see [4].)

Other models analysed in this study are given in equations (3)—(14):

(3) $$x_{t+1} = x_t(1 + r(1 - x_t)).$$

(4) $$x_{t+1} = x_t[1 + r(1 - x_t) + (r^2/2)(1 - x_t)^2],$$

(5) $$x_{t+1} = x_t[1 + r(1 - x_t) + (r^2/2)(1 - x_t)^2 + (r^3/6)(1 - x_t)^3],$$

(6) $$x_{t+1} = x_t \exp(r(L - x_t)), \text{ where } 0 < L < 1,$$

(7) $$x_{t+1} = rx_t^{1-b},$$

(8) $$x_{t+1} = x_t(1 - b\ln(rx_t)),$$

(9) $$x_{t+1} = r_1 x_t^{1-b} r_2 \exp(-x_t),$$

(10) $$x_{t+1} = x_t(1 - b\ln(r_1 x_t)) r_2 \exp(-x_t),$$

(11) $$x_{t+1} = x_t(1 - b\ln(r_1 x_t)) r_2 (1 - x_t),$$

(12) $$x_{t+1} = x_t(1 - b\ln(r_1 x_t)) r_2 (1 - x_t + x_t^2/2),$$

(13) $$x_{t+1} = x_t \exp(r_1 x_t^{m-1} - r_2 x_t^{n-1}) \text{ and}$$

(14) $$x_{t+1} = x_t(1 + r_1 x_t^M - r_2 x_t^N).$$

In the models (13) and (14) $r_1, r_2 > 0$. In the model (13) $n > m > 1$ and in the model (14), $N > M > 0$.

The models (2), (6) — (9), (13) — (14) and especially the logistic one (1) and (3) have been used either in their discrete or continuous form for economic problems such as innovation diffusion, forecasting of energy consumption, car production, on for biological problems such as the growth of an organism, the growth of a population or for demographical problems such as comparative study of demographic strategies, etc. (see [2], [7], [8], [9]).

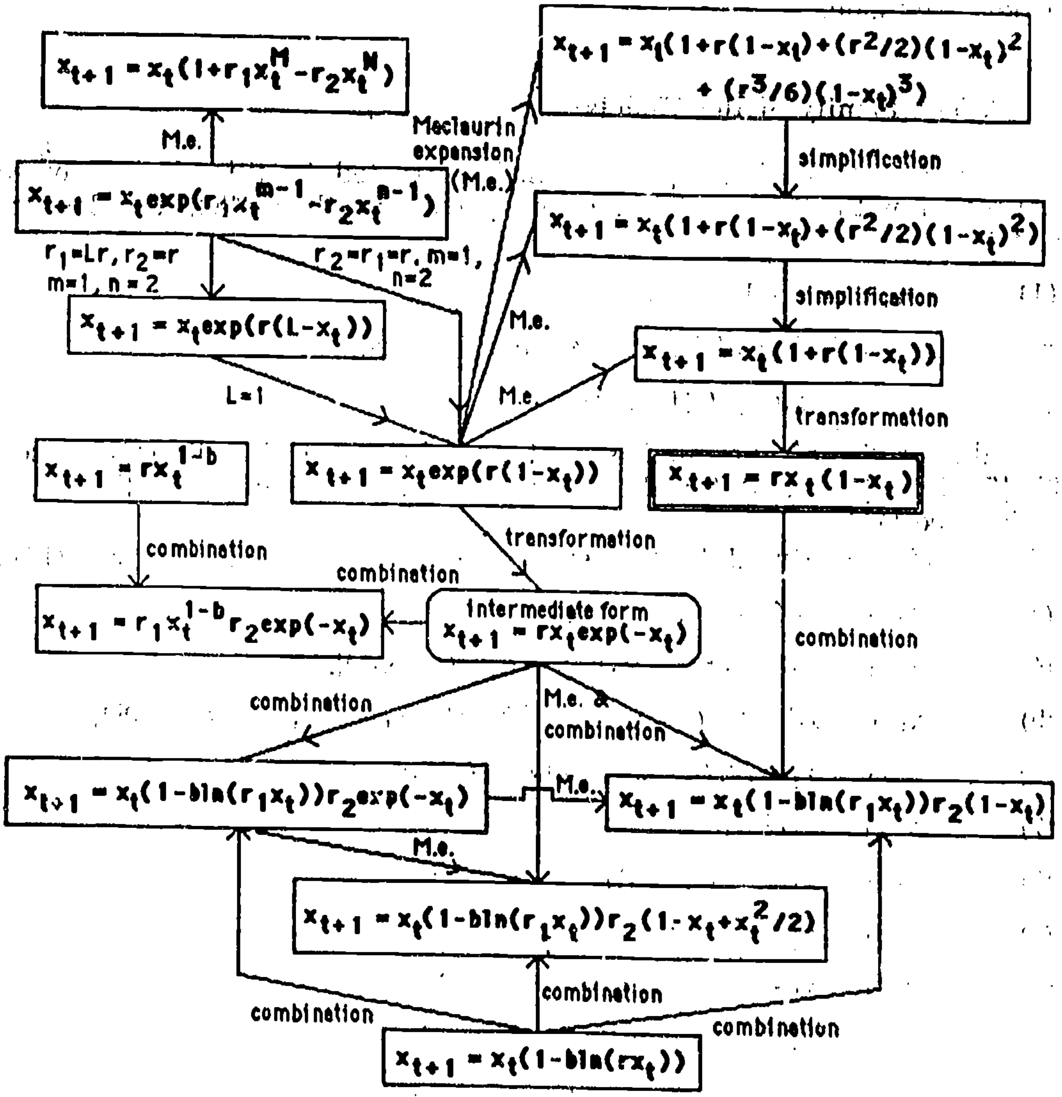

Fig. 1. A family of logistic models

In the chart above the arrows show the logical relationships between the different models. An arrow shows from which model(s) a model has been derived. This deriving has been made either by simplification, by transformation, by taking a MacLaurin expansion, or by connecting parts of two models.

3. A Demonstration of the Behaviour of the Models

3.1. Bifurcation Diagrams, and Period-Doubling

Behaviour of these growth models has been analysed with bifurcation diagrams and Lyapunov characteristic exponents. All parameters except one are fixed and the behaviour of the models as a function of this one parameter is studied ([4], [5]). One example of a different kind of behaviour in a growth model is provided by the model (8).

Figure 2 is a typical bifurcation diagram. It was created by making several runs with different values of the parameter b. The parameter r has the same value (r = 4) in all these runs. With a certain value of the parameter b one hundred iterations were computed according to equation (8) and after that the next 50 iterations were plotted. As can be seen with the parameter values b ∈ [1.0, 2.0) the system reaches the point $x_t = 0.25$ with the first hundred iterations and stays there. An attractor (i.e. a point or a region that attracts all the nearby points) that has this kind of behaviour is called a fixed point attractor. This fixed point can be found analytically (for solving the fixed points of difference equations analytically see [10] p. 460) by solving the equation

$$F(x) = x, \tag{15}$$

where $F(x) = x(1-b\ln(rx))$. This yields the solution $x_0 = 1/r$. A fixed point is locally stable (an attractor), if $|F'(x_0)| < 1$. For the equation (8) this yields $|F'(x_0)| = |1-b\ln(rx_0)| = |1-b| < 1$. Thus the fixed point $x_0 = 1/r$ is locally stable, when $0 < b < 2$ regardless of the value the parameter r assumes. Figure 2 confirms this result in the interval [1, 2) with $x = 1/r = 0.25$.

A small increase in the value of the parameter b causes the system to eventually oscillate between two points. When the value of the parameter b is increased, the system eventually oscillates between four points, and with a further increase between eight points, sixteen points, etc. This doubling in the number of the amount of the points that the system is oscillating between, continues until from some parameter value, b_k, and onwards the behaviour appears chaotic. This chaos is, however, deterministic : Repeating the run with the same parameter values and the same initial condition, the same sequence of the values x_t is obtained. An attractor that has this kind of chaotic behaviour is called a chaotic attractor whereas an attractor that consists of several fixed points between which the system cycles is called a limit cycle. A limit cycle which consists of k points is called a limit cycle of period k. The points can be found analytically by solving the fixed points of the k^{th} iterate $F^{(k)}(x) = F(F^{(k-1)}(x))$. For example the points of the limit cycle of period 2 can be found for the model (8) solving the equation

$$F^{(2)}(x) = x, \tag{16}$$

where $F^{(2)}(x) = F(F(x)) = x(1-b\ln(rx))(1-b\ln(rx(1-b\ln(rx))))$. As can be

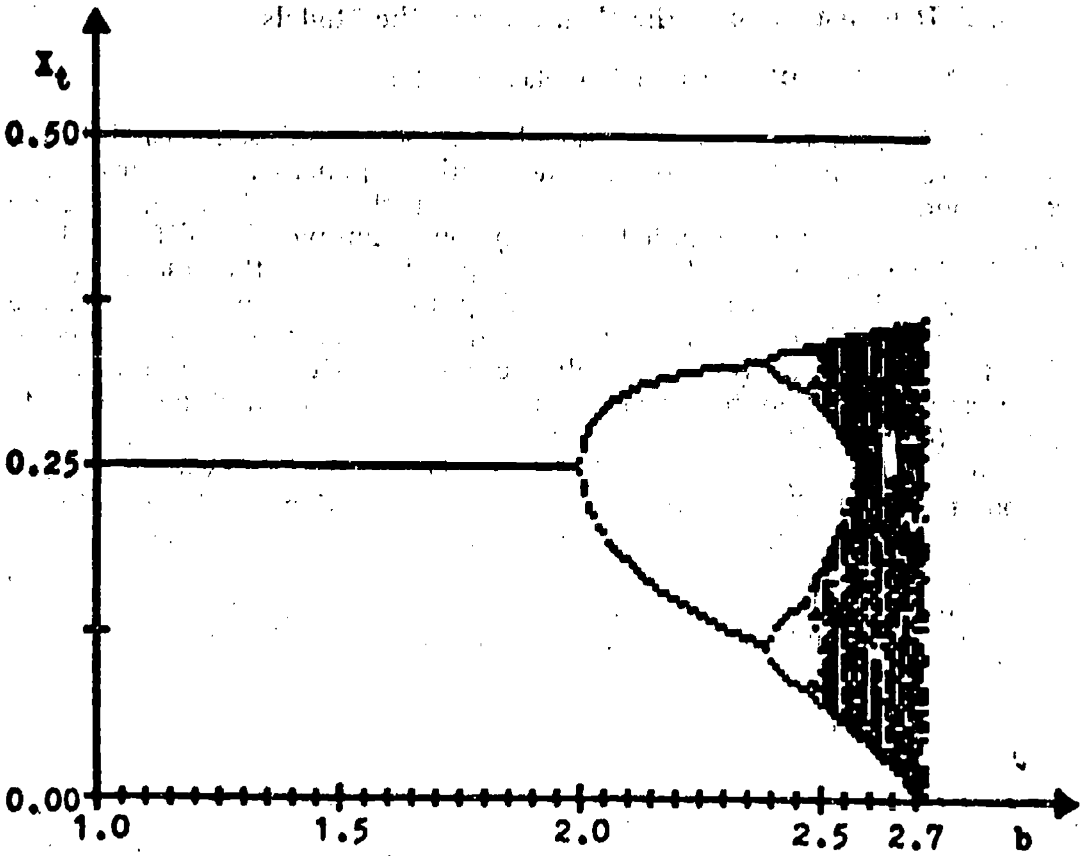

Fig. 2. The bifurcation diagram for the model (8).

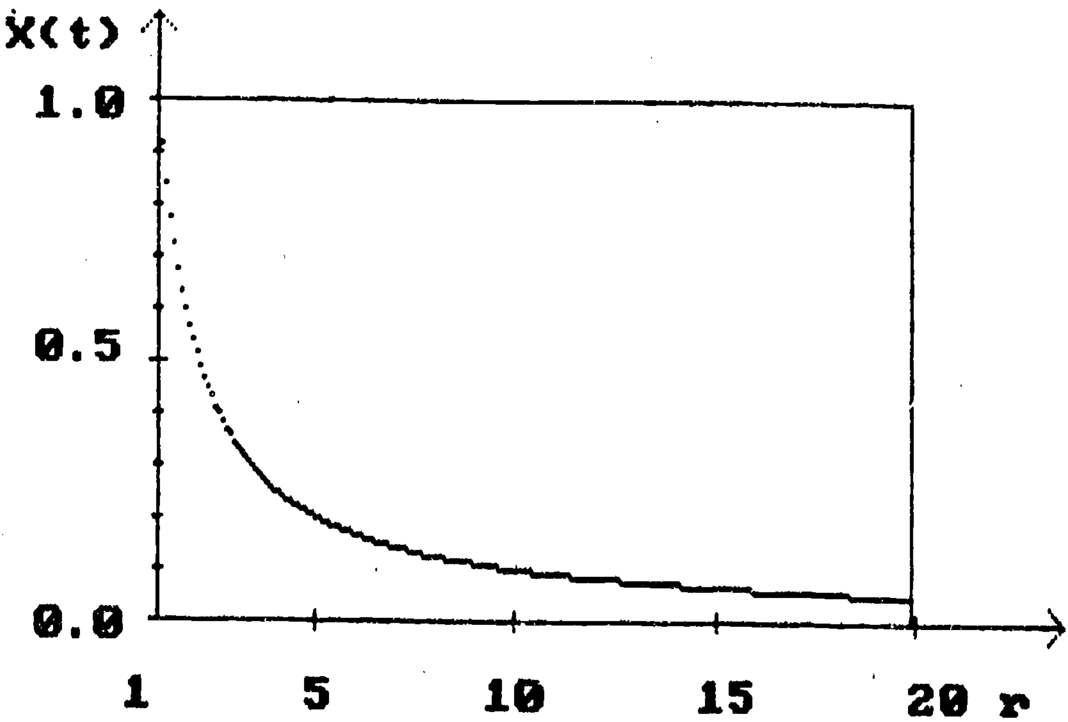

Fig. 3. The effect of the parameter r in the model (8), b = 1.5

foreseen from this equation, finding the limit cycle analytically soon becomes a tedious task as the period number increases.

The fixed point attractor can be regarded as a special case of the limit cycle attractor ; it is a limit cycle of period 1.

For the chaotic attractor it is typical that there can be some parameter values that give limit cycle behaviour. The period of the limit cycle is not necessarily of the period 2^k but the period can be any possible integer. (For analysing the period number possible for a difference equation see [12].) Some limit cycles can be seen also in Figure 2.

Figure 2 reveals the behaviour of the model (8) as a function of the parameter b. The effect of the other parameter, r, can also be analysed. This has been done in figures 3—5 where $r \in (1,20)$. To see what kind of change in the behaviour the parameter r brings, the value for the parameter b for figure 3 is picked from the fixed point region (see Fig. 2), giving b the value 1.5. According to Figure 3, only a fixed point attractor can be found. For Figure 4 the value for the parameter b is picked from the limit cycle region (with the period number two). Figure 4 drawn with the value b = 2.3 gives only a limit cycle of period 2. For Figure 5 the value for parameter b is chosen from the chaotic region, b = 2.55. Only a chaotic attractor can be found. According to Figures 3—5 the parameter r does not change the quality of the behaviour. It has merely a scaling effect.

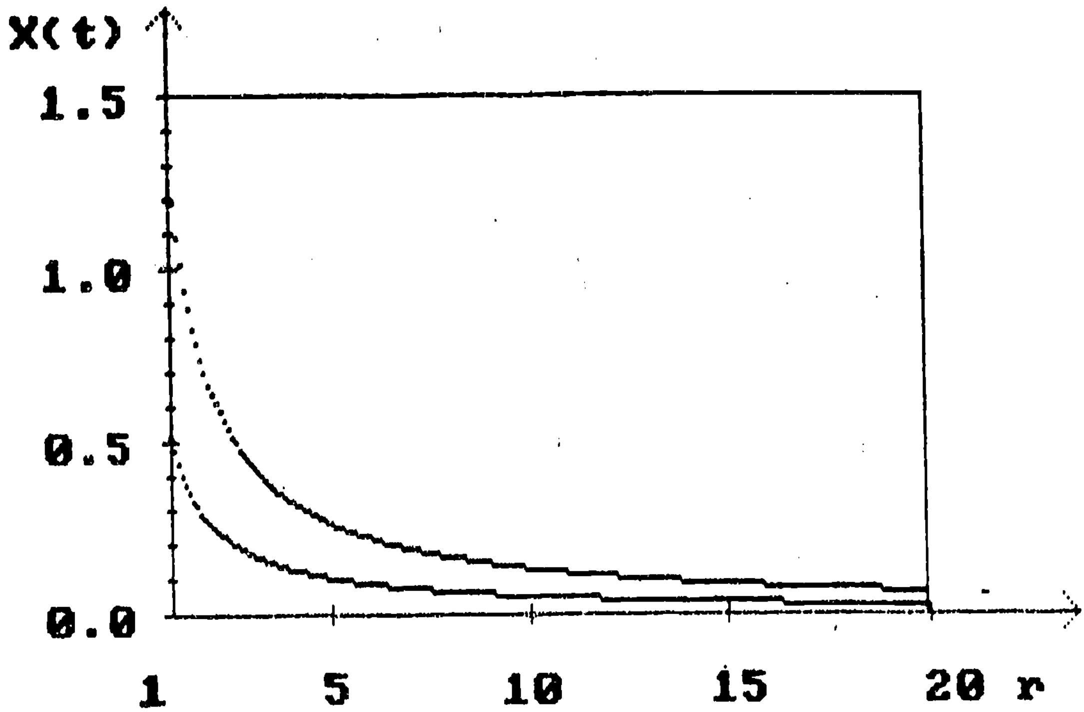

Fig. 4. The effect of the parameter r in the model (8), b = 2.3

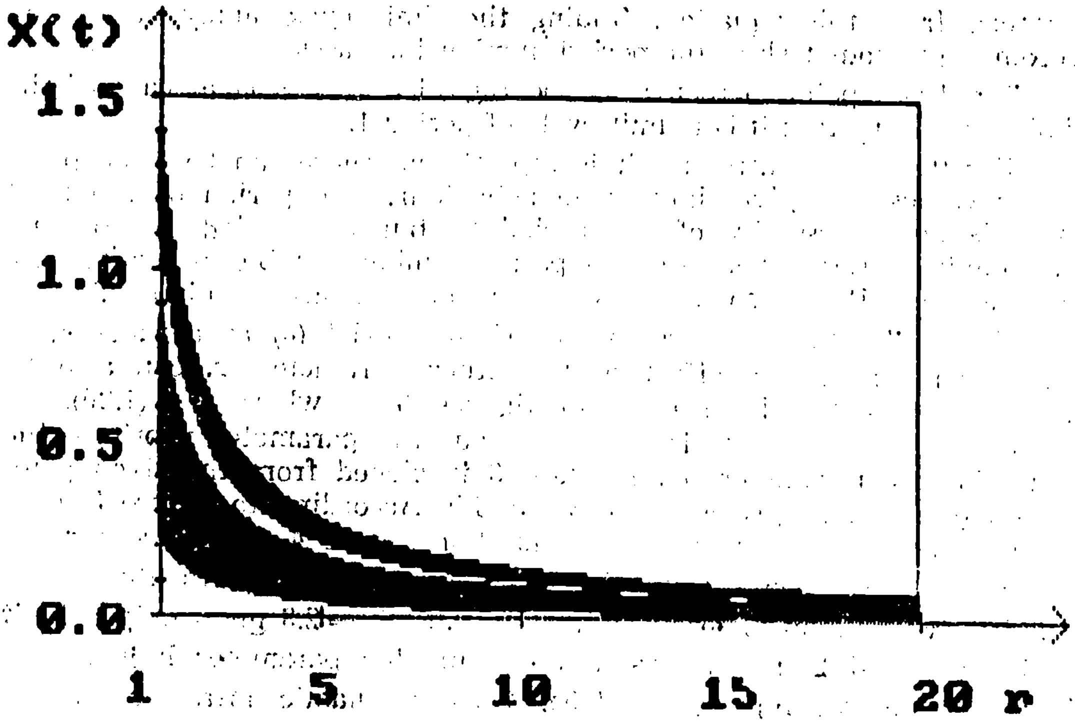

Fig. 5. The effect of the parameter r in the model (8), b = 2.55

As can be seen later with other models there care be more than one parameter which changes the types of behaviour. In the light of the models studied it seems to be rather an exception than a rule that the parameter does not effect the type of behaviour.

3.2. Lyapunov Exponents

Information about the types of behaviour can also obtained by computing Lyapunov characteristic exponents. The Lyapunov characteristic exponent is defined by the formula (for this formula and for the following stability limits see [1] p. 53) :

$$\text{(17)} \qquad LjE(p) = \lim_{N \to \infty} [(1/N) \sum_{n=0}^{N} \ln|F'(p, x^n)|]$$

where p is the parameter under study.

It can be easily seen that the value LjE(p) is associated with the average local stability of an orbit as follows :

i) If $LjE(p) < 0$, the orbit is locally stable,

ii) If $LjE(p) = 0$, the orbit is neutrally stable,

iii) If $LjE(p) > 0$, the orbit is locally unstable.

For a bifurcation diagram i), ii) and iii) mean that

i) there is either a fixed point attractor or a more general limit cycle attractor,

ii) a change in the type of the attractor or period-doubling occurs,
iii) the attractor is chaotic.

The estimates for the Lyapunov characteristic exponent as a function of the parameter b for the model (8) can be seen in figure 6. For this figure 400 iterations at each of 2000 increments of b in [2.0, 2.7] were used. The value LjE(2) = 0 indicates a change in the type of the attractor or period — doubling. According to Figure 2 this can be identified as the first period — doubling. The third time when LjE(b) has a value 0 is when $b \approx 2.47$.

With that value the limit cycle of period 8 appears the first time. Soon after this value of b chaotic region begins (LjE > 0). Signs of limit cycle behaviour are the negative values of LjE(b) in the chaotic parameter region.

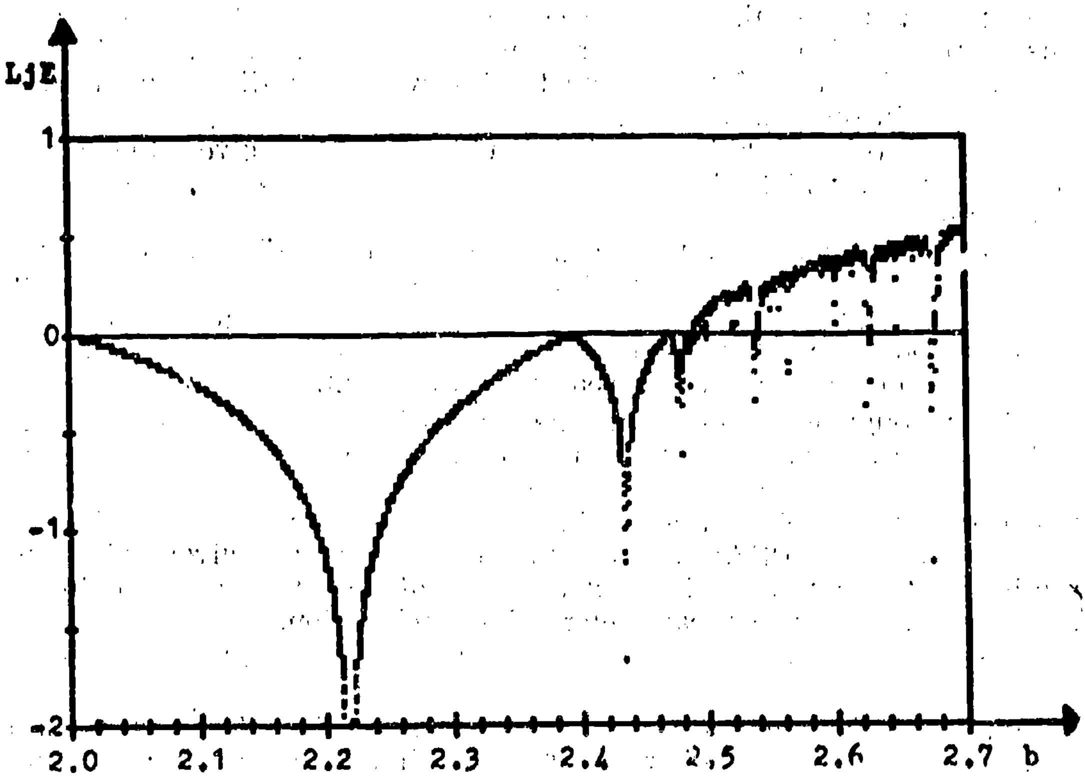

Fig. 6. Lyapunov characteristic exponents for the model (8)

4. Behavioural Characteristics of the Model Family

Some critical points of the behaviour of the models studied are collected into table "Critical values for fixed point and limit cycle behaviour for the models (1) — (14)". For each model in the table there are:

i) The parameter whose effect to the behaviour has been analysed and the parameter interval that has been used.

ii) The fixed values of the other parameters in the model.

iii) The direction of bifurcation development. If the period number of the limit cycles increases through the period-doublings when the value of the analysed parameters is increased, the direction of bifurcation development is marked with "+". The bifurcation diagram opens to the right. If the period number of the limit cycle increases through period-doublings when the value of the analysed parameter is decreased, the direction of bifurcation development is marked with "—". The bifurcation diagram opens to the left.

iv) The column marked "Fixed point attractor region begins" gives the value of the analysed parameter where the fixed point attractor region begins *in the analysed parameter interval*. If this value is the first point in the studied interval and the direction of bifurcation development is + or the last point and the direction of bifurcation development is —, then the fixed point region could have begun outside the studied region. The region extends from this point in the bifurcation direction of the parameter interval up until the parameter value given in the next column.

v) The column "First period-doubling occurs" gives the parameter value at which the first period-doubling in the analysed parameter interval occurs.

vi) The column "Limit cycle of period 8 apperas" gives the parameter value for the third period-doubling, i.e. the parameter value at which the region for the limit cycle of period 8 begins. After the third period-doubling subsequent doublings occur quickly and the chaotic region begins relatively soon after this point.

After rough estimation with the help of the bifurcation diagrams and Lyapunov exponent figures the limiting parameter values for the table "Critical values for fixed point and limit cycle behaviour for the models (1) — (14)" were obtained making experiments with Koçak's computer package PHASER (see [6]). The results are given with the precision 0.01. Before confirming the type of the attractor 2,500 iterations were made for each parameter value combination.

Three of these models ((1) — (3)) have been studied earlier by several authors (see [10], [11]). The most often used model, the logistic model, the logistic model (1) has been analysed first. The fixed point attractor region begins in zero and the first period-doubling occurs when $r = 3.00$. The third period-doubling occurs when $r \approx 3.54$. This is the beginning for the limit cycle of period 8. Soon after this chaos appears.

Another often analysed model is the model number (2). For it the fixed point region begins when r is zero and the first period-doubling occurs when $r = 2.00$. The limit cycle of period 8 occurs when $r \approx 2.66$. As for the model (1) soon after this parameter value chaos appears.

The models (3) — (5) are derived from the model (2) with the help of truncated MacLaurin expansion. Thus it is no wonder that the results for all these four models are rather close to each other. The fixed point region for them begins with $r = 0.00$. The first period-doubling

Table. Critical values for fixed point and limit cycle behaviour for the models (1)—(14)

	Analysed parameter and parameter interval	Values of fixed parameters	Direction of bifurcation development	Fixed point attractor region begins	First period doubling occurs	Limit cycle of period 8 appears
$x_{t+1} = rx_t(1 - x_t)$	$r \in (0,4)$	—	+	0.00	3.00	3.54
$x_{t+1} = x_t \exp(r(1 - x_t))$	$r \in (0,4)$	—	+	0.00	2.00	2.66
$x_{t+1} = x_t(1 + r(1 - x_t))$	$r \in (0,3)$	—	+	0.00	2.00	2.54
$x_{t+1} = x_t(1 + r(1 - x_t) + (r^2/2)(1 - x_t)^2)$	$r \in (0.0, 2.8]$	—	+	0.00	2.00	2.65
$x_{t+1} = x_t[1 + r(1 - x_t) + (r^2/2)(1 - x_t)^2 + (r^3/6)(1 - x_t)^3]$	$r \in (0.0, 2.4]$	—	+	0.00	2.00	2.32
$x_{t+1} = x_t \exp(r(L - x_t))$	$L \in (0,1)$	$r = 3$	+	0.00	0.67	0.89
$x_{t+1} = rx_t^{1-b}$	$b \in (0,2]$	$r = 1, 2, 3$ or 4	+	0.00	2.00	—
$x_{t+1} = x_t(1 - b\ln(rx_t))$	$b \in (0.0, 2.7]$	$r = 4$	+	0.00	2.00	2.47
$x_{t+1} = r_1 x_t^{1-b} r_2 \exp(-x_t)$	$b \in (0,1)$	$r_1 = 26, r_2 = 1$	—	—	1.00	0.88
	$r_1 \in (0,100)$	$b = 0{,}8\ r_2 = 1$	+	0.00	3.84	18.17
$x_{t+1} = x_t(1 - b\ln(r_1 x_t)) r_2 \exp(-x_t)$	$b \in (0.00, 2.75)$	$r_1 = 30, r_2 = 1$	+	0.00	2.03	2.52
	$r_2 \in (0.0, 1.8)$	$b = 1.5, r_1 = 30$	+	0.00	1.36	1.69
$x_{t+1} = x_t(1 - b\ln(r_1 x_t)) r_2 (1 - x_t)$	$b \in (0.00, 2.75)$	$r_1 = 30, r_2 = 1$	+	0.00	2.03	2.52
	$r_2 \in (0.0, 1.8)$	$b = 1.5, r_1 = 30$	+	0.00	1.36	1.69
$x_{t+1} = x_t(1 - b\ln(r_1 x_t)) r_2 (1 - x_t + x_t^2/2)$	$b \in (0.00, 2.75)$	$r_1 = 30, r_2 = 1$	+	0.00	2.03	2.52
	$r_2 \in (0.0, 1.8)$	$b = 1.5, r_1 = 30$	+	0.00	1.36	1.69

Table (continued)

	Analysed parameter and parameter interval	Values of fixed parameters	Direction of bifurcation development	Fixed point attractor region begins	First period doubling occurs	Limit cycle of period 8 appears
$x_{t+1} = x_t \exp(r_1 x_t^{m-1} - r_2 x_t^{n-1})$	$r_1 \in (0,4]$	$r_2 = 1, m = 2$ $n = 3$	+	0.00	1.41	1.62
	$r_2 \in (0,2]$	$r_1 = 1.5, m = 2$ $n = 3$	+	2.00	1.13	0.86
	$n \in (2,7]$	$m = 2, r_1 = 1.5$ $r_2 = 1.75$	+	2.00	3.48	3.90
	$m \in (1,3)$	$n = 3, r_1 = 1.5$ $r_2 = 1.75$	+	3.00	1.58	1.21
$x_{t+1} = x_t(1 + r_1 x_t^M - r_2 x_t^N)$	$r_1 \in [1.25,2.50]$	$r_2 = 1.75, M = 1,$ $N = 2$	—	1.25	1.87	2.12
	$r_2 \in [0.6,1.4]$	$r_1 = 1.5, M = 1$ $N = 2$	—	1.40	1.13	0.87
	$N \in [1.0,3.5]$	$M = 1, r_1 = 1.5$ $r_2 = 1.75$	—	1.00	2.48	2.88
	$M \in [0.0,1.0]$	$N = 2, r_1 = 1.5$ $r_2 = 1.75$	—	1.00	0.58	0.24

occurs with the same parameter value for all of these four models. The transformation from the model (3) to the model (1) causes the change of one unit in the parameter. This can be seen also in the table when the results for these two models are compared. The model (2) is a special case of the model (6). The increase in L in the model (6) has caused the acceleration in the bifurcation development.

For the model (7) no chaos has been found, but it gives the limit cycle of period 2 with the parameter value $b = 2$. With bigger parameter values the computations go out of the bounds of the computer, cf. [10] p. 462 where the model $F(x) = \lambda x$, if $x < 1$ and $F(x) = \lambda x^{1-b}$, if $x > 1$, has been analysed.

The model (8) was analysed already earlier. For the model (9) the effects of the parameters b and r_1 have been studied. However, the effect of the parameter r_2 comes actually also here, because the analysis of a parameter $r = r_1 r_2$ can be made instead of the analysis of the parameter r_1 with $r_2 = 1$. The changes in either parameter can lead to chaotic behaviour. The parameter value combinations giving limit cycle behaviour are given in the Table. Further decrease in the value of the analysed parameter (b) or increase (r_1) leads soon to chaos.

For the models (10) — (12) only the effects of the parameters b and r_2 are analysed. For the analysed parameter there are parameter values which give a fixed point attractor. When the value of the parameter is picked from this fixed point region and the effect of the other parameter is analysed, the change to chaos occurs with the changes of the values of this other parameter. Thus both parameters can cause alone chaos. The values for limit cycle behaviour on the way to chaos are given in the Table. The results for these three models are the same. This is no wonder because the models (11) — (12) can be obtained from the model (10) with truncated MacLaurin expansions.

For the models (13) — (14) the effects of all the four parameters have been analysed in some parameter interval. E.g. for the model (13) the parameter $r_1 \in (0,4]$. For the next parameter to be analysed (r_2) the value for r_1 has been picked from the limit cycle region. Other parameters have the same values as when the parameter r_1 was analysed. All the parameters are analysed like this choosing the value for the parameter to be fixed from the fixed point or limit cycle region. If the given value for the limit cycle of period 8 is further increased for the model (13) (14), when parameter r_1 or n (N) is concerned, or decreased, when the parameter r_2 or m (M) is concerned, chaos soon appears. All these parameters are able to cause chaos. The parameter values on the way to chaos are given in the Table.

5. Concluding Remarks

In this paper 14 growth models were analysed. Thirteen of them went through period-doublings into chaos. On the one hand this gives evidence of the possible usefulness of these models in forecasting complex behaviour of systems and on the other hand it emphasizes the importance of careful parameter setting when these models are used. This study also shows that chaotic behaviour is a general phenomenon, when growth models are concerned.

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Chapter IV

PROBLEMS OF EDUCATIONAL TECHNOLOGY

The previous chapters have dealt with significant points of view with regard to general debates on the introduction of new technologies. They have also reviewed certain important experiences which shed new light on ways of proceeding and strategies to be followed with regard to the use of new technologies in different sciences. The time has come to see what educational technology is and how it operates. This chapter opens with a study which presents the point of view of the teacher. It then provides a description of the resources offered by the latest findings with regard to programming languages and artificial intelligence in the preparation of computer-aided courses in education. It ends with a presentation of the institutional arrangements made at national levels with a view to promoting such courses for higher education vocational training.

The article by Pløn W. Verhagen and Tjeerd Plomp of Twente University, in the Netherlands opens with a clarification of various notions and terms. After reviewing three trends of thought which dominate educational technology (1. the design, the development, and the implementation of teaching aids and systems; 2. the process of the systematic development of instruction; 3. the systemic approach to problem solving), the authors plead for a definition of educational technology which makes clear that it is a methodology for solving educational problems. Thus, educational technology should not be mistaken for technology in general which is being used in education or for the latest technologies; it includes them both.

The study by Franklin C. Roberts of Control Data Corporation stresses the broad perspectives that one acquires through the use of authoring languages. Authoring languages, as distinguished from author languages, permit their users to create courseware without learning or using a programming language. With the use of a certain strategy or educational model wich can be of several types: drill and practice lessons, tutorials, games, simulation, testing, problem solving which is linked to a given performance type required of the student (remember, use, find). Specialists in a number of fields can make up an authoring system, that is, programs leading to computer-based curricula (courseware). The author provides an example of such educational model for the teaching of concepts.

The need for intra-university co-operation for the drawing up of CAI materials is emphasized in Roel van Asselt's article on the Dutch experience in the elaboration of materials for higher and advanced vocational education. The necessary infrastructure is based on the work of CAI development teams directed by a manager. The wide-scale production of computer based educational materials leads to a new educational process, the organization of which is suggested by the author in view of the consortium COO/HBO (CAI for Higher Vocational Education).

As higher education institutions are interested in the increased efficiency of their Computation Centres as well as in close and profitable collaboration with similar industrial and software elaboration centres, we have included Prof. Dines Bjørner's article in this chapter. It presents the experience of setting up and directing a centre for advanced computation science and software technology. The article clarifies notions on the application of computation sciences and software technology with regard to different specialities and activities.

Professors Arno Bitzer and Robert Sell, of the Aachen University of Technology — one of the outstanding vocational institutes in the Federal Republic of Germany — have written an interesting article on the strategies of information technology use. Every year the university trains hundreds of engineers. About 10% of them go on to take a Ph. D. in engineering, producing theses that are very closely linked to industrial projects. The organization of seminars and workshops which bring together representatives from industry (managers, unionists, workers) and from the university (professors, junior researchers, students) gives rise to a fruitful confrontation of the research potential of the university with the actual users.

EDUCATIONAL TECHNOLOGY AND THE NEW TECHNOLOGIES *

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Summary [1]

Like everywhere in our culture, new technologies gradually penetrate the field of education. This may be seen as a problem area, which asks for appropriate actions by teachers, curriculum experts, instructional designers and others. As "technology" seems to be the main issue, one may question whether the introduction of new technologies is to be considered as an educational technological problem. To a certain extent, the answer may be yes. In this contribution, the nature of educational technology is dealt with primarily. On this basis, the new technologies are placed in the context of educational problem solving in general.

In the literature, educational technology is defined in several ways. After discussing three major approaches to educational technology, it is put forward that educational technology should preferably be conceived of as the methodology of educational problem solving.

The program of the Department of Education at the University of Twente is described as an example of a curriculum in which this conception of educational technology takes a central position.

Three Concepts of Educational Technology

At intervals, publication occur about the nature of educational technology, its use for education and its influence on professionals in the field of education. Several conceptions have emerged from its short

* Paper presented at the 5th EARDL Congress, April 1987, University of Utrecht.

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history, which mainly may be categorized into three types of educational technology :

1. Educational technology as the design, the development and the implementation of teaching aids and teaching systems, using newer (often AV-) media. Educational technology is conceived as technology in education. It is a product (Romiszowski, 1981) or hardware (Davies, 1978) concept of Educational Technology.

Although the advocates of this approach received severe criticism, when they did not succeed to prove that new media would solve all educational problems (see for instance Unwins 1985 statement about unwarrented optimism) educational technology in this sense is still alive and well. Today's product — oriented educational technologists help education to respond to the new technologies to realize wider and more flexible educational and training opportunities, both at classroom level and for mass instruction.

The present trend is to put the learner in a central position, giving him control over his learning environment. Artificial intelligence for instance, could not possibly provide such an environment without the creativity of hardware oriented educational technologists.

2. Educational technology as the process of or the technique for the systematic development of instruction. This educational technology is characterized by a stepwise procedure : define objectives, decide on methods, develop materials, test, evaluate and impleament. Programmed instruction is an early example of this approach. In general, the design and bringing into operation of educational software of any kind to support learning is the central issue. Effectiveness and efficiency are important criteria. The starting point to apply this approach in a given situation, is the identified need or desire for some piece of instruction. This approach of educational technology is called the process (Romiszowski) or software (Davies) concept. It is common practice for many instructional designers, although often labelled differently.

3. The third concept is the problem solving concept of educational technology (see for instance AECT, 1977 ; Davies, 1978 ; Romiszowski, 1981). It goes beyond the other two, taking into account the problem to solve and its context. It is a holistic approach, often also called the systems approach of educational technology.

Educational technologists in this case develop a sensitivity for the needs of people and tasks in the problem situation. Hereby, a problem is defined as every situation where the actual situation differs from the desired one. Problems can be classified with respect to educational level (at the macro-level the problems concerning the educational needs of a society, at the meso-level the problems of instituions, and at the micro-level the problems of teaching and learning) and educational subdomain (curriculum, instruction, counseling, administration, evaluation) ; and be treated accordingly. The first two approaches of educational technology are incorporated in the third one, as they can act as valuable means to solve some educational problems. The systems approach leads to a systematic description of the variables (constraints as well as design factors) which influence the problem solving process, thus defining the problem space in which a prototype solution has to be designed, developed and tested in a cyclical process until an acceptable result is accomplished. This process may be symbolized by Figure 1 (adapted from Plomp, 1982). The future implementation is a key factor which is present in every stage, which is in line with recent implementation literature like Fullan (1985). For some problems, prototyping is only possible as a paper excercise. In that case, guided implementation is part of the problem solving process. Examples are large — scale innovations of any kind, for instance with respect to the introduction of information technology in schools.

Educational Technology, not a Comprehensive Discipline

The problem we would like to discuss is that of the theoretical foundation of educational technology. The attempts to provide a knowledge base for educational technology is one of the causes of the diversity of conceptions, as they are apparent from the literature. A central question is whether educational technology is to be considered as a separate discipline among other educational sciences, like psychology, sociology, etc. When do we want to call ourselves educational technologists instead of for instance instructional designers, courseware developers, curriculum experts, or other ?

The American Association for Educational Communications and Technology tried to provide an answer by developing a definition on the basis of the problem solving conception, which defines educational technology as a theory, a field and a profession (AECT, 1977). In this definition, educational technology is considered to be "a complex, integrated process involving people, procedures, ideas, devices and organization, for analyzing problems, involved in all aspects of human learning". It presents a view on the field of education in which problems may be solved by proper management of development functions like research, design, production, logistics and utilization, using the theory/research function to create a knowledge base. This approach is indeed holistic, and seems to try to incorporate all relevant scientific knowledge into educational technology. The attempt to adopt relevant theories may be clear from the concluding statements which were presented in the AECT text on the definition by Kenneth Silber, quoting Finn :

"Properly constructed, the concept of instructional or educational technology is totally integrative. It provides a common ground for all professionals, no matter in what aspect of the field they are working ; it permits the rational development and integration of new devices, materials, and methods as they come along. The concept is so completely viable that it will not only provide new status for our group, but will, for the first time, threaten the status of others. (Finn, 1965,

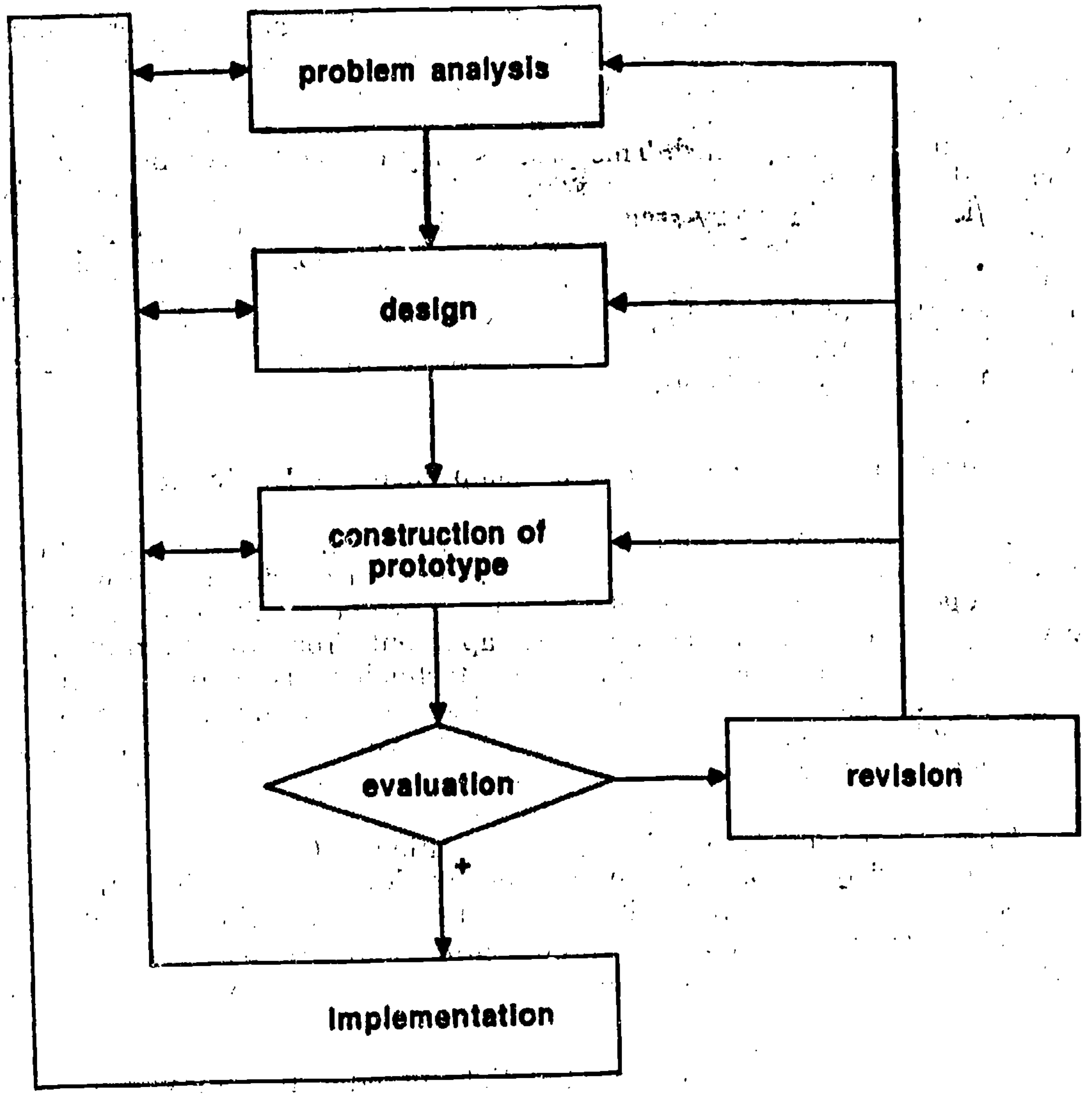

Fig. 1 : General model of educational problem solving

p. 193). The educational future will belong to those who can grasp the significance of [educational and] instructional technology. (Finn, 1964, p. 26)".

Now, ten years later it may be clear that these expectations were put too high. The merits of the AECT definition lie in the stressing of the need for management of the problem solving process ; the recognition of the need for certification and training of aides, technicians and specialists within a coherent set of career options ; and the striving for curricula which are substantially congruent from institution to institution. The integration of all theoretical fields into one educational technology did not occur, however. We contend that this is not even desirable. The educational reality is much more complex in its manifestation than can possibly be grasped in one unifying approach as a comprehensive discipline or theory. Different scientific fields show different representations of education. Theories about learning, sociology, pedagogy, philosophy, economy, management, all show their own perspectives. The same counts for derived design theories. As an example, in Reigeluth's overview of instructional design theories and models, the word educational technology is not mentioned once. The book shows nevertheless a range of applicable systematic approaches to design problems, representing different though often related theoretical schools with all their similiarities and — sometimes — controversies (Reigeluth, 1983). Reigeluth does not treat the subject exhaustively. Other instructional design theories or models exist or are being developed (see e.g. Gustafson, 1981). All together, one sees a manyfold of possibilities for approaching educational problems in what only is one subdomain of education, namely instruction. How to position educational technology with respect to the different subdomains?

Educational Technology as Methodology

One solution is to speak of technologies in all cases where theory is put into practice by a systematic working method. Several authors use educational technology in this way. For instance: Hackbarth (1985) speaks of instructional systems design as of a technology. Jonassen (1985) describes conceptional roots for instructional design and from thereof derives a new educational technology on the basis of learning strategies.

A consequence of the diversity of views is that the theoretical context of educational technology (or technolgies) is rather unstable. One educational technology leans on cognitive science (Jonassen, 1985), another is based on a constructivist view (Fosnot, 1984), a third approach advocates a philosophic analysis of the role of mediation in learning to be incorporated in educational technology (Jonassen, 1984). These educational technologies tend to change over time, together with the developments in the respective scientific fields (Remember, for instance, the shift from behaviorism to cognitive psychology as the dominant knowledge base for instructional design activities).

The problem is that each specific educational technology confounds in this way the methodology which is implied in "technology" with the theoretical content of some knowledge domain. Heinich (1984) tried to prevent this. He presented a conception of the proper study of instructional technology in which the process of design is elaborated in terms of activities, desired forms of cooperation of technologists and the needs for research to support technological methods. His stand is much in conformity with the AECT definition, but without falling into the trap of wanting a theory to describe the object of the technological activities, in his case instruction, as a part of the technology. This caused a reaction from Clark (1984), who suspected as an effect of his approach

"that instructional technology is itself turning into a craft — The craft of instructional design and development. While this new craft employs techniques (i.e. instructional design models) that are more systematic and organized than those typically used by teachers, in fact much of this design effort could be characterized as lending a "technologizing" sheen to a new craft".

Hlynka and Nelson (1985) are less pessimistic. Like Heinich (1984), they contend that "design" is the key concept of educational technology. Design includes art (i.e. creativity), craft, science and technology, all present at the same time in a synergistic combination. They in fact get round the craft/science dichotomy and come close to our opinion about the nature of educational technology. We wish to see educational technology as a problem solving methodology in which a systems approach, together with eclectic use of scientific and other knowledge, leads to the design and development of solutions. This conception means that educational technology is independant of educational or instructional theories to a large extent. With this conception, we may distinguish the problem solving process as such from its applications. The problem solving process then is symbolized in the generalized model which is presented in Figure 1. Aspects of an educational technology approach can be divided into three categories, as described by Ely & Plomp (1986):

"a) Educational technology as systems.
Using concepts and approaches of systems theory and operations research in the analysis phase, the problem can be handled by defining the problem space as a system with boundaries, within which related subsystems can be defined. Complex problems can be unraveled to reveal well-ordered partial problems with enoungh known properties to make an acceptable solution possible.

b) Educational technology as methods and techniques.
Many techniques, most of which are not specific to educational technology, can be used in the analysis, design and development and evaluation phases. The specificity of these techniques lies in their order within the technological cycle. This cycle can be considered as the methodological basis for the design process. A typical characteristic of educational technology is that techniques for design decisions are considered to be a vital part of the process.

c) Educational technology project organization.
A technological approach makes special demands on the organization of projects. This is partly due to the fact that the problem analysis will result in an overview of knowledge and skills needed for finding a solution. Many problems need expertise from a variety of disciplines. 'Management of expertise' is the key phrase: the classification of a problem with the right expertise at the right time. Continuing attention to the implementation of the solution makes

demands on the project organization. Planning has to be considered as one characteristic of a technological approach. The project organization is directed at achieving an optimal solution within the existing constraints such as budget, personnel and time".

On this general level the eclectic nature of educational technology is reflected in the way resources and man power are allocated in a specific project. They are chosen from a wide range of possibilities, indeed including the craft of, for instance, media personnel and the scientific knowledge of, for instance, curriculum experts.

In a particular problem situation, in most cases particular design methods will be used. On this level, the same principles apply.

Romiszowski's (1981) designing of instructional systems is an example of this for the instruction domain. Again, his approach is eclectic, offering design options as a result of divergent thinking, leading in specific cases to the selection of, for instance, methods and media by converging reasoning.

In conclusion, our conception of educational technology defines educational technology as the methodology of educational problem solving. In this methodology, the systems approach is central. The methodology is relatively independent of the different educational subdomains. Design models in the subdomains usually show great similarity with the general model from Figure 1. In our view, we prefer in these cases not to speak of different technologies, but rather of different forms of integrating problem solving methodology into the design methods of educational subdomains.

Example: Educational Technology in a University Curriculum

The thoughts on educational technology which were unfolded above, are the basis for the curriculum of the Department of Education at the University of Twente. The Dutch name of the department is "Toegepaste Onderwijskunde" (TO), which means literally: Applied Educational Science.

The curriculum of TO is a four year post secondary program. According to the Dutch educational system, the entrants into the program are graduates of a highly selective preuniversity school. The students in the program attain a degree which is equivalent to a Master's degree. It is the only program in The Netherlands in which educational technology takes a central position. The organizing principle for the curriculum is shown in Figure 2.

The subdomains listed in box 3 are reflected in the organization of the department. The department is composed of the following divisions:

— Curriculum, dealing with problems in curriculum (course, training) design, evaluation and implementation.

— Instruction, dealing with problems in the design and implementation of training situations and instructional methods.

— Educational instrumentation, dealing with the use of media, including computers, in education and with the physical teaching/learning environment.

— Educational administration, dealing with policy, planning and management problems in education.

Besides these four divisions covering educational subdomains, there is a division of educational measurement and data analysis, offering courses on research methods and statistics and dealing with testing problems.

There is no separate division of educational technology. Instead, there exists an interdivision technology group which is responsible for the courses on educational technology. In this way, educational technology is supported by all divisions in the department.

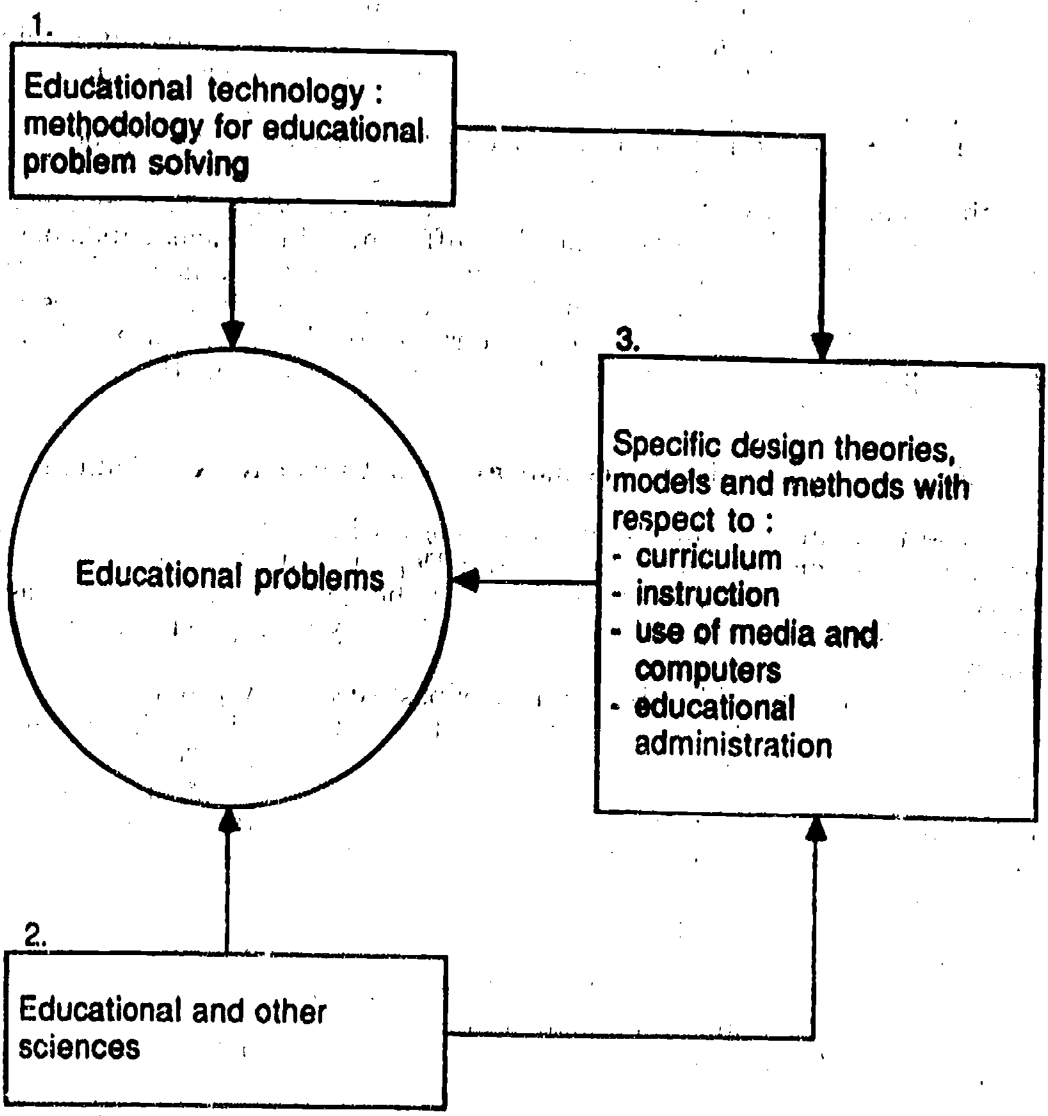

Fig. 2 : Organizing principle of TO Curriculum

In the first $2^1/_2$ years, the curriculum is common for all students. Figure 3 shows the domains on which courses are being offered in this period, and the relative amount of time spent on each.

The common curriculum is followed by a final phase — the last $1^1/_2$ years — in which there are broad options available from which students may draw up their own curriculum. Although the nominal time for the programme is 4 years, the students may spend 6 years on it as a maximum. The program started in 1981. The total enrollment at present is 300. At this moment — spring 1987 — 33 students are graduated. Now, some six years after the start of the programme, we may evaluate the first results of our approach.

Although only 17% of the common curriculum is devoted to courses on educational technology, these courses seem to be decisive on the development of the professional attitude of our graduates. This may partly be due to the central position of educational technology in the curriculum, as symbolized in Figure 2.

Students appear to continue the systematic approach to analyse problems and to develop solutions, after the common curriculum. This is obvious from reports on their work during their final project and from observations of supervisors inside and outside TO.

This attitude appears to be highly appreciated in the educational field, especially in business and industry. 60% of the final projects takes place with companies. Graduates appear to be successful when applying for jobs and again 60% of the jobs taken are being found in business and industry.

When to Apply Educational Technology

The experiences with the TO-programme lead us to the next characterization of the applicability of the educational technological approach.

Educational technology stresses the multidisciplinarity of the problem solving and design processes. This makes the educational technological approach especially suited for situations in which :

— the problems to be solved are complex in nature (where many interrelated factors are involved),

— a problem is placed on a higher level than that of the individual teacher (where many interests are to be combined),

— several people have to cooperate in order to develop a solution for the given problem.

The educational technological approach does not start a priori from the point of view of the teacher. In the approach, no priority exists for treatment format or delivery system. This by necessity includes relativation of the role of the teacher. This is not to say, that through educational technology the role of the teacher becomes less important. In many cases, the teacher remains in a central position. Further, it is not to be denied, that in some educational situations close to the learners, when an empathic approach of a problem is imperative, the objectiv-

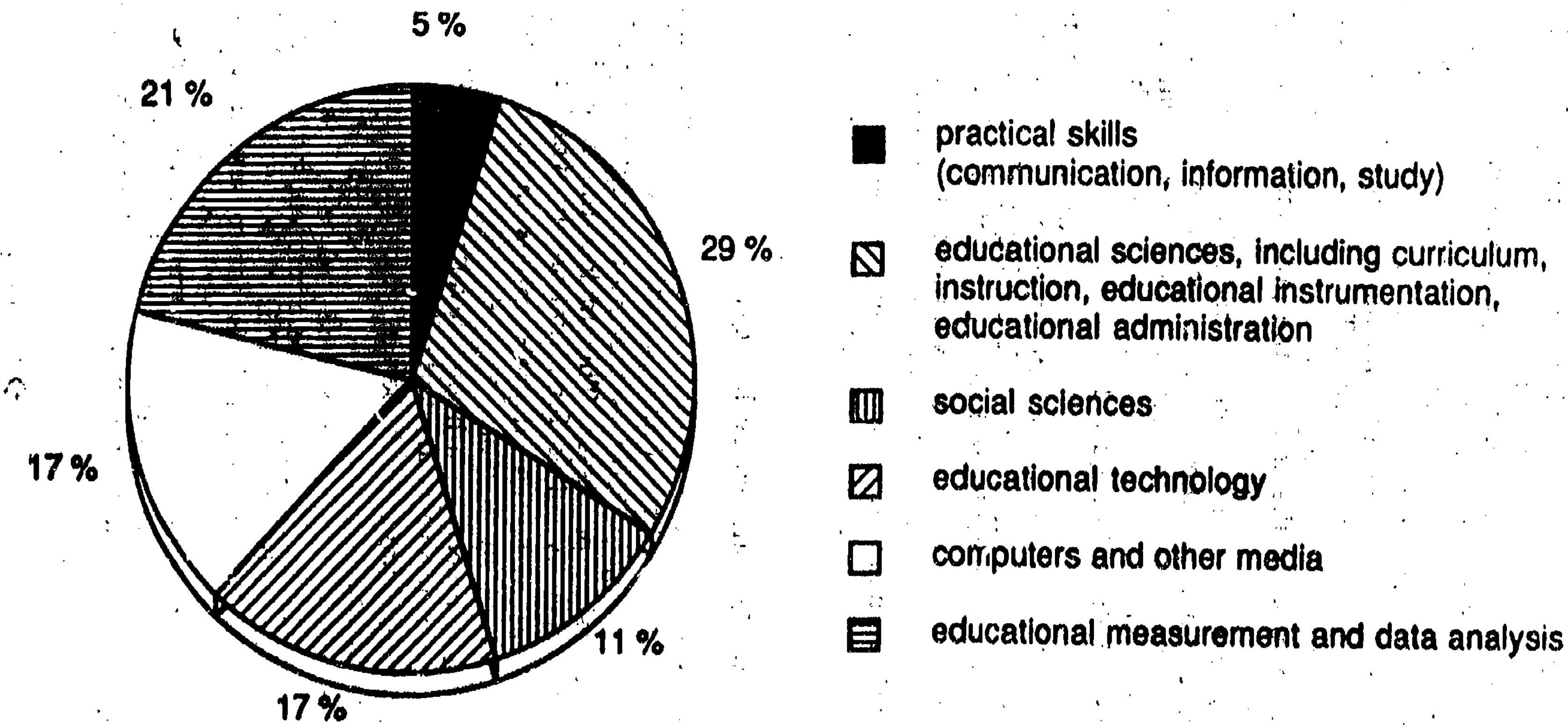

Fig. 3 : Common curriculum of TO (First 2 1/2 years of study)

ating nature of educational technology will most probably not be appropriate.

If we look now at *new* technologies, again one may say that there are no a priori decisions in favour of these technologies either. The new technologies offer new options to create teaching and learning environments. One may approach the new technologies with a positive attitude. But there is no reason to idolize. Careful analysis and design efforts, as an educational technological enterprise in the above described sense, may pave the way for beneficial innovations. The emphasis on implementation in our conception of educational technology should thereby safeguard an optimal balance between advantage and disadvantages.

In conclusion educational technology, being conceived as the methodology of educational problem solving, offers many perspectives for research and development efforts. Like in research methodology, many methods and techniques are needed to be able to act appropriately in complex situations. They should be derived in sound research and development projects. New technologies take their place in this process. For educational problem solving, they are optional components to accomplish a solution, among many others. Proper use of educational technology puts the new technologies in the right perspective, with problem context and care for implementation as key factors for design decisions.

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A KNOWLEDGE-BASE FOR INSTRUCTIONAL DESIGN

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1. Instructional Design and Authoring Systems

Designing effective instructional materials is a time consuming task that requires a deep understanding of several technologies, as well as the related subject matter content. However, there are a number of instructional design strategies that are performed frequently and in a similar fashion across many instructional design applications. These strategies are used in the teaching of such things as the learning of a large number of facts; being able to visually discriminate classes of objects; learning a sequence of steps; and so on. By building tools which reflect the similarity in these tasks, a great deal of redundancy can be eliminated in developing the related instructional materials, making them both more effective and easier to design.

The tools that are currently available for instructional development include general programming languages, specialized tools (such as graphic design tools or animation routines), authoring languages, and more recently, authoring systems. Most of these tools were built to satisfy a specific need of the people involved in the instructional development process. These tools have largely ignored the basic theries of learning and instruction upon which they might have been designed. While there are some exceptions, the authoring tools which are available today do little to aid the instructional designer in ensuring that state-of-the-art principles of instructional design are adhered to in the programmes they develop.

What is needed are tools that reflect the practical needs of instructional development, while ensuring that what is known about the underlying theories of learning, measurement, and human factors is transferred to the final products through the use of those tools. Unfortunately, the reality of the situation is that the existing tools only partly reflect the practical needs of the user, and barely address the underlying theories at all.

Authoring systems are the link between the science and the practice of instruction. While the definition of authoring systems varies widely, most provide some conbination of instructional models and specialized tools, often with access to some lower level language. Instructional models are what differentiate authoring systems from authoring languages. They provide a mechanism for incorporating knowledge about instruction and offer characteristic ways in which the instructional materials can be developed. One of the criticism of authoring systems is that the instructional models which they provide are too restrictive; that what you gain in simplicity you loose in flexibility. What is needed are models that reflect good principles of instruction, while retaining a degree of flexibility.

This paper describes a research programme that is attempting to define a structure upon which a flexible set of instructional models could be designed. These models are designed to reflect the state-of-the-art in instructional design. In order to address the concern of flexibility, each model is a collection of smaller procedures for such things as question design, feedback, item selection, and so on. Each of these smaller, micro-strategies includes a set of rules for either performing an action, or generating a new piece of knowledge that is required by some rule. The approach used in designing these models will be described, and then an example of this approach in concept learning will be offered.

2. Instructional Models : A General Solution

The most advanced authoring systems are providing an environment which supports a knowledge-based approach to courseware development. Most of these systems have separated the various components of instruction. The approach used in this research has been to separate the knowledge-base (KB) into three components, representing the instructional strategies, the content to be taught, and information about the student. The goal is to develop models of instruction which reflect both practice and theory, and which can be defined in terms of these three KB components.

The approach used in developing these models has been to start with the goal of designing pedagogically sound models of instructional design. These models should represent the types of models currently used in the design of instructional materials. These basic models (often referred to as istructional strategies) include tutorials, drill and practice lessons, simulations, games, and testing.

This issue of global strategies was analyzed, revealing many classification schemes. Manion (1985) suggested the six categories of drill & practice, tutorial, educational game, simulation, problem solving, and word processing. Merrill (1982) suggested seven categories that include various hybrids of computer assisted instruction (CAI), simulations (SIM), and artificial intelligence (AI).

The strategy categories used in this research include: drill and practice, tutorial, physical simulations, situational simulations, procedural simulations, intrinsic games, extrinsic games, and testing. Simulations are defined as exploratory environments, with physical simulations representing manipulative devices, situational simulations representing role playing types of activities, and procedural simulations representing the performance of a sequence of steps. Intrinsic games are games which are directly related to the content being taught, and extrinsic games are game formats that can be used with any category of content (Malone, 1980).

While it is recognized that other models could have been chosen, these categories were selected as representing a core set of such models. The procedure being employed in this approach would easily lend itself to later development of additional model categories, or alternative methods of defining instructional model categories. In addition to the global instructional strategy categories, the models in this research have also been organized according to the type of content which is to be taught.

Typologies of content have been addressed numerous times in the educational literature, perhaps most notably in Bloom's Taxonomy (1956) and Gagne's Categories of Learning Outcomes (1979). In addition to the categories proposed by Bloom and Gagne, several other categorizations were also reviewed. These include the types of content as defined by the Interservice Procedures for Instructional Systems Development (TRADOC, 1975), and the content classifications from Component Display Theory (Merrill, 1983). By cross referencing the global strategies which have been identified with a typology of content, the strategies which are used in each of the global models start to become more focused and distinct. The typology which is used is considerably less important than the act of cross referencing the inherent strategies with a content typology, creating a content x strategy matrix.

Our work has used a typology which is similar to Merrill's Component Display Theory, using four categories of content : facts, concepts, rules, and procedures. Facts are isolated pieces of information. Concepts are sets of facts that share some common attributes. Rules are conditional statements that prescribe some action, and procedures are a sequence of steps that produce some specific outcome.

Not all global strategies are appropriate for all content categories. For instance, a situational simulation of facts is not a reasonable instructional application. Thus, the models addressed in this research include 27 basic content x model categories.

These models also need to reflect the nature of the expected student behavior. This dimension is addressed in Component Display Theory (CDT) and is referred to as the student's level of performance. CDT proposes three levels of performance : Remember, Use and Find. Each of these three levels interacts with each content x global model category, generating a matrix of smaller models. These categories will be referred to as macro-instructional models (see Figure 1).

Each of these macro instructional model categories is comprised of a set of smaller, micro instructional strategies that in turn act on the different knowledge bases. These micro instructional strategies include such topics as feedback strategies, prompt structures, use of advance organizers, structuring pretests, and so on. A detailed description of

Macro Models and Levels of Student Performance

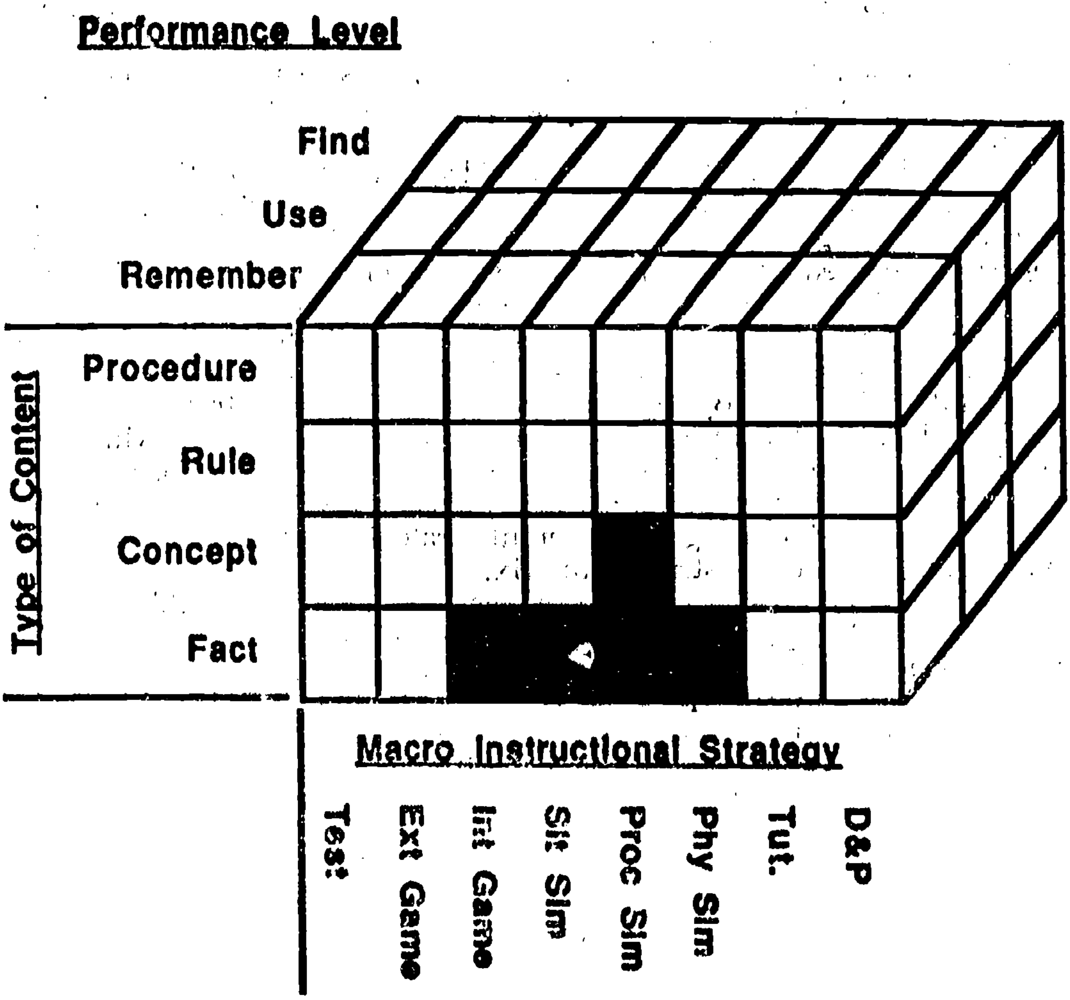

Fig. 1 : Categories of Instructional Models

micro-instructional strategies was proposed by Park (1983) that were organized around display variables and process parameters. These micro-instructional strategies are the bulding blocks used in designing instructional materials. The macro strategies and the larger, global models are really the integration and implementation of these micro instructional strategies.

Our research has focused on the specification of these micro instructional strategies. Our preliminary research has shown that each of the macro instructional models is addressed by a finite set of these micro instructional strategies. Each of these micro strategies can be viewed as a set of decisions that need to be made during the development or delivery phase of instruction, and these decisions can be specified in a rule base. Thus, one of the goals of this research is to define the categories of rules that bound the instructional strategies appropriate to each macro instructional model.

In addition to the modular advantage that an IKB offers, it also provides a structure for the solicitation of content from subject matter experts. One of the perennial problems in instructional design is the efficient collection of content from subject matter experts (SME). By using th model based approach to instructional development outlined here, each insructional model defines a necessary, corresponding IKB. This IKB has explicit requirements, and could be used as a guideline for eliciting the necessary information from the SME. If the IKB structures were incorporated in an authoring system, the SME could be prompted in filling in the related IKB.

The goal in developing the macro instructional models is to specify a comprehensive set of modular, flexible micro instructional strategies. The guiding philosophy has been to define these micro strategies so that they incorporate the approaches which are used in practice, as well as the strategies which have been supported by research. Thus, the final micro strategy models could be used to replicate virtually any approach to the delivery of the related instruction.

One of the advantages of having such an array of alternatives is the ability to change strategies with a given IKB. When averaging across individuals or groups, many instructional strategies show no significant difference. Yet, there are clearly differences when the strategy is used with a single individual, or sometimes with a group of individuals, even though we may not know why. Allowing all possible strategies to exist in the micro models facilitates the modification of strategies which are proving to be ineffective. Further, if a macro model had a set of rules for testing the effectiveness of a particular approach, it could adapt its own teaching strategies until it found the optimal strategy for any given student, group, or particular IKB. The self-adaptive feature of this approach lends itself to highly adaptive courseware.

3. A Specific Example : Concept Learning Models

This section describes the results accomplished to date in the design of instructional models for concept teaching. A brief overview of concept learning and related research is provided in the next section. The concept learning model used for this project is then described, including a description of the twelve rule-set categories which have been defined.

The model proposed in this report relates to Drill & Practice and Tutorial strategies, at the Remember and Use performance levels of the Concept content category. The long — range goal of this research is to develop instructional models in each of the categories proposed by the classification scheme described above.

3.1. An Overview of Concept Learning

Research and development in the field of instructional design has always assumed a strong relation to the structure of the knowledge being taught. This relation has been overtly recognized in work in the organization of content elements (i.e., Tyler, 1949; Bruner, 1960), as well as in various attempts to develop taxonomies of instructional outcomes (Bloom, 1956; Gagne and Briggs, 1979). One additional outcome of this relation has been a set of empirically based instructional strategies designed to effectively organize the content elements in the teaching of concepts (see Markle and Tiemann, 1969; Merill and Tennyson, 1977; Tennyson and Park, 1980). A concept is defined as "a set of specific objects, symbols or events which share common characteristics (critical attributes) and can be referenced by a particular name or symbol" (Park and Tennyson, 1980, p. 56). Concepts include such things as birds, furniture, geometric figures, and so on. These strategies, as outlined by Tennyson and Park, include: "(a) the relationship between examples, (b) the relationship between examples and nonexamples, (c) the ordering of examples and instructional help, (d) developing a procedure for selecting an appropriate number of examples, and (e) the relationship between coordinate concepts" (1980, pp. 55—56).

3.1.1. Two Approaches to the Teaching of Concepts

The criterion task in learning concepts is being able to classify newly encountered instances as being either examples or nonexamples of the concept. Research suggests two basic strategies which have been effective in accomplishing this goal: (1) the example comparison strategy and (2) the attribute isolation strategy. Each of these strategies involves the presentation of the concept definition, use of the list of critical attributes which define the concept, and the presentation (and explanation) of pairs of examples and nonexamples of the concept. A critical aspect of these strategies involves the relationships both among and between examples and nonexamples.

Any object which is an example of a concept must, by definition, have all of the critical attributes which are required by the concept. A nonexample will be missing one or more of the critical attributes. However, it is often the case that classifying some examples (and nonexamples) is considerably harder than classifying some others. There are three notions in concept learning strategies which address the issues among and between examples and nonexamples: matched pairs, rational sets, and divergent examples.

A *matched pair* is an example and nonexample pair that are very similar (ideally identical) with the exception of the missing attribute in the nonexample. A collection of matched pairs that have one matched pair for each critical attribute is referred to as a *rational set* (Markle and Tiemann, 1969). A rational set is used in concept teaching strategies to ensure that the student has had exposure and/or practice on each of the critical attributes which define the concept.

The third notion, *divergent examples*, has to do with the difficulty of the classification tasks that a student must perform. It is clear that some examples (and nonexamples) are more difficult to classify than others. For instance, it is probably easier to classify a robin as a bird than it is to classify a penguin as a bird. All of the matched pairs in a rational set have a similar degree of difficulty, and the rational sets can be ordered in terms of their overall difficulty level. A generally recommended procedure for teaching concepts is to start with a rational set at an easy difficulty level. When a student becomes proficient at this level, a rational set at the next level of difficulty can be used, and so on. In this sense the examples are said to be progressively divergent.

So, with these notions in mind, two general procedures for teaching concepts can be described. The first procedure is the Attribute Isolation Strategy (AIS). The key focus in the AIS methods is to reference both instruction and feedback to the list of attributes which define the concept. The first step in this method is to define the concept and provide a list of the critical attributes of the concept. Then, a matched pair is displayed. The example (and the nonexample) are discussed in terms of the presence (or absence) of each of the critical attributes. Additional matched pairs may also be explained. The student is then given a rational set of matched pairs to classify. Informative (and/or corrective) feedback is provided for each classification which explains the answer in terms of either the presence or absence of the critical attributes. The student is given additional rational sets of practice items until he or she demonstrates proficiency at the desired level of difficulty. The lesson ends with a restatement of the concept definition and a summary of the concept's attributes.

The Example Comparison Strategy (ECS) is similar to the AIS method, except that the key focus is to reference the instruction and the feedback to the most typical example of the concept, instead of the list of critical attributes. As in the AIS method, a definition is provided and the student performs some practice activities. All explanations and feedback are offered in terms of comparison to the prototype example. That is, a comparison is made between the example (or nonexample) and the prototype, highlighting the similarities (or differences).

Several additional micro-instructional strategies are also employed in these basic methods of concept teaching. For instance, pretests can be used to determine readiness or prior mastery. Feedback as well as the selection of practice items can be effected by the student's response history. Other strategies have to do with the type of error that the student is making.

In concept learning, each question is either an example or a nonexample. The student can respond either correctly or incorrectly. In the case of incorrect responses, the student has either classified an example as a nonexample (which is an undergeneralization), or a nonexample as an example (which is an overgeneralization). One strategy relating to response history includes the method of replacing the incorrect responses in the rational set item pool, and not continuing to the next rational set until each item has been answered correctly. More elaborate strategies are possible, and may require evidence of whether or not a student is exhibiting a trend of either over—or undergeneralizing.

Thus, these are some of the general methods and issues which have been proposed for the teaching of concepts. This description is necessarily brief, and has omitted many of the more subtle issues which have been addressed in the research on concept teaching. In addition, what has been described has only addressed the teaching of a single concept. One of the more interesting aspects of concept learning has to do with the fact that concepts are generally part of a hierarchical network of concepts. In these hierarchies, concepts inherit all of the attributes of the parent concept. In addition, examples of coordinate concepts provide ideal nonexamples which facilitate discrimination. The next phase of this reasearch will be to extend the model to include hierarchies of concepts. However, the current paper describes work primarily at the teaching of a single concept.

3.2. Description of the Model

The Generic Concept Teaching Model (GCTM) has been designed to reflect the various recommended strategies which have been proposed for concept teaching. There are four basic steps in the model : (1) preinstructional strategies, (2) presentation of main body of information, (3) practice, and (4) post-instructional strategies. This description of concept learning offers a simplified view of what the actual design embodies. However, it does offer a general orientation to the underlying structure of the GCTM.

3.3. A Description of the Rule-Set Categories

Pretests. The pretest strategies determine the selection of items, the order of items, and test termination criteria for a pretest. There are three basic purposes for which pretest can be used. (1) Readiness : assessing whether or not a student has the prerequisite skills and knowledge necessary to learn the current material. (2) Assessment : determining a student's overall level of understanding of the topic to be taught. (3) Sensitivity : a pretest can be used as an advanced organizer, sensitizing a student to the types of questions and related content she or he will encounter. A pretest may be used for more than one reason, resulting in six different pretest reason conditions.

Each of these pretest goals affects three test delivery parameters. (1) Topic choice: some tests will cover several related topics. Which topics are chosen, and the order in which they are presented will be affected by the purpose of the pretest. (2' Test items : within each topic to be tested, items must be selected from the corresponding item pool. Items can be chosen on any of several parameters, such as item difficulty level. (3) Test termination : the number of items in a test can be fixed or variable. Tests of varying length can be terminated based on a variety of criteria. These criteria include : terminate as early as possible, terminate based on a preset reliability level, and so on.

Matched Pairs. The matched pair rules take a given example and search the list of available items for the nonexample which most closely fits the matched pair definition as defined above. This requires that all items be structured in a way which clearly delineates the presence or absence of each critical attribute.

Rational Sets. The rational set rules generate a rational set of matched pairs of a given level of divergence. This is accomplished by creating lists of matched pairs, with one matched pair for each critical attribute. In addition, all available matched pairs are reviewed to find those pairs with the most similar level of divergence.

Trend State. The trend state is a continuous assessment which is made of the students' performance. There are four possible trend states for the single concept model : (1) competence, where the student appears to understand the classification task ; (2) undergeneralization, where the student is tending to label examples as nonexparnles ; (3) overgeneralization, where the student is tending to label nonexamples as examples : and (4) confusion, where the student is making both under-and overgeneralization errors. Each of these four trend states is updated after each student response. Each state is given a probability level from 0 (not evident) to 1.0 (certain). Trend state influences both the selection of subsequent questions, as well as the feedback which is provided. The goal is to reduce the probability of the confusion and over-and undergeneralization trends, and to maximize the value of the competence trend.

Prompting. The prompting rules determine what prompts are provided in addition to the practice items. Prompts might include the definition of the concept, the list of critical attributes, the prototype example, or previously answered questions. The choice of prompts is largely determined by overall strategy decisions.

Feedback. The feedback rules determine the feedback givenf to a student after answering a specific question. Determining the feedback to provide includes such issues as what type of question it was (example or nonexample), whether the student's answer was correct or incorrect, the overall instructional strategy being employed, how much information will be contained in the feedback, and whether or not the feedback will be keyed to the correct answer to the question, or the student's incorrect response. The twenty-four categories of feedback rules are shown in figure 2.

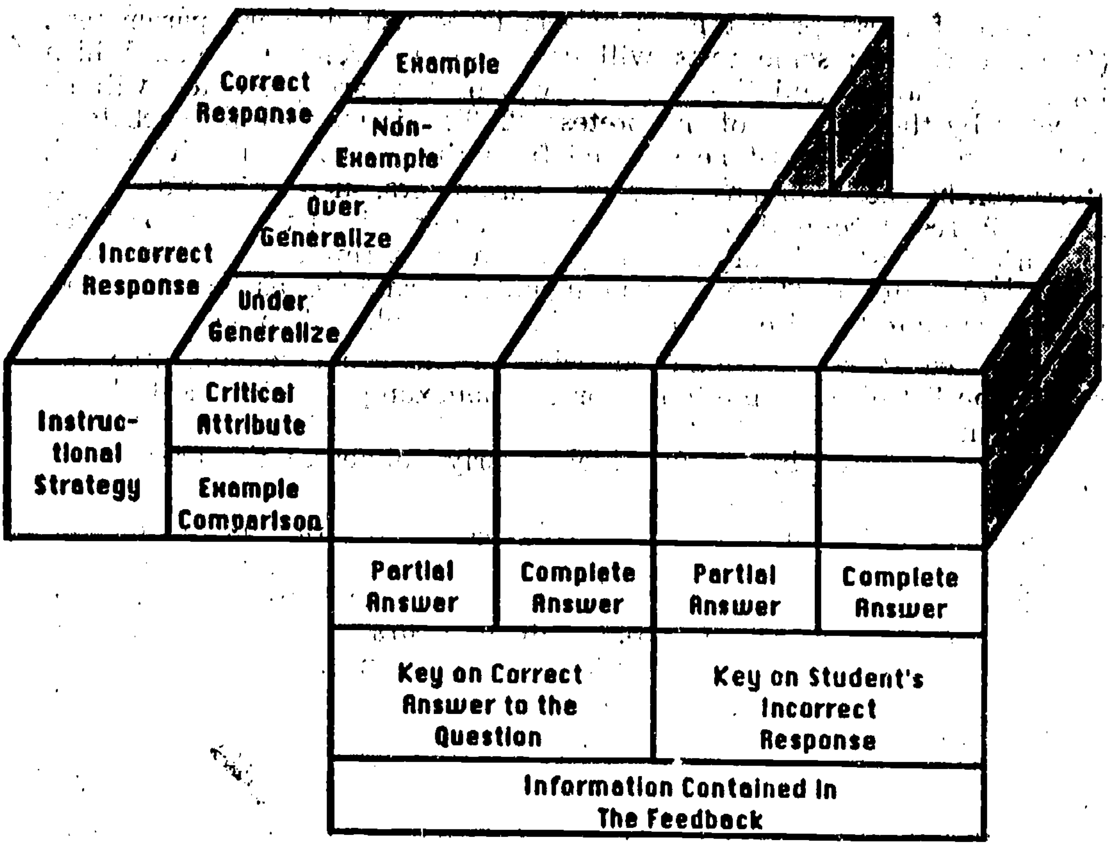

Fig. 2 : Feedback Rule-Set

Item Transformations. The item transformation rules generate parallel items, either in the same item format, or in a different format. There are six basic item formats : true/false, multiple choice, matching, short answer, fill-in-the-blank, and numerical. This gives 36 possible transformations between item types. Of these 36 possible transformations, rules have been developed for 19 transformation categories. Each category requires that the items be stored in the item form structure described above. Of the 19 categories, only a subset of them will be feasible at any given time, depending on the nature of the item form, and the availability of any additional information which may be available. For instance, one of the alternatives for short answer to multiple choice requires the collection of student responses to the short answer question, with the most frequent incorrect responses being specified as the multiple choice distractors. In the single concept teaching model, only a small number of these transformations are applicable.

Posttests. The purpose of a posttest is to assess a student's overall level of competence on the material just taught. Thus, the conditions for delivering a posttest are similar to those for delivering a pretest whose purpose is assessment. The same three test delivery parameters are also affected : topic selection, item selection, and test termination.

In addition to these strategies, it may be desirable to measure pretest-posttest gain. In order to facilitate this, alternative rules are provided, which allow the identical questions but in a random order, or a set of parallel items presented in random order.

4. Summary

The goal of this research is not to automatically generate courseware. Rather, development of these models is intended to accomplish two tasks. First, if successful, they will generate a lesson design (and accompanying lesson) which reflect the best instructional design principles for teaching that content category. This prototype could then be modified by an instructional designer in any way deemed appropriate.

The second goal is to define what constitutes an instructional knowledge base for the teaching of various categories of content. While the difference between a subject matter knowledge base and the knowledge needed for teaching that subject matter has often been acknowledged, these has not been a rigorous attempt at defining the structure of these related instructional knowledge bases. This project has had to address, as a major by-product of the development of these models, the definition of several categories of instructional knowledge bases. Ultimately, the definings of these instructional knowledge bases could greatly facilitate the extraction of the appropriate content from the subject matter expert, for a variety of types of instruction.

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FACILITIES CONCERNING THE INFRASTRUCTURE FOR DEVELOPMENT OF CAI IN ADVANCED FURTHER AND HIGHER VOCATIONAL EDUCATION IN THE NETHERLANDS *

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Within the world of education and business in the Netherlands, there are no possibilities to develop large CAI courses locally, at a single University or at a single College.

The only way to build sophisticated CAI of some size is by means of cooperation within the field of advanced further education. However, cooperation between educational institutes and a common use of material for educational purposes are concepts unknown up to now in advanced further and higher education in the Netherlands.

If two important criteria are met, common production and common use of CAI material can be generated, namely :

— an adequate national infrastructure, created and supported by a professional (educational) management, and aimed at the production, distribution, maintenance and salability of CAI material ;

— a considered implementation of CAI, suited to the educational policy of the educational institutes aimed at making the process of teaching and learning more autonomous and rearranging it into modular instruction.

First, this paper will offer an insight into the facilities concerning the infrastructure for the complete process of developing CAI material, next the aspects concerning appreciation, acceptation and implementation of CAI will be illustrated. The issues described here are currently being developed in the Dutch HBO. As it appears, this will happen in a business-like way without government interference.

We will end with some conclusions.

Infrastructure & Process of Development of CAI-Materials

The complete process of development has three routes (see Fig. 1), namely : the acquisition and implementation route, the production route

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and the sales and distribution route. As is usually the case with the development of teaching aids, there is a continuous feedback on this process :

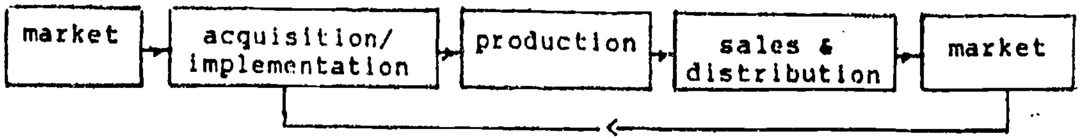
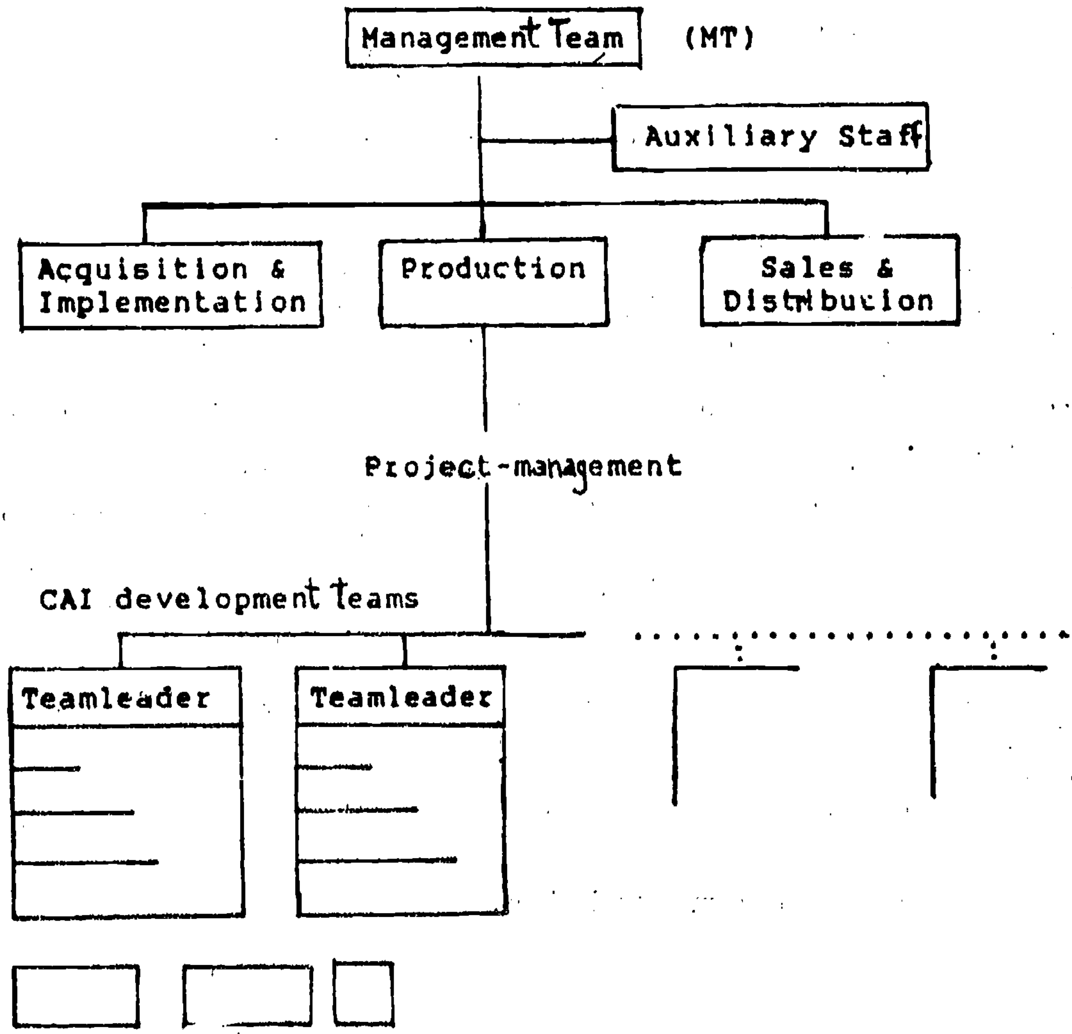


Fig. 1. Diagram of CAI development

A very important feature of this CAI development is that it is COHERENT, which, in our opinion, is vital for the infrastructure. The diagram for the project's organization is shown in figure 2. The three



External partners for the development support.
(Universities, publishers, software-houses, ...)

Fig. 2. Diagram of the organization

routes indicated above are included in this diagram and will, like the other units, be elaborated below.

Tasks

The following belong to the undivided task of the MT:

1. Financial policy ;
2. Market research policy ;
3. Publications.

The acquisition and implementation portfolio includes the responsibilities for :

4. Consultations with the institutes of HBO ;
5. Feasibility study/determination of course subjects ;
6. Qaulity control of the CAI material ;
7. Course implementation as regards content ;
8. CAI implementation in the HBO ;
9. Public relations ;
10. Instruction ;
11. Research and development of educational/product innovation ;
12. Personnel management.

The production portfolio includes the responsibilities for :

13. Making plans for course projects ;
14. Team formation ;
15. Overall design of CAI course development ;
16. Prototype design ;
17. Production of CAI materials ;
18. Monitoring developmental standards and progress of projects ;
19. Contacts with publishers and external organizations for production.

The sales and distribution portfolio includes the responsibilities below :

20. Technical implementation ;
21. Marketing, distribution, sale of courseware ;
22. Maintenance and management of courseware ;
23. Distribution of (written) information ;
24. Copyright control.

The Management Team consists of educational and business managers.

CAI Development Teams

For carrying out the production activities in the project, the primary working groups formed are CAI development teams. Each development team consists of some authors/experts on the subject matter, working in the organization and remaining at the institute of HBO as a teacher, each on a half-time basis. One of the team membres is appointed team leader.

The development teams are managed by project managers from the world of business, in this case the firm of S-CON. A project manager can be the manager of several development teams. The institutes "invest" in this development of CAI by supplying members for the project teams and by maintaining the infrastructure; the business world participates by bringing into action the hardware, the software and the project managers, and by financing in advance the external expertise (from universities, national groups of subject teachers, hardware and software firms, publishers etc.). The investments can be recovered by means of sales.

The exact procedure of the organization, laid down in the business plan and working routines, was developed by:

— the Consortium CAI-HBO;
— the firm of S-CON;
— the SCB (Foundation for Computer Management in the HBO);
— the Educational Centre of Twente University;

which will undertake the implementation in a partnership.

Based on market research, about 40 CAI projects (forming about 1000 hours of courseware) have been defined. Dependent on the financial possibilities and competitors' activities choices will have to be made.

Implementation

The conditions.

For the acceptation and implementation of CAI in the HBO the following conditions for success are important:

Quality (high quality of the courseware; high quality of the written study material; good coherence between the courseware and the written study material).

Performance (positive learning results; gain in learning time; decrease in the number of contact hours).

Service (well-considered strategy for implementation; good documentation; good facilities for distribution, management and maintenance; public relations policy; research and development policy).

Adequate cost price (positive cost-benefit relation for the institutes; possibilities to become self-supporting).

However, these conditions for a successful acceptance of CAI offer no guarantee for success.

The educational and organizational implications of CAI are so extensive that a specific introduction of CAI is possible only if it is embedded in a specially adapted educational policy of the institutes. This means a policy aimed at expansion, individualization and modularization of teaching methods. The management team will therefore develop strategies to promote this educational policy in the institutes.

Only within such an educational policy at the institutes will the acceptation of CAI by the teachers, students and the school management prove to be successful.

The "parameters for acceptation" mentioned here will be elaborated in the next sections for the teacher, the student and the school management.

Acceptation by the Teacher

A first important step (towards implementation) is that the teacher becomes acquainted with the possibilities of CAI through concrete CAI projects and measurable project results. This implies publishing the infrastructure for CAI development.

A second important step is the choice of the subject matter, which will have to fit in with the subject matter laid down in the institute's plan of activities. Furthermore, it will be necessary to follow HBO study material which is much used and more or less standardized.

A third important aspect is the possibility to be offered to the teacher to use CAI units flexibly. For this purpose the courseware will be divided into small units, with which the teacher and/or the department can easily put together a study program that is geared to his own curriculum.

A fourth aspect is making clear the advantages teachers will have when using CAI. It is a matter of interest that CAI can make the teacher free to perform important (new) tasks, which are now left on the shelf because of the packed teaching practices.

A fifth aspect, which is of strategic importance in this context, is the choice of the teacher as the prime courseware developer, and the influence of National working-groups on course (ware) contents.

The Education Departments of the institutes will, if necessary, point out the necessity and the consequences of the changing role of the teacher in the student's learning process, and the role CAI can play in this. The Consortium will have to propagate its own views on this matter and will have to help making this concrete, for example by means of workshops, seminars and through the Educational Network of the HBO-Council.

Acceptation by the Student

Implementing CAI opens up the possibility of increasing the student's self-motivation. However, this self-motivation can only be developed in a process-like way. Breaking the acquired consumptive study habits is extremely important in this. The possibilities of CAI with regard to specializations according to content and pace of the learning process challenge the student to become independent and self-motivated. A good private-study guidance, a written study material following it a good quantity of CAI and a measurable gain in learning time will facilitate the student's acceptation of CAI.

Acceptation by the School Management

School managers come to realize more and more that within the scope of the new methods of financing Dutch education new ways must be found to teach effectively and efficiently. Developing a coherent educational development policy aimed at expansion, individualization and modularization is essential for this. Only within this policy a professional curriculum construction by sections and departments can be developed. In an educational innovation carried out in this way CAI will be a viable method, because it is supported by a vital and established educational policy. In short, acceptation of CAI will be successful only in a new integrated educational approach. The organizational aspects of individualization in general, and of CAI in particular, are, however, numerous and complicated.

Furthermore, nothing venture, nothing gain: an institute will have to invest in computers, human capital and management facilities, before the effects on the efficiency of teaching become noticeable.

For schools participating in CAI development projects by bringing teachers into action the time to recover costs is even longer and more risky. In short, acceptation of CAI by school managers is only successful if the efficiency (contact hours made free and used well, and development time to be recovered) can be made clear. CAI running smoothly at an institute of HBO helps to create a positive image of the institute and can promote (indirectly) the acceptation by the school management.

Educational Management

Especially with CAI the importance of a good management of testing and study progress is obvious. By means of CAI expansion, differentiation and individualization of teaching can take place. Therefore an educational management system should be designed which, on the one hand provides the student with a larger freedom to choose a study route, and on the other hand supplies information about the student's progress at any given moment.

Conclusions

As we mentioned, the implementation of CAI, of some size, in school-environments is very complicated. In short it is not only a matter of using a new *product* (like a new textbook or the like), it is the acceptation of a new educational *process*. To acquire, to produce, to sale, to distribute and to maintain CAI-materials, and to implement the new educational process, a strong professional educational management is required. It must be able to adjust in all parts and details of the coherent developing process, described in this paper. Good connections with the Educational Departments of the Institutes of Higher Vocational Education are indispensable.

It is clear that all this is much more than (exaggerating...) just building a "courseware-factory" in splendid isolation. CAI-development is a mere educational task, at a national level, for the Higher Vocational Education itself. The infrastructure necessary for this challenging enterprise is given in this paper.

The *Consortium COO HBO* is building CAI-materials for the higher and advanced vocational education, and is developing the infrastructure described above.

(COO = CAI and HBO = Higher Vocational Education).

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SOME THOUGHTS ON STRUCTURES, OBJECTIVES AND MANAGEMENT OF CENTRES FOR COMPUTATION SCIENCES AND SOFTWARE TECHNOLOGY

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Abstract

We give some principles that have guided us in the build-up and management of an advanced centre for the computation sciences and software technology. By such a centre we understand one whose primary aim is to bring latest software technology out into industrial use. The principles centre around **clarifications :**

(I) of what is meant by the cluster of sciences and engineering illustrated by : theoretical computer science, computing science or programming science & methodology, and software engineering ;

(II) of what the various fields of activity in information technology are : software, informatics, technology and simulation modelling ;

(III) of what is meant by an advance project : its trinity of constituents : concept formation, development of design methods, and prototype construction ;

(IV) of base components often omitted in advanced projects in the highly intellectual fields of software and informatics : terminology development, library build-up, development graphs, and the SEA tripos : study-experiment-action, and

(VI) of ways of effecting relevance of projects and technology transfer.

The special problems of Software Technology appear to require that centres of the kind we are going to refer to need put special emphasis on our last issue :

(V) project planning, decision and monitoring, i.e. in the broader issues of project management, including

(VII) search-, study-, experiment- and prototype project phasing.

We have interchanged (V) and (VI) since (V) belongs more properly to a matter of principle whereas (VI) is more concerned with implementation of (the 5) principles ; but we treat (V) since its component-issues come from (IV).

Background

Several research & development (R & D) centres are being formed in these years, or have been established for many years without the desired impact, centres whose aim it is :

to provide advance work in the computation sciences with a view towards improving software technology, and

to further transfer of such technology from academia to industry.

These centres are not necessarily to become centres of fundamental, or basic research, but rather focal points of "technology" (i.e. computation science + software technology) transfer.

These centres are formed :

(i) either nationally
(GMD [FRG]; INRIA [F]; CNRS [I]; ICOT [J]; CWI [NR]; NCST [IND]),

(ii) or between a group of industries or private & public companies
(DDC [DK]; IST [UK]; ECRC [Eur]; MCC [USA]; SICS [S]),

(iii) or by a university :
(iii. a) either with industry membership ['science parks'],
(iii. b) or in response to government funding
(SEI [CMU]; ICSI [UC Berkeley]),

(iv) or they serve solely within :
(iv. a) a ministry (BSI, CSTC, etc. [PRC])
(iv. b) or a private company (IBM, SRI Intl., HP-Labs., TCS).

The present author is aware of around 30 such attempts in Europe (several), the USA (several), South America (a couple), India, the People's Republic of China [PRC] (several, competing, between ministries), the USSR (— similarly), Japan (a couple), etc.

The present author has been very active in building up one such in Denmark : the **Dansk Datamatik Center : DDC.** The reader is referred to the English language annual reports of the DDC for details.

In talks with leaders and leading researchers of these centres — over the last 4—6 years — a number of observations has been made, several of them, unfortunately, reflect a lack of coherence in what one actually wishes these centres to do. As a result of these perceived defects these centres seem not (able) to succeed in what they were technically and scientifically supposed to do, seem to have become empires in and by themselves, and seem shut off from the world some of them were intended to serve.

We must all realise that we have been asked to conduct a new kind of "business" in ways we are not quite familiar with, and where we cannot always copy management strategy ideas from other areas. The present note, therefore, hopefully as a useful contribution, shall attempt to give some guiding principles that were and are used in directing the reasonably successful DDC.

We must realise that among the major stumbling blocks to proper success of these new centres with regard to their originally stated aims is that directors and management often cannot cope with the span from [or the gap between] the material, gadget- and device-oriented universe of technologies (faster, more, smaller, cheaper, ...) to [and] the intellectual, concept-oriented universe of informatics (better).

I : Some Definitions

To establish and manage a centre for advanced technology is a meta-project. In any project, whether meta-, or advanced (as the latter will be defined in a separate section below ["III : Advanced Projects"]), a first undertaking is to establish a sound, complete and consistent terminology. It is then a subsequent, running activity to stick to the terminology, and, if required, to update the terminology.

Failure to do so will lead to confused projects : to projects whose members do not know precisely what is being researched and developed, what strategy, tactics and operational plans to invoke, and hence to projects which are hard to manage, and which in only rare circumstances will lead to useful results.

In this section we define the following terms :

Computation Sciences and Engineering

The computation sciences and engineering consist here of : *computer science, computing science, software- and hardware [computer] engineering*. The underlined terms are defined.

[Theoretical] Computer Science

Theoretical computer science is the study of programs :

of what is computable (meta-mathematics, computability theory, ...), of how complex it is to compute things (algorithm analysis, complexity theory), of the mathematical foundation for various abstractions of computing (automata theory, formal language theory, net theory, fix point domain theory, denotational semantics, algebraic semantics), and of the foundation of the reasoning that goes on in programming (proof systems, Hoare Logics, ...), etc.

Computing Science — or Programming Science & Methodology

Computing science is the study of programming :

of the methodologies, languages, techniques and tools that go into the development of software : requirements analysis & definition, functional and non-functional specification, program transformation, of the special development techniques required in order to secure reliable, robust, fault-tolerant, and secure software, and coding.

Software Engineering

Software engineering is the practice of programs and programming : thus it includes the syntactic and pragmatic human as well as mechanical (tool-building and tool use) concerns of how to produce, validate, control and monitor documents needed in the software development process, not just from the point of view of supporting these processes mechanically, but also of securing interaction (the social processes) between people : customers/users and developers, and between developers.

Programmer

When a person is concerned with the *semantic* aspects of the programming process, for example : which functional properties to capture in abstract specification and which to focus on in concrete design and coding, which formulation to give to development documents, what they mean, how to verify what documents describe, and how to transform abstract descriptions into more concrete ones, then that person is a programmer, and is programming. A programmer proposes theories (with the theoretical computer scientist guarenteeing these to exist).

Software Engineer

When a person is concerned with the *syntactic & pragmatic* aspects of the software development process, for example : with the non functional, current technology constraints, the tracking of external design [constraint] requirements, the journalling of development documents, the creation and maintenance of versions of specification, design & code documents, their configuration into products, and with the validation of non-functional requirements, then that person is a software engineer. The software engineer is a tool builder (with the tools always reflecting a new instance of a methodology, but bound by current technology constraints and theoretical know-how).

Programmer vs. Software Engineer

The software engineer "harnesses" the laws of nature, the programmer the laws of mathematics, computer and computing science. The software engineer interfaces with the ever current limitations of hardware technology, the programmer with the always fixed laws of computability. The same person is at times a programmer, at times a software engineer, and a good programmer knows exactly when transitions are made between the two activities, and when the assistance of a computer scientist is called for — to help secure the foundations of what is being described.

Subsequent sections will introduce (define and use) additional terms.

The morale of this section is the following : in every industrial software development project, and hence also in every R&D center project, make sure that your staff comprises all talents : programming, engineering, theory and management. I, personally, currently, believe in the usefulness of separating the concerns, ie. of letting different state people man the positions : programmers, engineers, scientists and managers. References 1—2 outline the specific roles of the four groups : programmers, engineers, scientists and managers; suffice it here to emphasize that even state-of-the-art theory results have proven useful in mundane developments. The very successful DDC Ada Compiler development is a testimony to that.

II : Activity Fields of Information Technology

We basically see the fields of activities centered around the use of computers to fall in 4 areas :

Software Methodology,
Informatics,
Technology, and
Simulation Modelling

That is : the projects of an advanced computation science and software technology centre can be classified to primarily belong to either of these 4 areas.

Failure to identify with either of these, or, in cases, to compartmentalise centre projects in a similar way, will lead to projects that are confused, lack focal points, are hard to manage and will only lead to useful results under very traumatic conditions.

Each of the four areas will now be defined and described.

Software Methodology

The *objective* of a project in this area is to create concepts, (meta-) methods [techniques and tools], and products useful primarily to professionals of the field itself, that is to programmers, software engineers and their managers. The *aim* of a project is basically to advance the state of the art of programming science & methodology.

The primary *interface* of the products of this area is to other products of this area !

The primary *theories* of this area are those of computer and computing science.

Examples of projects are : operating systems design methods, compiler development methods, methods for database design, incl. data models and their database management systems, programming & software engineering support environments, methods for the design of reliable, fault tolerant, robust and secure systems, of distributed systems, etc.

Informatics

The *objective* of a project in this area is to create concepts, design methodologies and products useful primarily to non-edp professionals, i.e. to end-users. The *aim* is to advance the state of the art in human applications of computers.

The primary *interface* of products of this area is to humans, i.e. to people.

The primary *theories* of this area are :

computation,
linguistics,
cognition and
organisation.

That is : building upon state-of-the-art in programming to combine this with concepts from the linguistic, the cognitive and the organisational (management, behavioural, sociological) sciences to bring about user-friendly man-machine interfaces (MMIs) for knowledge-expert-system based systems which function well in ever-changing human environments.

Examples are : advice-giving decision support systems, office automation systems, desk-top publishing systems, spread sheet systems, ..., computer aided learning & instruction systems (CAL/CAI), ...

Technology

The primary *objective* of projects of this area is to develop concepts, design methodologies and products useful primarily to systems consisting of hard technologies. The *aim* is to advance the state-of-the-art in technological, embedded systems uses of information technology.

The primary *interface* of products of this area is therefore to technology.

The primary *theories* of this area are, besides those of the computation sciences, and in cases also those of the broader informatics sciences, those of engineering : civil, mechanical, chemical, electrical & electronic, incl. communication, systems & control theory. Other sciences are presently entering the scene : biology, biochemistry, etc.

Examples of products of this area are : medico-electronics, LANs WANs, OSI, electro-mechanical gear and instruments of any kind : CAM CIM, incl. robotics, flexible manufacturing sytems, engineering systems : CAD CAE, etc., etc.

Simulation Modelling

The primary *objective* of this area is to develop concepts, design methodologies and products which simulate or model large scale systems for the purposes of validating hypotheses, or predicting behaviours. The *aim* is to gain improved insight into natural or human systems.

The *interface* of products of this area, namely of the software models of large scale systems, is to the researchers, scientists and advanced technicians who research, control or monitor such large scale systems.

The *theories* entering this area are any of the ones entering the problem domain being modelled, with most of them resting on firm mathematics.

Examples of products are : environment/ecological models, economic forecasting and planning models, models for example of the 'nuclear winter', pattern recognition/image processing, etc.

Note : there are overlaps, in kind, of this field with that of informatics : whenever a simulation model is run repeatedly, for decision support in everyday 'business', then it becomes, not a hypothesis validating, or behaviour predicting model, but more like a knowledge-based, or an expert system.

III : Advanced Projects

In this section we define what is meant by an advanced project.

By an advanced project we understand one which contains "equally" all of the three objectives : development of

(i) new *concepts*,
(ii) new design *methods*, and
(iii) a (prototype) *product*.

To develop new *concepts* means, in different contexts, different things. Basically the idea is the following : the product produced must reflect some new notions in computing, for example a new programming paradigm (in the area of software methodology), a new office automation system notion [desk-top publishing, spread-sheet, ...] (in the area of informatics), a new process control or flexible mfg, scheme, etc. (in technology), or a new theory for a given problem domain (in simulation modelling).

To develop new design *methods* means likewise there must be an element of methodology R&D in every advanced centre project : given a successful completion of an advanced project it must now be more clear how similar *products* (applications) should be developed in the future, by industry, by end-users, by other, non-edp oriented technologists, by mathematicians and engineers.

Thus to develop concepts has to do with *what* the product exhibits, whereas to develop new design methods has to do with *how* the product achieves its functionality.

If a project does not aim at a product, be it just a prototype product, then there is a danger that it will become a 'pure, speculative' research project. If an advanced R&D centre for the computation sciences and software technology does not adhere to this trinity, in all of its projects, the word 'advanced' will soon become 'commercial', the prefix 'R&D' will instead become 'marketing and sales', the word 'computation sciences' can be dropped, and the word 'software technology' be replaced by 'edp' !

If an advanced R&D centre, of the kind we are talking about is not staffed by people who are all equally interested in all of the three areas, and who are all primarily interested in their interaction, then management will have a hard time directing the technology transfer aspects, and in avoiding the centre becoming just another for-profit company, competind with the environment it was supposed to serve.

IV. Some Project Components

The following components, commonly omitted or overlooked, have been found crucial to the success of any advanced project :

(i) **Terminology,**

(ii) **Library, and**

(iii) **Project Graphs.**

That is : the establishment (creation), daily use, and continued maintenance of each of these three is deemed an essential feature of good project management.

Then the division of work, as described, on a per package basis by the project graph, into

(iv) **Study-Experiment-Action (SEA),**

has also been found crucial in the continued, uninterrupted on-the-job education and training of all staff.

The universality of computing, it being applicable to well nigh any area of human and technological concern, and the thereby connected highly intellectual nature of conducting project in the area, require the presence of all four of the project-independent components in any project. Finally the overall combination of these ingredients into a 'whole', namely that of : Project-Management will be reviewed in a subsequent section.

We now elaborate on each of these 4 base components of any good project, and their total interplay.

Terminology

It has been mentioned, above : in any advanced project it is decidedly important to establish, use and maintain a terminology.

It is triply important since our advanced project involves both :

— concept formation (i.e. the intellectual development of new ideas),

— design methodology development (i.e. the engineering development of new construction procedures, techniques and tools), and

— [prototype] product development (i.e. the commercial, market-oriented "manufacturing" of saleable goods).

A terminology is a dictionary and a thesaurus. The dictionary' thesaurus introduces, both a vocabulary of all the terms new and crucial to the product concepts, and the design methodology, but also its taxonomy. For each term a precise definition is to be given, relating it also to other defined terms. This may sound as a bit of an academic "egg-head" approach. But then the reader has to accept that software products are entirely and exclusively intellectual products, artifacts of the mind, primarily free from any technology constraints, or at least attempting to be so.

In establishing, enforcing (using) and maintaining (updating) a terminology we avail ourselves of a terminologist, a person who also looks after the library function — see below. Thus : at the very outset of a project we nominate a person, and we establish procedures for that person and all project staff to follow, for creating, using and controlling the terminology.

We consider the Terminology/Dictionary/Thesaurus/Taxonomy to be part of the resulting delivery (product). It is not uncommon to find that the job of creating, enforcing and updating this document in a 8—12 person per year project is a 1/2 time job !

Library

The next important manifesto or an ongoing project is the literature it refers to and the reports, documents, and publications, it itself generates. As will transpire from the SEA notion (Study-Experiment-Action), our project study experiments with, refers to and results in literature.

In making design decisions with regard to concepts adopted, design methods proposed, and product functionalities, we make extensive reference to existing or generated literature. This is all bibliographed and extensively annotated by the library function.

A project library is a triple :

— a *schema* for the organisation of the library,

— an hierarchy structured *catalogue* of all the entries of the actual document base, annotated with regard to the taxonomic terminology, and

— the actual *document base* — wherein all documents : books, journals, reports, etc., are stored in physical form.

The schema and catalogue is usually computerised, whereas the document base is in conventioal library form : copies of the referenced and annotated documents, stored on accessible shelves.

We find that an advanced project usually generates 3—4 worthwhile reports per project member per year, and that each of these reports make extensive reference to the library, and that, hence the library concept is an important, indispensable one.

We find that in an 8—12 man per year project the library function is a 1/2 time job. Hence we find that the jobs of a terminologist and a librarian are a full time job for any interesting project.

Project Graphs

The notion of software development graphs, and the derived notion of project graph is described in refs. 1—2.

Since these references are generally available we shall not here go into any detail of what software development graphs are, see however our article in the 32 issue of the EACTS Bulletin on *Aspects of the Role of Theory in the Computation Sciences and Engineering,* the section named *Software Development Graphs.*

Suffice it here to repeat : if the management of a project cannot itself generate its appropriate project graphs, then the project should not be undertaken.

SEA : Study-Experiment-Action

Each node, and each edge of a project graph, stands for certain activities leading to certain documents. Each node or edge activity takes time. We divide this time into three phases :

Study Phase :

In this phase, usually of 3—6 weeks of duration, we study existing literature, summarise it, present its findings to our project colleagues, and enter annotated entries of concepts into our terminology and entries of referenced literature into our library. The study phase could also be called the 'education phase'.

Experiment Phase :

In this phase we aply essence of the most promising findings of the studied literature to small, but difficult "toy" examples. The results are additional concepts, introduced into our terminology, and various research and development notes — these latter are entered into the document base. This phase is usually double the length of the study phase. The experiment phase could also be called the 'training phase'.

Action Phase :

In this phase, usually of 3—6 months duration, we actually apply what the aducation and training phases have taught us to the real, full-scale problem we were asked to solve in the first place.

The decomposition of work into three phases has been applied successfully in DDC projects. Even in commercial projects with tight dead-lines and tight funding, it was found that rather than lengthen the process, it was shortened, that rather than diverging over differently manageable activities (study, experiment, action) staff and management were better able to conduct their business in unison, more focused. It is strongly believed, and has been simply upheld, that staff, in R&D centres of the kind we are talking about, should not need to be taken off projects to be sent to summer and witer schools for the sake of cantinued education and re-training. Such continued education and training must be part of every project, but related very strongly to its semantically meaningful sub-components.

V : Project Management

The above four notions (terminology, library, project graphs, and study-experiment-action) are but components in the overall project-management puzzle. It is true that the notion of project graphs subsumes the other, but then the notion of overall project management subsumes everything.

We see two facets here :

— non-technical management issues

— technical quality assurance.

Non-Technical Management Issues

Project creation, to establish, to direct and to successfully conclude a project is a project, hence a meta-project, in-and-by-itself. The object of project management is, in the cases we are here dealing with, primarily the highly intellectual processes of forming concepts, and of finding methods. This gives a new dimension to project management. To create the objects that software people are creating, is like writing a book. Only, instead of having one, or 2—3 authors, you have a minimum of 10—20 ! This process, of having some highly literate people work with many, usually, "culturally"-speaking, illiterate people — that process — is not well understood. Again and again we see ghastly tales of exorbitant cost and time overruns, and of products completely missing even a minimum of expected functions.

We besically believe that these often catastrophic failures are due to a complete decoupling of ordinary management issues from the technical ones of first creating, and then executing a semantically meaningful project graph. We shall therefore hinge, as an extreme, but hopefully useful point of view, all of our non-technical management issues around the notion of project graphs.

The overall issue of project management is :

— organisation building and maintenance

that is : to create the organisation necessary and sufficient to create, conduct and conclude a, or the, project.

The subsidiary, non-technical issues of project management are :

— budgetting, financing and accounting

— resource allocation, scheduling, monitoring and control

— decision analysis, assignment, making and follow-up

— manpower motivation and competence-monitoring

— project graph creation, monitoring and update

We conclude by repeating that we believe, strongly, that [a treatment of] all of the above "bulleted" items should be primarily structured by (linked to) the notion of project graph.

Technical Quality Assurance

In other technologies quality assurance includes quality control — as something that can be done on the side, by functions orthogonal and independent of remaining project work. We believe that, with the highly intellectual 'book-writing' character of software creation, quality is an integral part, both of the project, in-and-by-itself, and of the product :

Project Quality Issues

These are the project quality issues :

— budget, financing and accounting affinity : *economical*

— measurable project execution : *objective*

— correct resource estimation : *resourceable*

— *reusable* product (component) results

— *security* : project leads to expected results
— project staft *satisfaction*

Product Quality

These are the product quality issues :
— *fitness* for purpose
— *correctness* : product implements specified functions
— *reliability* : unambiguous rejecton of clearly specified non-input
— *fault-tolerance* : unambiguous rejection of unforeseen data
— *secure* ; system cannot be tampered with
— *robust* : incremental changes preserve product quality
— *maintainability* : incremental changes linearly implementable

Quality Assurance

Quality assurance is to work with the right projects, to plan, and to conduct these correctly, satisfying the project- and product quality criteria.

VI : "Technology" Build-Up and Transfer

Two aspects are covered here :

(i) how to secure, in a non-university environment, the safe build-up of proven methods, techniques and tools, of relevant concepts, and of relevant products, and

(ii) how to secure the transfer of methodology, concepts and product — our triple word "technology" — to industry and business.

We now elaborate on our thoughts and experience in this area. The presentation is in the form of advices.

"Technology" Build-Up

With each project we associate groups of permanently and temporarily retained advisors, respectively consultants, and with the entire centre we associate a science & technology board.

Advisors, consultants and S&T board members come from both industry and academia. When they come from industry, they usually come from partners, or in cases, from project-clients. We advice on seeking an international mix.

Permanent project advisors stay with a project usually for its entire duration. Temporary consultants are hired on a per problem basis. The S&T board members stay with the centre for 3—5 years. One should seek a continual renewal of board members.

The S&T board visits [should visit] the centre once a year, for 3 days, and are daily given 4—5 hours of presentations of 2—3 projects : of their conceptual basis, on their strive for methodology, and on their product aims. Presentations are part formal, part informal, with extensive interaction between S&T board members and presenters. The interaction is always both pinpointing problem spots as well as suggesting remedies. The entire centre management down to relevant project management and sub-project leaders/supervisors take part in these meetings. Each day is ended with a 2 hour top-management + centre board directors + S&T board member free-wheeling discussion. The meeting starts with an overview of status and immediate plans, and ends with an overview and discussion of longer range future plans. S&T board members usually write no reports.

Permanent Project Advisors visit, individually, the project once or twice a year for 1—5 days, and are regularly sent documents central to the project. Occasionally they take part in residential, week-long project work-shops. They are given formal presentations, spend most of the time discussing with individual project scientists and engineers, and write short evaluation reports.

Temporary Consultants are called in to solve specific problems. Sometimes they actually visit the project for 1—2—3 weeks, and then usually also give a series of colloquiae, in addition they work with individual project staff, or present their solutions to project staff.

A final ingredient in the quest for building-up know-how and in securing its objective relevance is the insistance on project staff publications : at conferences and in journals. The concept- and methodology facets of advanced project quite unproblematically lead to publishable results, free from specific product (and client/customer) confidentiality concerns. The SEA : study-experiment-action tripos together with the advisor and consultant interaction facilitates this attempt to let the open market-place of paper evaluation and conference feedback help secure "technology" build up.

"Technology" Transfer

We see three target groups for technology transfer, and we basically only believe in transfer through people, not through reports or products The three target groups are :

(a) Partners
(b) Clients
(c) Subscribers

The partner group may typically be from 10—25 partners, the client group may typically number from 100—150, over a span of 3—5 years, and the subscriber group usually consists of some 1000—3000 subscribers. The economic involvement of these groups is inversely proportional to their size : 100—10—1. Partners are also clients, and clients are also subscribers -i.e. partners are also subscribers.

Partners

Partners are like the stock-holders of an incorporated, i.e. a stock capital company. Partners form the group that speak up at the annual stock-holders meeting and elect the centre board of directors.

The centre may either status as a non-profit association, as a publicly or privately-owned, non-profit foundation, as a stock capital, incorporated company, or some such thing. In either case the partner pays respectively membership dues, or an initial, large financial contribution (interest on which would equal membership dues).

The centre board of directors usually come from partner companies (institutions, etc.), and hence partners influence the policies, strategy and tactics of the centre.

In return the centre should be secured a token share of partner stock, and a reasonable role in leading-edge, advanced project within the partner company itself.

Some centre projects may require special funding — in which case it is proposed that a separate, stock-holding or other interest company be set up, between the centre and a subgroup of partners, to finance, monitor and control such specific projects.

Partners have a right to get involved in any of the centre's many projects, and usually can do so, either by financing it, or by assigning own staff to it. Not all partners do necessarily get rights to all results of all projects. Usually it is negotiated, at the outset of a project, which, if any, partners, get which rights to which parts of project results.

When a partner becomes engaged in any specific project, in any of the roles mentioned above : financing, staffing, and rights exploitation, then the partner plays the additional role of a client.

Basically, partnership has to do with basic funding of entire centre activities and thereby related influence on the entire centre. Partners are generally interested in the general welfare of the fields of computation, informatics and related technology.

Clients

A client is not necessarily also a partner. A client is like a customer. Any person, company, or institution is eligible to become a client. A client is one who is actively engaged in a project with a centre. Either as a co-contractor on a project towards a third party, or as a customer, funding part or all of the project costs.

Clients usually assign staff to stay, on the centre premises, for longer duration during projects.

Clients tend to become partners.

Clientship has to do with specific funding and participation in specific centre projects, with little, if any influence even on project-direction — thus it is a take-it-or-leave it, thereby distinguishing the client relationship from that of a fully paying customer in conventional trade.

Clients are usually primarily interested in products, and only secondarily, in as far as process know-how is required to take over a product and maintain it, in methods.

Subscribers

Groups of centre projects usually produce concepts and methodologies of interest to a larger audience of individuals, companies, etc.

Subscribers are, in this context, not interested in the projects as such, nor in the product results — only, to repeat, in concepts and methodologies.

The centre therefore factors out a separate activity to serve such special interest groups. Subscribers quarterly receive [extracts of] reports, a centre journal, and discount offers on seminars, colloquiae and courses.

Seminars, Colloquiae, Courses

Seminars are usually 1/2 to full day, in rare circumstances 2-day events. *Colloquiae* are usually 2—4 hour events, with *courses* being anywhere from 1—2 day, to 1—2 week events, sometimes residential.

A seminar presents finished, polished project results sometimes at a popular, informative, sometimes at an educational, pedagogical, and sometimes at a technical/scientific level.

Colloquiae offer insight into ongoing work on projects, with their presentation being less polished.

Courses are delivered with concern for pedagogics : participants must be able to show that they have learned something.

Target Groups

Target subscriber groups fall in three overlapping groups : (i) technical & scientific professionals who must keep abreast in order to do actual work on actual project in their own companies, (ii) company staff : planners, who must be more generally informed so as to advice management, and (iii) medium-to-top level management, i.e. policy and decision makers.

VII : Project Phases

For the kind of R&D centres that we are talking about it seems useful to break projects into four phases :

— search phase
— study phase
— experiment phase
— [prototype] production phase

For management control purposes it might be useful to view the above decomposition also as one into kinds of projects, and to indicate their relative number within a centre :

— search phase : 8
— study phase 4
— experiment phase 2
— production phase 1

That is : the centre at any one time may have, say 15 projects, or a multiple thereof, of which 8 (etc.) are in their search phase, 4 in the study phase, 2 — etcetera. Or, to put it differently : in order to generate good production oriented projects we must search for good ideas, scrap half of these, study the remaining, scrap half the studies, etcetera.

The resources spent, per project, in the various phases would, for budgetting and other purposes, typically be :

— search phase :	1— 2	manmonths
— study phase	8—16	manmonths
— experiment phase	1— 2	manyears
— production phase	8—....	manyears

In the search phase a new area is surveyed (for example Flexible Manufacturing System, seen from the point of view of, for example, either knowledge based expert systems, or base software technology, or LAN protocols, etc.). The search phase identifies, relative to the centres existing competence and its desired future profile, the topics that could be studied. The result of a search phase project is a management report together with an embryo terminology and a study/experiment [software development] project graph.

In the study phase such topics are studied, leading to further elaborated terminologies, technical and research notes, and possibly a (experiment + production) project proposal (including further refined graphs).

Etcetera, etcetera.

The study-experiment-action notion attached to each note and edge of software development (project) graphs, repeats, in the small, what the study-experiment-production phase notions concerning entire projects express in the large.

Conclusion

We have tried to outline a few of the orthogonal issues that go into successful build-up and daily management of new centres for advanced R&D in the areas of software, informatics and technology.

We believe it important for management of such advanced R&D centres :

(I) to understand the essence of the distinctions between theoretical computer science, programming science & methodology, and software engineering ; and between programmers and software engineers,

(II) to appreciate the fields of software methods, informatics, information technology, and simulation modelling,

(III) to convince themselves of the importance of having each project be advanced : containing aspects of concept formation, design method development and prototype product construction,

(IV) to base all projects on a-priori established development graphs, to incorporate terminology and library development in each facet of each project, and to alternate each work-package of each node and edge activity of a project (graph) between study, experiment and action,

(V) to be able to cope with the special management problems of projects involving highly intellectual results and oftentimes "primadona" like knowledge workers.

(VI) and finally to understand the sources of technology build-up and the targets of technology transfer.

We believe that many failures of centres projects can be traced directly back to lack of adherence to these issues. We believe that their adoption is a necessary requirement for new centres to succeed.

The totality of the many issues respond to the base premiss : work in the areas of the computation sciences (software), informatics, information technology and simulation modelling is not engineering in the classical sense of harnessing laws of nature, but is a highly intellectual endeavour, requiring new principles.

An issue often overlooked in several centres I have visited over the years is that of hiring people educated by scientists who have themselves founded schools, and to let these hires form the core of projects. We are assuming that most of the centres, that we are here talking about, are technology transfer centres, i.e. sit between academia and industry, and that they take the best available theories from universities and apply them systematically in order to come up with worthy transfer items. That is, we are assuming that most of the centres need not themselves be high-strung, fundamental research centres.

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THE SOCIAL IMPACT OF TECHNOLOGY — AN ISSUE FOR ENGINEERING EDUCATION

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The main forces for change within university teaching in the years to come are, on the one hand, the students who are widely dissatisfied with poor quality of teaching in contrast to high emphasis on research and, on the other hand, the industrial companies which are increasingly threatened by fast complex technological developments (e.g. automation, communication technology etc.). These companies have to tolerate university graduates who are rarely up to the needs of society under the impact of technology, including its progress, failures and even catastrophes. The impact of technology on society may be useful as a lever to help bring about substantial change in university teaching and learning. Hence, we recently initiated a program within our university to raise awareness of and promote discussions on the impact of technology on society. The aim of this staff development program is to shape technological research and development projects at our university taking into account their societal and ecological effects (Sell, Henning 1986).

Our university, the University of Technology (RWTH), Aachen, is one of the largest in the Federal Republic of Germany. Every year hundreds of engineers of all disciplines graduate here and about 10% of them go on to a PhD in engineering. Most of them do this in very close relationship with industrial projects. This means that they are working as junior researchers under the supervision of a professor in the framework of an industrial contract. The aim of their thesis is usually to develop elements of the new technologies which are to be introduced to industrial production.

We try to use this situation to promote a new approach to technological development within our university : from the very beginning of such a university project on technological development, the researcher is asked to consider its future effects on man and society. We assume that the most important elements in this approach are the consciousness of the researcher himself in relation to possible effects and his strong intention to minimize any negative effects of technological development.

Accordingly, our program has three main aims :

1. To encourage critical attitudes towards technological research and development within our university.

2. To cooperate with and to support junior researchers in relation to issues of technological development.

3. To set up working groups of junior researchers, encouraging them to develop further their critical attitudes towards technology.

In our seminars and workshops, we assemble representatives from industry (managers, unionists, workers) and from the university (professors, junior researchers, students). The most important aspect of these activities is the confrontation of the university researchers with those who are the actual users of new technological products, e.g. industrial managers or workers.

As a detailed example, a series of workshops is designed to give workers the opportunity to talk to junior researchers about their practical experiences with the new technologies. The workers' representatives who report in these seminars are mostly unionists. They have the self-confidence needed to question the university researchers in the subsequent discussions. In this way our university staff gain insight into the on-going processes of the power-struggle between management and workers on these issues of new technologies. In addition the researchers learn about the effects of technology on working conditions.

Some other examples of workshops include the following:

— CAD/CIM
— artificial intelligence
— expert systems
— tele-homework
— biological waste
— traffic and its ecological impact
— energy supply
— communication skills and team-leandership.

In our seminars on communication skills and team-leadership, we simulate and practice discussions about and arguments on the issues of society and technology as they take place in reality. Thus, junior staff experience a new insight into their roles as university teachers and researchers by experiencing conflicts of a non-technical nature. For most of our engineers, it is a new experience that they have to come to terms with.

In these seminars, we take into account the specific problems of women as part of the labour force. They are particularly affected by developments of new technologies which produce rationalization, automation and tele-homework.

Another approach to reach our university colleagues involves joint panel discussions with representatives of unions, industry, university and government. These discussions are attended by an audience of more than 200, mainly consisting of students. The large attendance stresses once more the significance of our concept.

It is important to involve professors personally in interdisciplinary cooperation on these issues of technological development. To achieve this aim we organize a different series of lectures. Each lecture is given in turn by different professors of engineering and social sciences. Another approach is to offer seminars for professors in order to get them into close contact with modern industrial management facing the challenge of new technology.

But these different activities are still not sufficient to develop a "humancentred technology" (Brödner, 1985 ; Corbett, 1986). The individual problems of technical research are too varied. Individual support is necessary. The usual problem of junior researchers is a lack of time. In spite of their self-motivation they are not able to develop the knowledge and skills needed to integrate ideas about the social effects of technology into their daily work. In this situation we facilitate their access to the necessary information and publications.

In addition we organize contacts for the researchers with experts. These "experts" in our sense are the users of technology or those affected by technological development. Discussions with these kinds of experts and the resultant confrontation with their experience and ideas influence in a very fruitful way the process of research. However, it is not always easy to overcome communication problems. Another difficulty relates to locating experts who will be affected by future technologies as not yet existing in industrial production.

It is obvious that the problems caused by the use of new technologies (e.g. computers, microelectronics) recur time and time again. These are mainly problems relating to automation and the introduction of information networks. Besides the effects of rationalization we often observe negative consequences such as problems caused by working with video screens, the constraint of adaptation of human work to computer conditions, and the increasing possiblities of greater control of workers. Whenever similar problems arise in the course of a dialogue with a junior researcher we can offer him the benefits of the experiences which our interdisciplinary team makes available. In other cases we additionally refer to the experiences of our collegues in other disciplines, e.g. social sciences.

When there are several researchers with similar research problems, we set up working groups comprising researchers and representatives from industry who are affected by technological developments. Their task is to re-design these engineering projects with the aim of reducing risks and dangers arising from these projects within a wider social context. Up till now we have established 15 working groups, most of them focussing on themes like expert-systems, changing qualifications of workers, CIM, designing a railfreight terminal etc. Some other working groups have dealt with developing relations between the following groups :

— university ;
— trade unions ;
— professional associations of engineers (VDI etc.).

In the beginning we offer these groups our assistance and support. But after a time the groups should be able to work on their own. We expect these groups to continue their work even after our project which will have finished in 1988. We furthermore hope that the activities of these groups will generate new projects.

The most interesting result of these efforts is the project to develop further the qualifications of workers in the Three-Nations-Triangle of the Aachen area (Belgium, Netherlands, Germany). The qualifications aimed for include computer competencies, problem-solving strategies, team-work and creativity training. In this way, we hope to contribute to workers coping with the new technologies.

The program described is the first of its kind in the Federal Republic of Germany. It is supported by a government grant. Our evaluation of the program is based on a series of interviews with our colleagues involved in the different parts of our program. The interviews have shown us that their involvement in the program has brought about a lasting impact on their views of technologies and society. In addition, these interviews have contributed to deepening the personal contact between our team and our colleagues across the University. However, we have only limited indications so far that our colleagues are prepared to change their approach to engineering research. It will need even more efforts to achieve visible changes of this kind.

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Chapter V

MANAGEMENT OF HIGHER EDUCATION INSTITUTIONS

The literature on the new technologies in higher education emphasizes the fact that so far their most frequent use has been in administration, not in fields like education or research. Moreover, in countries in which these technologies have been introduced on a wide scale, more than half of the financial resources allotted to them have been absorbed by the administrative services.

The four articles on this aspect of our topic emphasize the role played at local and national levels by computers in the management of higher education institutions and the evolution of this role from the mere organization of simple administrative data to the devising of strategies and the making of decisions.

Edgar Frackmann's article deals with higher education institutions in the Federal Republic of Germany. The study illustrates the use of computers at the local level in the administration of institutions (budget, etc.) as well as at the national level, in providing the necessary data for the decision-making process. A new element with regard to microcomputers is that these can be found on the desks of almost all administrators, including rectors. These officials regularly tackle problems of institutional planning, policy formulation and decision-making with the help of the computer. Continuing with this line of thought, the article also offers a description of the role of institutional researchers, information centres, and information managers.

Although Ari Heiskanen's article contains an enlightening description of the whole system of administrative data processing in the universities of Finland, it concentrates primarily on the systems used by Helsinki university and their tasks (accounting, payroll, student registration, study results, student financial aid, student selection, reservation of classrooms, space, employment registry, etc.). The article describes all the student information systems down to the smallest detail.

The article by Roland Bouchet of the Educational Research and Innovation Centre of Paris explicitly and convincingly presents the ways in which university adminsitration has changed and is continuing to change information technologies. The influence of information technologies is especially evident in the fact that : 1) the intermediary link between user and computer facility has ceased to exist; 2) managers must now think directly in terms of the information system. The new information technologies bring with them a certain managerial attitude; they also promote fresh thinking as well as new equipment policies and development strategies.

New solutions for effectively improving the living standards of the 3.5 billion inhabitants of the developing countries is one of today's great challenges. A specific and efficient way to undertake this task is to investigate how the international scientific and development community might best organize itself to assist the developing countries in using computer and information technology to promote progress and growth. "Computers need not be confined to the elite — they should be accessible to everyone", is the opinion of Mohan Munasinghe, from the Third World Academy of Sciences, Trieste. His article describes an interesting project concerning the establishment of a new International Centre for Computers and Informatics to be based on the network principle.

THE EMERGENCE OF INSTITUTIONAL RESEARCH AND THE USE OF MICROCOMPUTERS: NEW ROLES FOR INSTITUTIONAL RESEARCHERS IN WESTERN EUROPE HIGHER EDUCATION INSTITUTIONS *

Edgar FRACKMANN

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Abstract

New roles for European institutional researchers derive from two developmental lines in European higher education, on the one hand the development towards a market system in higher education including a strengthened autonomy of the individual institution, on the other hand the development of information technologies which lead to a widespread use of microcomputers on the campus.

While (until recently) institutional researchers in European universities have rather been administrative data processing specialists than institutional researchers in its true sense, their tasks now combine their ability of using computers with real institutional research.

1. Introduction

At the beginning of my paper presentation I would like to tell you about the task I got from our convener: "Edgar — the personal computer and associated software made a change in our ability to design analyses to fit differing individual administrative styles and changing institutional conditions. Some of the European workshops have illustrated these applications and perhaps you would like to give us a state of the art appraisal".

When Craig Johnson first tried to draw some conclusions from the European AIR-Fora (Johnson 1983), he stated an increasing interest of institutional researchers in the use of computers, focussing especially on the question of microcomputers. However, this greater interest in information technology, is only scarcely mirrored in the contributions to the EAIR-Fora; when counting the contributed papers of the AIR-Fora

* Paper presented at the 26th Annual Forum of the Association for Institutional Research, June 1986, Orlando, Florida.

from 1979 to 1985 I only found 8 of 129 pages dealing with computer applications, which seems to me to be an inadequate representation of this topic in institutional research contexts.

Indeed all of these 8 papers are dealing with *microcomputers,* which could lead to the conclusion that the new interest in information technology on the side of institutional researchers coincides with the emergence of microcomputers. This is true for the American institutional researchers, but not to the same extent for the German institutional researchers for example. They dealt with computers and data processing from the very beginning at the end of the sixties, although I must concede that what they did was not institutional research in its true sense.

year of forum	papers on microcomputers	of papers total	contents of papers
1979	-	12	
1980	2	13	- Management Information System and Modelling System - Computer as a tool for IR-office
1981	1	7	- Computer as a tool for IR-office and decentralized administrative computing
1982	1	25	- Use of microcomputers in the administration
1983	-	25	
1984	3	23	- Decision support for managers - Tool for budget allocation - Microcomputers and top administrators
1985	1	24	- Information management and decision support

Table 1

Contributed Papers at the European AIR-Fora on Microcomputers

To solve this enigma, I would like to

(1) go back to developmental stages concerning higher education in its political and economical contexts and information technology in higher education institutions.

(2) look at the actual situation of higher education institutions with regard to :

— the emerging tasks of real institutional research ;

— the microcomputers functioning as decentralized computing power.

(3) trace some new tasks for institutional researchers in Europe.

My paper has of course got a bias towards the German situation, but I think that a similar situation prevails in most of the European countries. In order to point out the main trends it appears necessary to exaggerate or simplify some developments or situations to some extent.

2. Looking Back to the Roots of "Institutional Research"

German higher education institutions are state institutions, which means that they receive their funds from the states by virtue of the law. The federal state has got only minor competences in higher education although it contributes 50% of the money for investments in the institutions and tries to induce planning and coordination in higher education on a national level.

To start with an exaggeration and simplification : German higher education institutions are managed (i.e. planned and controlled) at the state level.

We have to go back to the late sixties, the time of extraordinary growth in higher education (i.e. growth of the number of students, of state money, of positions and personnel, of investments, and new institutions).

Due to the dynamics of growth the need (or I would rather say the "desire") for planning at the state and federal state level grew accordingly. But soon the lack of information for planning was recognized and the idea of a national Management Information System (MIS ; compare the name of the author's institution : HIS) was created.

Higher education was regarded as a *total system* on the national level (total system approach). A national data base with higher education data should be fed from institutional data bases with data on students, personnel and positions, space and equipments, and finance.

Soon this idea was fixed by law and higher education institution were forced to deliver these statistical data to statistic offices at the state and federal state level.

"Institutional research"-offices were created at the institutional level, called "Planning and Information Centres" (PIZ). Their task was to keep up the data bases on the institutional level and to maintain the cyclical delivery of data to the state level. Their investion marks the birth of the German "institutional research".

Let us now take a closer look on three elements of this systems : (1) data bases and decision making, (2) institutional researchers, (3) information technology.

Data Bases and Decision Making

The data bases on the institutional level and the statistical data bases on the states and federal state level did not mainly operate for the sake of the institution but for the state decision making. As the data were delivered in pre-structured and in pre-programmed reports and as it also took a long time to prepare "official reports" it turned out to be necessary to conduct additional surveys (samples) and investigations in order to answer up-to-date questions important for specific political decision making processes.

We are proud that today we have very good, up-to-date and longitudinal data (and instruments to acquire these data for future needs) especially on students and alumni, for example on reasons to enroll at the university, choice of majors, time spent at university, drop-outs, motivations, behaviour, social data, financing of studies, changing majors, career of alumni, etc.

As these surveys are conducted outside the institutions we must concede that the data is only available on a state or national basis and again proves to be "institutional research" for state decisions.

With the growing demand for higher education of a greater part of the youth and with the scarce state finances the idea of (computer aided) models to enhance the higher education planning was born, for example resource requirement models (in Germany): "Kapazitätsmodelle", in the United States f.e. RRPM), cost accounting models, and indicator models.

All these models were built up to reflect the structures among the basic data elements of a "university production process".

The models were never used in practice. They failed for several reasons (not all reasons are true for all models):

— they were initiated on the state level. Universities did not co-operate because they feared to strengthen the managing capacity on the state level and universities were not interested in the transparency of their "production processes".

— the data collection was supposed to be too expensive and too extensive.

— the models would replace, not support decision making.

Institutional Researchers

We now should compare the activities of the German "institutional rersearchers" with the definition of institutional research: "Institutional research is research conducted by an institution of higher education in order to provide information which supports institutional planning, policy formulation and decision making... The subject of institutional research is the individual college, university, or system, and results which have implications beyond this subject are not sought". (Saupe 1981).

The German institutional researcher, although located on the institutional level, but preparing data to be delivered to the state level is not an institutional researcher in the true sense of Joe Saupe's definition. Institutional research in Germany does not mean self-study for strategic planning of an individual university.

Indeed if the individual institution is managed from the State level there is neither opportunity for planning and decision making nor need of information on the institutional level. A study at the end of the sixties on German chancellor's (head of university administration) day-to-day activities showed that less than 10% of their activities consist of "decision making" (Brinkmann, p. 85).

At the 1985 EAIR-Forum Peter Massen reported about another study on institutional research in Europe : "The main image with respect to institutional research in the field of higher education in Western Europe which emerges from our study is that institutional research as a separate administrative function within higher education institutions does *not* exist in Western Europe". (Maassen 1985, p. 3). "The more a higher education system in a country tends to move in the direction of autonomous choice and market exchange, the more need there will grow in that system for the use of institutional research as an instrument to measure institutional performance" (Maassen 1985, p. 7, compare the triangular model of coordination in Clark 1983).

I have to focus on another activity of German institutional researchers not mentioned before. In order to keep up the data bases and the flow of data towards the state offices the researchers implemented data processing systems at the basic level of the operational activities of the university administration. Thus the main task of institutional researchers within the university turned out to be the support of rationalization of university administration with electronic data processing, the statistical data being a by-product of these activities.

Now I hope the difference I made before has become clear : American institutional researchers are interested in computers as soon as computers provide a really fast and flexible access to data and as soon as semi-structured decision problems are supported by computers (microcomputers !). German "institutional researchers" have been in touch with computers from the first days they took up their work, because they maintained administrative data processing.

Information Technology

At the time being German "institutional researchers" are working on the third generation of data processing systems and information technology for the administration of German higher education institutions. To repeat once more : information technology does not only maintain data bases but supports operational administrative tasks inside the university.

The *first generation* can be called the batch-system generation, with only centralized computing power and rather unflexible support of operational administrative tasks.

The *second generation* the online-system generation, is characterized by users having their own terminals, transaction oriented data-processing and realtime updating of data files. This generation of information technology and administrative software enables the employees in the university administration to get their work done efficiently and quickly. Apart from this operational support good retrieval functions enhance decision making on the dispositional level, for example :

Within a few seconds the leading budget officer is informed at any time about the use of university sub-budgets (budget control) as well as the personnel officer receives information about actual or future vacancies.

At the moment the German "institutional researchers" are working on the transition to the *third generation* of administrative computing. Wheras the second generation brought the data bases closer to their users, the third generation of administrative university computing will bring the whole computers to their users, to their desk-tops. This is the generation of the decentralization of data processing, the time of microcomputers.

The emergence of the microcomputers was accompanied at the same time by a significant qualitative amelioration of the user interfaces of the implemented software-products so that the computer really can be on top of everybody's desk.

Microcomputers will soon be found :

— in very small higher education institutions for their operational data processing ;

— in academic departments and sub-departments for administration and decision making ;

— in administrative departments and sub-departments ;

— for personal computing at the desk-tops ;

— at the desk-tops of institutional managers (presidents, vice presidents, chanchellors, administrative leaders) with small data bases and decision support systems ;

— in the institutional research offices.

The three generation thesis of the data processing development in higher education on the instituional level shall be summed up by the following illustration showing the link between data processing support and the wellknown decision pyramid :

To complete the generation model I should mention that according to my opinion the next generation will be called the generation of re-integration. One of the integrative functions will focus on the integration of office automation and data processing. I will come back to this problem later.

3. The Emergence of Institutional Research

The development of information technology and the software support of German "institutional researchers" might lead to the microcomputer and the affiliated software products being on the desk-tops of presidents and in the institutional research office. But so far neither the

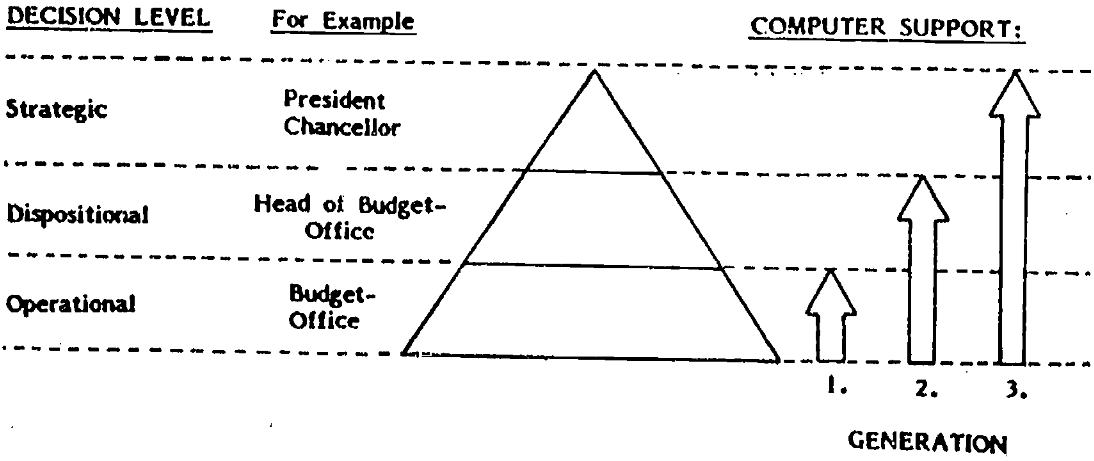

Fig. 1.
The Three Generation Model of Data Processing in Higher Education Administration (Institutional Level)

president's nor the institutional researchers' need of microcomputers for decision support and decision making have been explained in my presentation, because when universities are managed by the State, management information is not necessary on the institutional level.

To stress my thesis of the emergence of real institutional research in German higher education institutions I have to trace another line of development, which I want to call the changing political, economic and societal environment of the higher education institutions.

Let us call the first phase of this development the *expansion phase* and start our consideration again in the sixties (end of the sixties beginning seventies). This phase can be characterized by a lack of financial problems in higher education. It was unproblematic for the politicians to justifity that more and more money had to be invested into higher education. Young men and women were even encouraged to enroll at universities by financial and educational means. It was a time of immense planning efforts on the state and federal state level.

The second phase might be called the *efficiency phase* (beginning seventies to midth of the eighties). As soon as the demand for higher education exceeded the capacity of higher education institutions, as soon as the state funds for higher education proved to be limited, the states tried to introduce the idea of efficiency in higher education institutions. The models I mentioned can be regarded as state efforts to shed light on the higher education production function under the auspices of efficiency. The electronic data processing systems located in the administration were of course helpful for the universities to enhance their efficiency. But if we remember efficiency being the relation between input and output, and higher education output not being easily quantifiable, efficiency turns out to be an activity of reduction of state fund's input into higher education.

Indeed a relative reduction of state funds in higher education has been observable since the days of expansion in higher education, although the enrollment figure did not stop to increase until now. But today higher education institutions have to face two additional challenges other than financial problems : a slow but probably soon accelerating ernollment decline due to demographic trends and perhaps due to labor market problems, and a public opinion which does not leave the universities' performances unquestioned.

We can conclude that now a phase is reached in which higher education institutions have to care for their own survival (ranging from cure of illness, to mere survival, to strive for excellence (Cameron 1984). I call this phase the *effectiveness phase*, and regard a higher education institution being effective as far as it attains the goal of survival in the sense mentioned above.

The three phases can be differentiated by the question of whether the main activities lie on the state or the university side :

PHASE	ACTIVITY ON THE SIDE OF	ACTIVITY
EXPANSION	STATE	INCREASING FUNDS FOR HIGHER EDUCATION, ENCOURAGING THE YOUTH TO G TO UNIVERSITY
EFFICIENCY	STATE	MODELS CAPS FUND REDUCTION
EFFECTIVENESS	HIGHER EDUCATION INSTITUTION	SURVIVAL (CURE FROM ILLNESS, MERE SURVIVAL, STRIVE FOR EXCELLENCE)

Fig. 2

Phases of Higher Education Environmental Situation

I should add some more traits of the effectiveness phase : what we find in the German situation is a slight tendency of the states to give more autonomy to the institutions :

— laws are changed to foster the spending flexibility of funds on the university side ;

— the allocation of budget cuts are left to the institutions' own discretion ;

— the idea to give the universities the right to choose students by university-specific admission criteria are discussed ;

— discussions to "introduce" competition into the university system are initiated.

If this direction of changing patterns in higher education continues, a reverse shift of management, decision making, need of information and decision support will occur :

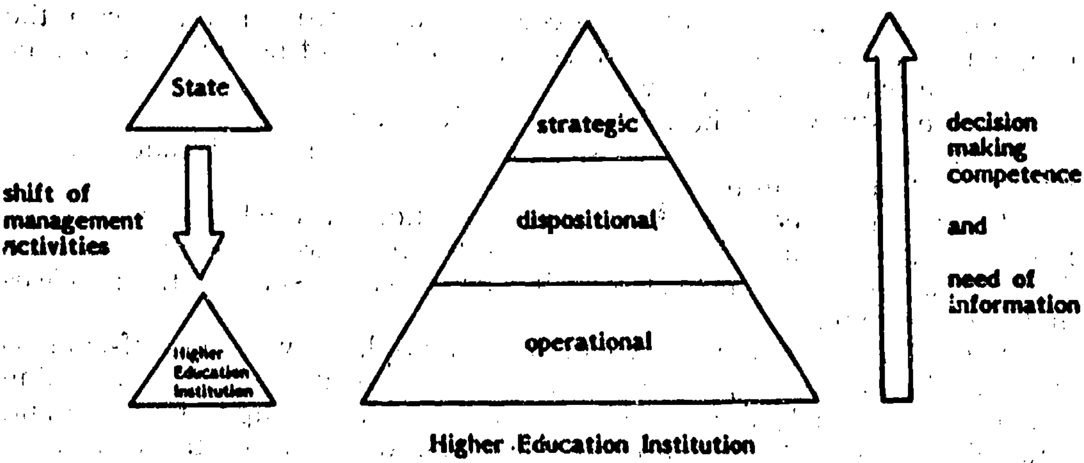

Fig. 3.

Shift of Management Activities in Higher Education

On the side of the individual university new problems will have to be solved :

— identifying the institution's specific role and mission ;
— finding the market niche ;
— self-evaluating the institution's performance ;
— setting priorities in fund allocations ;
— aiming at the survival of the whole university ;
— enhancing public relations.

The time has come for institutional research in its true sense to support these management activities. Indeed, German university managers started asking for the support of institutional researchers to foster this kind of institutional decisions.

4. New Roles for Institutional Researchers

As a result of the before-said, we have to take the following two facts into account when considering the new roles for German institutional researchers :

(1) the emergence of institutional research in its true sense as an activity to enhance *institutional* planning, policy formulation and decision making ;

(2) the distribution of data processing capacity with the widespread existence of *microcomputers* and comfortable software within the university.

The emerging activities of German institutional researchers will be a consequent continuation of their concern for the use of computers in higher education institutions. Six tasks of the institutional researchers can be identified :

The Original Institutional Research Task

With the emergence of the need of real institutional research the original instituional research tasks have to be fulfilled, which can be briefly characterized as follows :

— "self-study" of the individual institution ;

— "market analysis", focussing on the environmental conditions of the individual institution.

I need not say that these tasks are not fulfilled sufficiently by maintaining the administrative data bases that are now mainly used for internal purposes instead of being delivered to state statistic offices at the same time.

Special investigations have to be conduced, as well as self-evaluations of institutional performance, institutional goals and functioning studies, educational outcomes studies etc. in order to support ad hoc and strategic decisions of institutional managers. What makes the difference for institutional researchers' situation now compared with former phases is that they have to look beyond the bounderies of their individual institution, they have to conduct followup studies, look at regional demographies, local images and public relations.

The Information Manager Task

The information manager task of institutional researchers derives from two facts :

(1) To the same degree as the individual institution receives more autonomy from the state it has to find its own way of positioning within the higher education market, or more general : environment. The institution has to consider itself as a whole unit. The object of research is not any longer the student, the equipment, the personnel on its own, but in the institutional context. The object of research is the institution as a whole.

(2) With the microcomputers being distributed all over the campus and with a decentralized data processing the advantage can be attained that much more data are available on computers (which means comfortable retrieval), but to really get these data for central decision making and integrated decision support the obstacle of decentralization of data has to be removed.

Exactly this is the task of the institutional researcher as an information manager to transform the decentralized data into *integrated* management information for the institution as a whole. He "serves the institution by identifying, clarifying, informing and coordinating key institutional decision" (Kriegbaum 1980) (Delaney 1985, p. 10).

The information manager knows where to get the relevant data files on the campus, he/she is familiar with the retrieval problems on microcomputers and mainframes.

The Information Centre Task

End-users of information technology, especially microcmputer-users will provide for their own computer applications. German institutional researchers are traditionally skilled in computer technology and they know very well the basic problems of higher education administrative departments.

With the information center task, the institutional researchers have to

— help the end-users at the operational as well as at the dispositional and strategic level of the university administration to use their (micro)-computers by

- counselling at the stage of purchase of microcomputers
- teaching the use of standard software and high level programming and retrieval languages
- teaching the use of hardware and operation systems
- providing prototypes of applications

— guarantee the integrity and actuality of data on the campus

— keep up a valuable data dictionary for all users

— avoid redundant applications.

(Martin 1985, p. 143—172, Schlemmer 1986)

I just want to repeat, what Berhard Sheehan stated at the Portland Forum : "It may well be that the path to institutional research prominence in decision support management will include apprenticeships as an information center". (Sheehan 1985)

The Decision Support System Task

One of the microcomputer user groups will be that of the decision makers within the higher education institution, that is the president, the vice presidents, the chancellor and the others. Some of them will have their own decision support systems and small data bases on their microcomputers, others will not use microcomputer on their own.

For those not having microcomputers at their disposal the institutional researchers will function as the users of the decision support systems and the demonstrators of the results (compare Johnson and Tuckman 1985).

For those decision makers who use microcomputers on their own the institutional researchers will have to provide for the small data bases and the integrity and actuality of the data.

Support does not only mean data and information, but also use of data, that is "modelling" in the context of decision support systems. The decision maker will not use the microcomputer and the software unless he/she is able to use it like paper, pencil, scotch tape and calculator. "The user of the DSS must be comfortable with the system — both conceptually and technologically". (Silver 1982)

The institutional researcher has to

— teach the decison maker how to use the hardware and the software

— prepare the user interface of the software, "that it is compatible with the thinking style of the decision maker" (Mayo 1984).

— develop formats of recurring questions and problems to be solved (Johnson 1983).

— find out new decision support software that fits best to the personal style of the decision makers and the problems to be solved.

The more decision makers use their own hardware and software, the more institutional researchers are facilitators and consultants and the least programmers (Keen 1982).

The Institutional Research Information System Task

One of those to profit from decentralized computing power is the institutional research office itself. It will use its own computer or microcomputer. The institutional researcher will have four tasks to fulfill with their own computer :

— using statistical software packages to support their empirical investigations and surveys

— maintaining longitudinal data from cyclically conducted investigations

— maintaining data bases derived from the instituional administrative files

— maintaining data bases on data of the institutional environment.

The Office Automation Task

The last task I want to mention seems very essential to me. It suggests the institutional researcher to support his/her institution to step into the next generation of information technology, the generation of re-integration of data processing and automation.

What is true for campus computing, is true for decision makers in the university as well : "Since most of the work in colleges and universities deals with words and images, *not numbers*, the greatest future growth in computing will be in support of individuals who have not been represented in the traditional community of computer users". (McCredie 1982) To translate this statement into the president's case : For his decision making the president does not only need "numbers" from inside and outside the university, what he needs for a decision I would like to call a "bundle of information packages", that is for example

— memos he has written several weeks ago
— memos another person has written even a year ago
— a letter from the state ministry
— a special part of a state law
— a proposal from a faculty member
— an article from a newspaper
— or even a paper from an AIR-Forum, that might be found in the university's record-office.

What he might need in addition is to deliver this information very quickly to other persons inside the university or get it mixed with numbers and own comments, etc.

I think it is not quite sure *how* these problems can be solved by office automation technology for all the mentioned details, but it is sure *that* office automation will support these information retrieval and dissemination tasks by any rate. Anyway, institutional researchers should try to find the path to integrate data and office automation as soon as information technology allows.

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**HIS: Hochschul-Informations-System GmbH (Higher Education Information System): Conducts surveys on a state and national basis, serves institutions with sofware systems, empirical investigation instruments, organizational analyses, management consulting.

THE STUDENT INFORMATION SYSTEM OF THE UNIVERSITY OF HELSINKI

Ari HEISKANEN

University of Helsinki, Finland

1. Introduction

This paper contains a short description of Finnish universities and their administrative data processing systems, and a more detailed description of the student information system of the University of Helsinki. Description is made based on several written sources (see the list of references), most of which are not printed, and personal experience of the writer gained during the 1980's.

The aim of the paper is to describe the "state-of-the-art", evaluation is nearly absent.

2. Finnish Universities

Finland currently has 20 university level institutions of higher education widely spread across the country (see Table 1). The number of teachers is about 7,000 and other personnel number 10,000. The annual enrollment of new students is about 12,000, which is about 17—18% of the age group. The total number of students is about 90,000. The university of Helsinki is responsible for more than 25% of all students, and for more than a third of postgraduate students.

The roots of Finnish universities can be traced back to 1640 when the Academy of Turku was established as the easternmost university of the Kingdom of Sweden. After Finland had been incorporated into the Russian empire as an autonomous Grand Duchy in 1809, the Academy was transferred to Helsinki in 1828 under the name of the Imperial Alexander University. In 1917, after the Declaration of Independence, it became the University of Helsinki.

Finnish Institutions of Higher Education

Name of institution	Foundation year	Number of fields of study (cf. pp. 16—17)	Number of teachers in the autumn term 1984	Number of students in the autumn term 1984	Foreign stuudents in the autumn term 1983
University of Helsinki	1640	12	1,756	23,743	384[3]
University of Joensuu	1969	6	328	3,725	8
University of Jyväskylä	1934	8	496	6,244	48
University of Kuopio	1970	6	269	1,832	8
University of Oulu	1958	7[1]	778	7,434	27
University of Tampere	1930	9	531	8,882	58
University of Turku	1920	8[2]	751	9,066	18
Åbo Akademi	1917	8	295	4,254	38
University of Lapland	1979	3	75	895	—
University of Vaasa	1966	3	96	1,548	—
Helsinki School of Economics and Business Administration	[illegible]	1	154	2,914	[illegible]
Swedish School of Economics and Business Administration	1909	1	90	1,614	22
Turku School of Economics and Business Administration	1949	1	64	1,387	4
Helsinki University of Technology	1908	1	577	7,912	82
Lappeenranta University of Technology	1969	1	120	1,403	—
Tampere University of Technology	1965	1	214	3,060	31
College of Veterinary Medicine	1945	1	48	283	—
Sibelius Academy	1939	1	261	942	19
University of Industrial Arts	1973	1	145	863	17
Theatre Academy	1979	1	61	125	1

1) 8 from 1 August, 1986.
2) 9 from 1 August, 1986.
3) Includes the 6 foreign students of Swedish School of Social work and Local Administration, annexed to the University of Helsinki Faculty of Social Sciences in 1984.
NB. The figures given in this table are based on preliminary statistics made by the Central Statistical Office of Finland and may differ considerably from the more detailed information given in the articles concerning each institution of higher education

Regional distribution of students institutions of higher education in t autumn of 1984

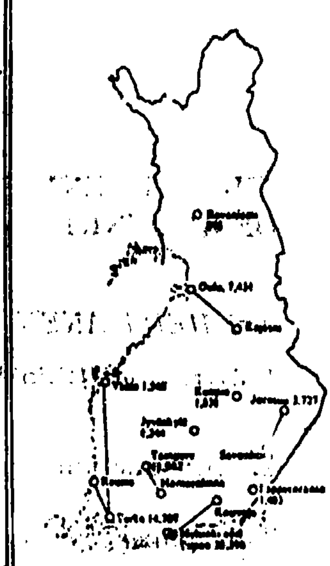

Table 1. Finnish institutions of higher education [2].

Field of studies	Number of students (%)
Theology	1.9
The humanities	18.5
Law	4.5
Social sciences	10.2
Economics and business administration	10.4
Psychology	1.3
Education	9.1
The natural sciences	14.7
Agriculture and forestry	2.9
Physical education	0.6
Engineering and architecture	16.8
Medicine	4.0
Dentistry	1.2
Health administration	0.4
Veterinary medicine	0.3
Pharmacy	1.1
Industrial arts	1.0
Music	1.1
Theatre and drama	0.2

Table 2. The distribution of students among various fields [2].

The institutions of higher education are under the direct supervision of the Ministry of Education (see Figure 1). They are all state institutions, but each of them has an internal administration with autonomy in internal affairs. The autonomy of the University of Helsinki

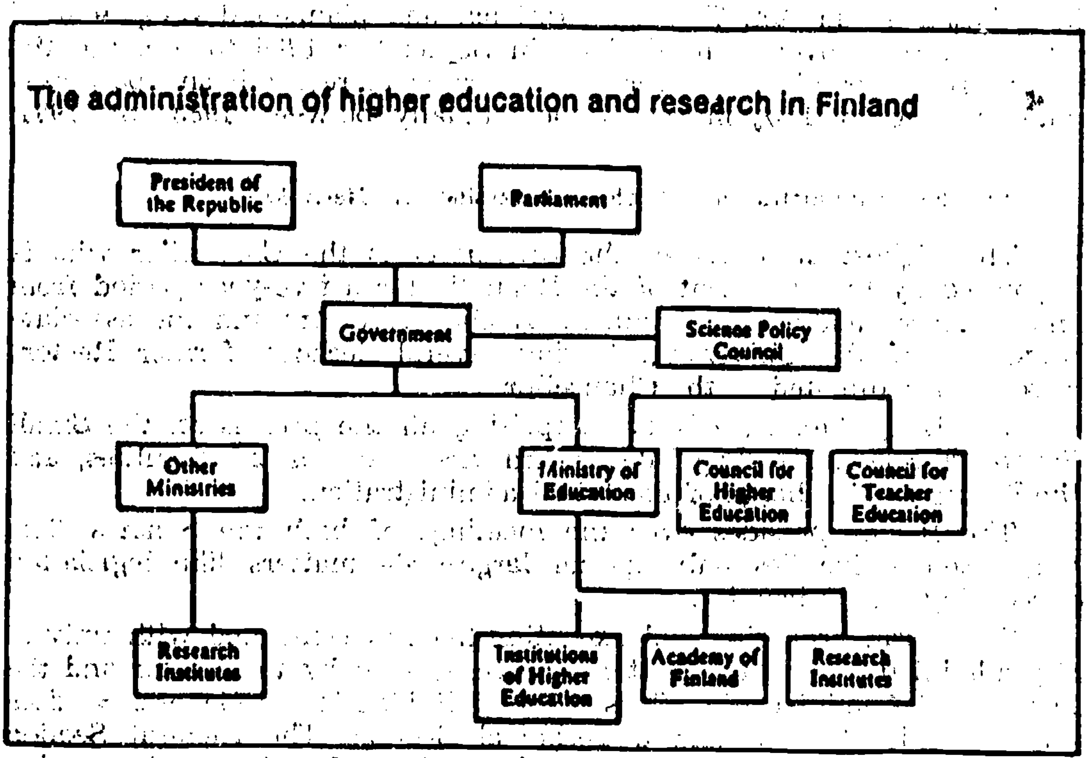

Fig. 1. The administration of higher education and research in Finland [2].

is defined in the Finnish constitution. The Council for Higher Education functions as an advisory expert body and consists of the representatives of universities.

The model of university internal administration has been developed gradually over the years. The University of Helsinki and the Helsinki University of Technology are the only institutions where the old administrative system with all formal authority for decision making in the hands of professors is still retained. In other institutions also other teachers and other staff as well as students are allowed to participate in the administration.

The State is the main source of finance for the institutions of higher education. Funds granted by the Parliament have been regulated by the Act on the Development of Higher Education. The Ministry of Education supervises the utilization of these funds and makes annual budget proposals to the Government. These proposals are based on proposals made by the institutions themselves and on the opinion of the Council of Higher Education. At the Ministry of Finance, the proposals made from all ministries are combined into the National State Budget proposal, which is finally approved by the Parliament.

The expenditure on higher education is slightly over 2% of the State Budget and roughly 15% of the Budget of the Ministry of Education. This means about 2,000 million Finnish marks.

Developing the resources of higher education has since 1960' ies been based on an Act. To secure rational and planned development of resources, the Government decided in September 1986 to increase the central resources of the universities allocated to research and postgraduate training by 15% in real value annually between 1988 and 1991.

2.1. The Administration of the University of Helsinki

The highest authority of the University is the Chancellor who is appointed by the President of the Republic for a five-year period from among three candidates nominated by the professors and the associate professors of the University. During several decades, former Rectors have been nominated as the Chancellor.

The Large Senate, a body comprising all the professors, the Small Senate, a collegial body of deans and vice-deans of the faculties, and the Rector are in charge of the actual administration.

The Rector presides over the meetings of both the Senates. The Large Senate handles only special large-scale matters like legislation concerning the University.

The organ preparing and executing matters connected with university administration is the Rector's Office, headed by the Rector and the Director of Administration. This office is divided into a General Section, an Economics Section and a Technical Section. The General Section is made up of the Administrative Office, the Office for Study Affairs, and the Actuary's Office which is responsible of the student information system as a user.

The faculty is the basic unit of administration of the University. Headed by the Dean and the Vicedean, the professors make-up the decision-making bodies of respective faculties. Faculty secretaries and study secretaries are the leading officials of the faculty.

The Department (or Institute) is the basic administrative unit for teaching and research in one or several subjects of study or fields of research. One of the (full) professors of the department is the head, and there is no official department council.

The administration of the University will probably soon be reformed and all personnel groups and students will have their own representatives in the decision-making bodies.

University of Helsinki 1986

The total enrollment on May 31, 1986, was 25,437 (including ca. 57% women, 1,683 Swedish-speaking and 492 foreign students).

During the period June 1, 1985 — May 31, 1986, totally 2,320 dergees were completed, out of which 130 were doctorates.

There are altogether 1,355 teaching posts, i.e.,
- 434 professors and assistant professors,
- 312 lecturers and other teachers,
- 609 assistants.

There are 1,275 docents.

Other staff : Researchers 70, auxiliary teaching and research staff 869, library 278, data processing 94, administration 578, maintenance 688, other 217.

Administration

Chancellor : Nils Oker-Blom
Rector : Olli Lehto
Vice Rectors : Risto Ihamuotila, Johan Wrede
Administrative Director : Elisabet Helander (Jan. 1, 1987—)
Great Senate : all professors (234)
Small Senate : The Rector, the Vice Rectors, the Deans, the Vice Deans.
Deans : Kalevi Tamminen (Theology), Mikael Hidén (Law), Pentti Rokkanen (Medicine), Yrjö Blomstedt (Arts), Antti Siivola (Science), Pertti Kansanen (Education), Olavi Riihinen (Social Sciences), Matti Nuorteva (Agriculture and Forestry).

Premises

The University premises are spread at ca. 60 different locations in the city : out of these about 20 rented. The total space occupied by the University in the Helsinki area is ca. 1,600,000 m³ (including the 88,000 cm³ of the main building). Outside Helsinki there are 9 teaching

Faculty	Departments	Students		Degrees + Doctoral dissertations	Tenured teaching posts					Full-time teacher equiv. (fee-paid)
		Registered May 31, 1986	New 1985—86		Total	Prof.	Ass. Prof.	Lecturers and other teachers	Assistants	
Theology	5	1 548	179	103+ 6	42	12	6	5	19	12
Law	5	2 579	260	327+ 2	72	24	15	1	32	8
Medicine	45	1 466	157	204+ 41	286	56	41	81	108	32
Arts	23	6 772	639	455+ 15	238	47	24	89	78	53
Science	26	5 597	718	593+ 37	341	53	47	13	228	139
Education	2	1 732	289	187+ 3	103	6	11	70	16	27
Social Sciences	11	2 946	338	189+ 11	111	25	15	23	48	24
Agriculture and Forestry	32	2 497	295	311+ 15	132	37	14	13	68	46
Other Institute	18	—	—	— —	17	—	—	8	9	60
Total	168	25 437	2 875	2 320+130	1 335	260	174	312	609	401

Table 3. Facts about the University of Helsinki.

and research institutes with premisses totalling 170,000 m^3. The teaching and experimental farms have field and woodland at their disposal: Viikki 400 ha, Muddusjärvi 1,000 ha, Suitia 480 ha.

Finances

In the national budget for 1986 the allocations of the University amounted roughly to 593 million Fmk, out of which salaries accounted for 67%. Additional research expenditure amounted to 81 million Fmk (1985).

(Public Relations Office)

3. The State of the Art in the Administrative Data Processing in the Universities of Finland

The stage and scope of the use of EDP in the administrative routines varies greatly among the Finnish universities. There are a couple of nationwide systems used in many universities, while other systems are individually developed for one university only.

In Figure 3 there is a general overview about the situation. The accounting system is the only remarkable system that is common for the most of the universities. The reason for this is quite straightforward: there is a rule given by the state government that the common system must be used.

The student information systems are unique ones in each university. There has been some attempts to adapt a functioning system from one unit to another, but results have been poor.

Nationwide centralized systems use the machines in the state computing centre and Postbank which is owned by the state and has official position in the fund transfer systems that is used in accounting and payroll systems.

The machinery and system software is quite varied in the computing centres of Finnish universities. These are several VAX: es by DEC, a couple of UNIVACs and IBM-type mainframes. The machines used in administrative purposes are typically the mainframes of the universities, but several universities have also computers dedicated only for administration. However, there are no administrative computing centres in Finnish universities, but administrative EDP is normally handled by the same computing centre that takes care of the educational and research EDP.

A couple of universities use also private firms for their administrative EDP-services.

The planning staff of administrative EDP varies between 0.5 to about 10 persons per university. The total amount in Finland is 20—30 persons.

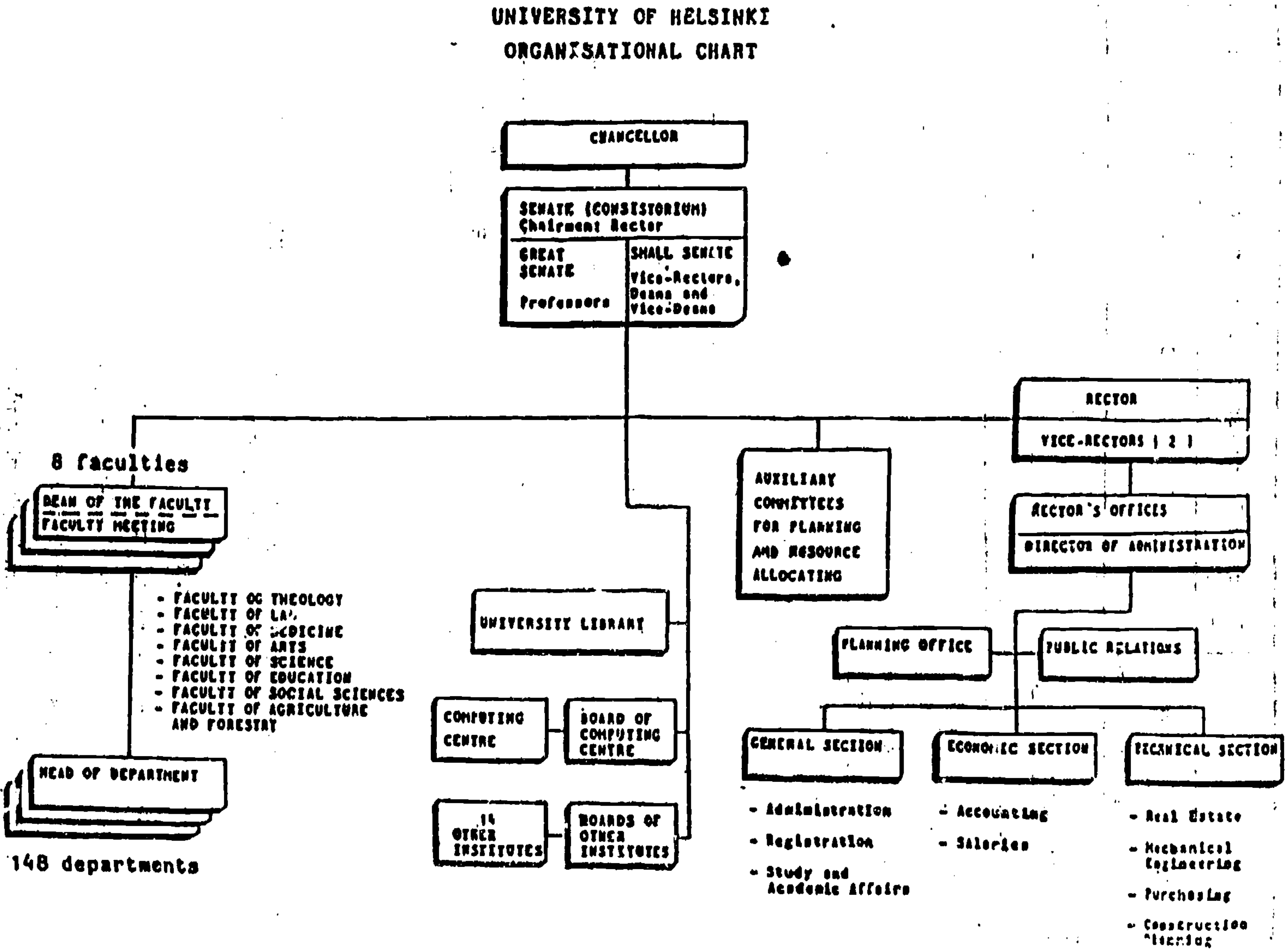

Fig. 2. The administrative organisation of the University of Helsinki.

Alternative / EDP system	Number of univ[illegible]ing alternatives 1 - 5.				
	1	2	[illegible]	4	5
Accounting	16	1			1
Payroll	9	4	3	1	
Student register (Basic data)			13	5	
Student register (Study results)			12		
Financial Study Aid System	11	2		1	1
Student selection	7	2	11	2	
Personnel		1	2	7	4
Reservation of classrooms			4	4	5
Machine inventory			6	7	1
Room register	13		4	2	1
Vacation register			1		

Fig. 3. The nature of the adminstrative EDP systems in different universities in Finland [5].

Explanation of alternatives

1 — Nationwide system in use

2 — Nationwide system in planning phase

3 — University's own system in use

4 — University's own system in planning phase

5 — No EDP system in use or in plans

4. Administrative EDP in the University of Helsinki

4.1. Organisation

The formal organisation of the university of Helsinki in the figure 2. EDP affairs are discussed in the EDP council headed by the Rector and consisting of "EDP-active" professors (8), Director of Administration, the head of the computer centre, one section chief from the Rector's Office and the chief data processing officer (EDP chief) of the Rector's Office. The EDP council is mainly a forum for discussions, and decisions are made according the normal line organization. EDP council has about four meetings per year.

Administrative EDP is lead by the administrative EDP leading group consisting of the Director of Administration, section chiefs of the Rector's Office, the head of the computing centre, head of the planning office and the EDP-chief of the Rector's Office. EDP leading group has about ten meetings per year.

In addition to these bodies there is a "working group for administrative EDP" whose members are the heads of each office of the offices of the rector, secretaries of the faculties and some other prominent persons in administration. This group is mainly a discussion forum and information channel. This body has five to eight meetings per year.

The annual costs of administrative data processing are about 3 million Finnish marks. This figure contains the costs of services paid to the State Computing Centre and Postbank for payroll and accounting, and also the maintenance costs of the equipment and systems software but not the wages of the EDP personnel. The purchasing of equipment per year is about 400,000 FIM, excluding the basic purchase of the VAX-11/780 (see section 4.3).

4.2. Personnel

The Data Processing Office (about five persons) in the offices of the rector is responsible for the development of systems and software for administrative purposes. In the case of nationwide systems (payroll, accounting) the role of this unit is minor, merely coordinating. The computing centre uses about four person years per year for administrative EDP, half of which is data entry, starting of runs and computer operation.

Systems planning is a part-time duty for several workers in the university administration. Now about twenty persons are working (part time) in the projects going on.

4.3. Hardware

The University of Helsinki has used Burroughs mainframes over fifteen years. During this year Burroughs B7800 is replaced by a cluster consisting of VAX 8300 and VAX 8800. Administrative applications are transferred from Burroughs to VAX-11/780 which was purchased for administration in March 1986.

University is building quite a comprehensive data transmission network along the installation of the VAXes. The network will consist of several local area networks connected by bridges. Thus we will have to the end of this year an ETHERNET linking together most of our institutes with nominal speed 10 Mbits/sec.

5. The Student Information System of the University of Helsinki

The student information system can be divided into three disjoint parts:

1. the student selection system
2. the centralized student information system — the student register — run by the Actyary's office
3. the department level student information system

The main focus of this paper is in the second subsystem, but the other ones are also discussed. The connections between these systems are described briefly, too.

5.1. Stakeholders

Several organizations and groups of people need the information stored in the files of the student information system. The importance of the system is constantly growing, because of the trend to use also exact information of study results etc. when evaluating the activities of the universities. The Ministry of Education has launched a process in order to establish a rational procedure for the evaluation.

The principal intressents of the student information system are (see also Figure 4)

teachers and administrators of the university of Helsinki
students of the university of Helsinki
Ministry of Education
the State Centre for Educational Grants and Loans
the Statistical Central Office

The information products made from data in the student register are the regularly printed catalog of students and the statistics in the Statistical Annual of the University of Helsinki, several reports and listings of various kind for student organizations etc., and excerpts from the study prestations for student, e.g. for application of jobs and financial study aid.

Student information statistics are used in evaluation and planning the functions of faculties and institutes. Main source is the above mentioned Statistical Annual, but in addition to that on every semester a less comprehensive publication is produced. Also several ad hoc analyses are performed.

The statistics contain information, e.g. about :

the amount of students in different faculties and departments
the amount of studies pursued in different departments classified according to various criteria
the amount of examinations classified according to the field of science, faculty, institute and principal subject matter.

The University itself and the Ministry of Education need partly the same information in evaluation of the activities of the University. The principle clearly announced from the Ministry is that the University should evaluate its own activities. In this respect, the following statistics can be used in addition to the above-mentioned ones :

the information about studies in minor subjects
interruptions of studies
how long the studies for various degrees take
duplicate education
the intensity of studying
the age distribution of the graduates.

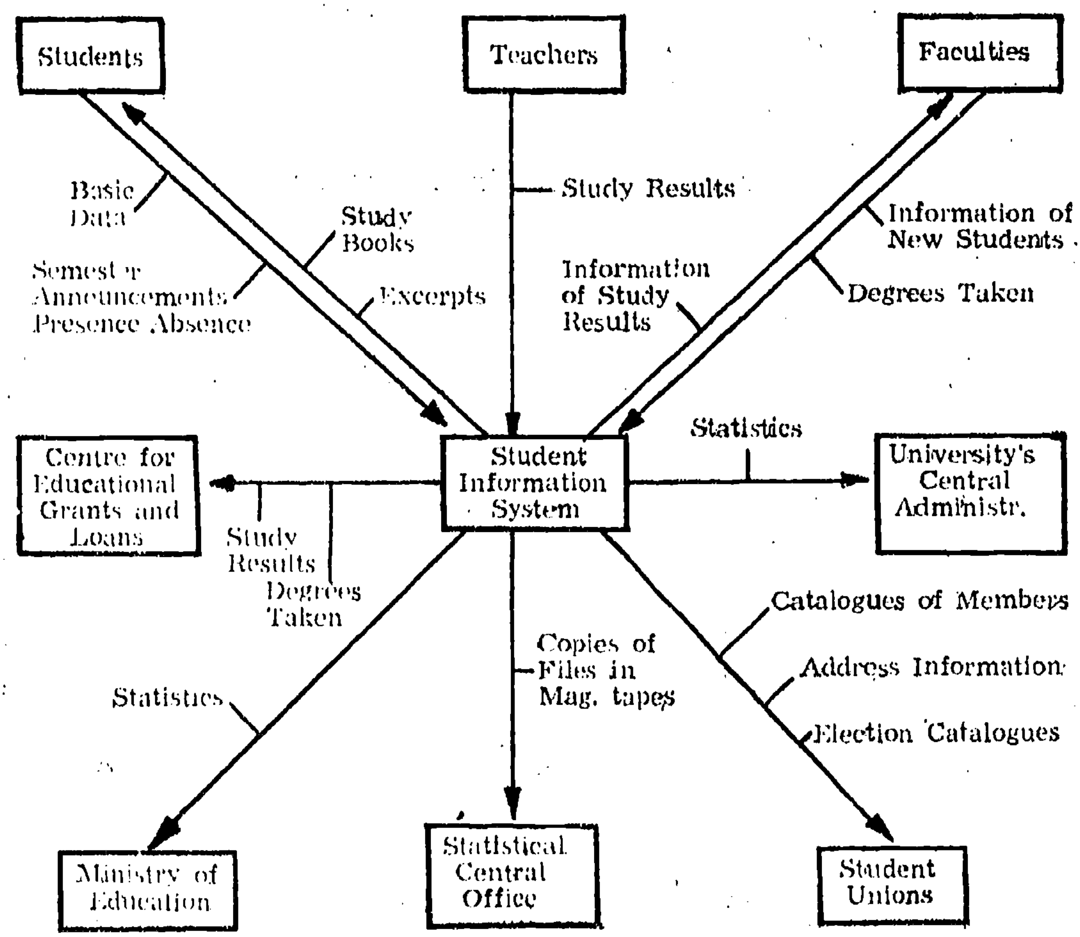

Fig. 4. The intressents of student information system [6].

The Ministry of Education has established an aggregated statistical data base about the activities and degrees passed in all the universities in Finland. The so-called KOTA data base (KOrkeakoulujen Toiminnan Arviointi, Evalution of the Functions of the Universities) is run by the State Computing Centre on a VAX 8600 owned by the Ministry of Education using the SAS software.

The State Centre for Educational Grants and Loans needs informa- on concerning the conduct of studies in order to make decision of the discontinuing the aid because of graduation or interruption of the studies. The Centre has its own EDP register which obtains data in magnetic tape from the files of the University.

The Statistical Central Office makes national statistics about student information. It uses its own EDP system for this purpose, and data is transferred to it from University files using magnetic tapes.

5.2. The Student Selection System

The procedure and data processing system according to which the faculties take their students varies between different faculties.

The faculty of theology uses a micro computer based system programmed with dBase III. The system in run by the office of the faculty. Input data contains social security number, name, address of the applicants and points obtained by school reports and entrance tests.

The faculty of law uses a nation-wide system run by the computing centre of the University of Helsinki. The system has quite complicated algorithm to choose the students containing e.g. quotas for various groups.

The faculty of medicine has developed by its own personnel a system run by the Burroughs B7800.

The faculty of arts uses a combination of microcomputers and Burroughs. Micros are used for data entry and Burroughs for sorting out the students to be selected.

The faculty of science has produced by its own staff a microcomputer system with dBase III for the election of students for mathematics, physics, chemistry and data processing. Students for biological subjects are selected using a national joint selection run by the computing centre of the computing centre of the University of Jyväskylä. The students for geography are selected by manual methods.

The faculty of education has used manual system for the student selection, but it is planned a microcomputer system for this summer to be used in several branch subjects. The class teacher students are selected partly with a national system.

The faculty of social sciences will use its traditional manual system at least this summer, but plans are prepared in order to make an EDP system.

The faculty of agriculture and forestry has until now used a Burroughs system, but it has hired an EDP analyst in order to get a macrocomputer system to be in use this summer.

As it is evident from the description above, the procedures and technical solutions are quite varied. There is no direct link between the selection data system and the centralized student information system. The possibilities to use the data in the selection systems also in the centralized system will be studied to the end of this year. The historical reason not to use the selection data has been that there was too little common and valid data between these systems to make the data transfer profitable.

5.3. The Centralized Student Information System

5.3.1. Functions

The functions described in this section are pertinent to the system currently used. The main functions remain principally the same with the new system to be implemented this summer. The system is used by the Actuary's office, and at this moment there is no other unit using this system by terminals. The information flow between departments etc. and the Actuary's office takes place with paper forms.

The centralized student information system can be divided into subsystems as follows.

1. The base information system containing personal data of the students and their study rights. This subsystem has following subfunctions.
1.1 The enrollment of new students
1.2 Registration of the study rights acquired by the students
1.3 The annual registration of students pursuing their studies or being absent from the university

2. The system for processing the study results
2.1 Registration of results of the examinations
2.2 Registration of results of the examinations
2.3 Registration of degrees and their contents with individual students

3. The system for producing reports of list-type

4. The system for producing statistical tables.

5.3.2. History

The technical solution for processing student information has changed several times during the history. The following main phases are relevant in this context :

1. Totally Manual System

This system was based on huge books, where was written

> date of admission, name of the student (signature written by the student him/herself), degrees passed, marital status, date of birth, name of the school of the matriculation examination,

> grade of the matriculation examination, father's' name and occupation, students' union, and faculty.

Later, as the studies proceeded, the information about degrees taken by the individual students and information of removals from the student catalog were added beside the original data on the pages on the enrollment books. The students were identified by the serial archive number printed on the marginal of the book where the student information was written. The serial numbers were unique for each year. Social scurity number was taken into practice at the beginning of the 1960's and it could not have been used earlier, naturally.

The products of this system were quite limited, but the so called degree diary was made by this information.

2. First EDP System

The processing of the basic student data was partially automatized in the middle of 1960's, and the first EDP system was installed in 1965. The system was run on the IBM 1620 equipment which had 40.000 decimal digit core memory, two 2.6 MB disk units, card reader and line printer.

The system was a typical small batch application centred around the student information file containing

> the year and serial archive number (key data), name of the student, date of birth, sex, native commune, mother language, citizenship, date of matriculation examination, grade of matriculation, school, code, address and phone number, students' union, faculty, branch of studies.

Programs were made in SPS (Symbolic Programming System, an assembler-level programming language) and FORTRAN. Main products were the student catalog and various statistical tables.

3. First Burroughs-System

The IBM 1620 was replaced by Burroughs B6500 during the year 1970, and the student information system was programmed for the new machine also. The data in the student file (ACTRE, Actyary's register) was enlargened to contain also the grades obtained by the students. The system was still batch oriented.

Programs were made in COBOL, and the main file was a serial one with fixed length records, one per student. Some direct access auxiliary files for example containing codes were also established. The software evolved gradually during the 1970's, main efforts being directed to the producing of a more comprehensive set of reports and statistics.

4. Second Burroughs-System

Because of the degree reform performed during the 1970's the fixed length record format became infeasible in the beginning of the 1980's, and the file structure had to be modified to contain more study results. This was done by changing the main file to consist of variable length records. The varying component was to hold the varying amount of study results per student.

The inflexible structure of the software and file made it necessary to make several amendments into the system. In addition to the serial main file a direct access file was installed. It was based on Burroughs data base management software DMS-II. The direct file (DIRECT ACTRE) was created from the batch updated serial main file, and it was used for small queries and as a starting point of production of statistical tables and reports.

The registration of new students in every autumn into the batch register demanded a lot of "tayloristically" divided routinework. In order to alleviate this procedure an on-line subsystem was created. It used DIRECT ACTRE when checking if the data of a new student to be registered already existed, perhaps in a different faculty. After the registration was completed, the content of the online file was transferred to ACTRE.

The production of statistical tables from ACTRE was based on a system where DIRECT ACTRE was used as a starting point. By the help of COBOL programs a lot of files containing records to be tabulated were extracted from DIRECT ACTRE to magnetic tape and transferred to the state computing centre, where the tables (about 900 pages per semester) were made by a statistical program package especially suitable for this kind of work.

5. Current VAX-System

The use of the new system will start during June this summer. The basic software on VAX-11/780 will be in full operation in the beginning 1988, when the subsystem for reports and statistics is completed. The structure of the current system is explained in the next section.

5.3.3. Information Content of the New Student Register

The student data base is organized according the relational data model. The conceptual model was achieved in a planning process during which the information architecture for the administration of the university was formed. The data base consists of the following tables (some auxiliary tables are omitted for brevity).

Basic Student Data

Table contains one row per student identified by her/his social security number. Data fields are :

> students name, social security number, address, sex, home community, starting date in the university...

Study Rights of the Students

This table contains information of the degree programs which the students are allowed to participate. Data fields are :

> students social security number, faculty, degree program, alternative course of study, dates when rights are obtained and data about the way how this particular right was obtained.

Study Performances of the Students

The table contains information on those study units that the student concerned has passed. Data fields are :

> students social security number, code of the study unit, date, amount of credits earned by this unit, teacher who has accepted the performance, grade of the performance, data concerning the examination where the performance is originating.

The Structure of Students' Performances

The table contains information how study performance are blocked. There is one row in the table for the fact that a student has tied one study performance to a certain block of studies. This table is necessary because there are too many relationships between study performances and the blocks of studies. Data fields are :

> students social security number, code of the study unit, code of the block of studies and date when the connection is made.

Data of the Course Examinations

The study results can be processed according to two criteria : one can obtain all study results of a student, or all study results of a course or examination. In order to accomplish the possibility to get the latter option, the data base contains data on the course results grouped by courses. There are two tables for this purpose, one consisting of the heading information of the courses (course code and serial number, date of the course, teacher) and one consisting of the results of the students in the course examination. i.e. the rows of the result list (course code, and serial number, date, students social security number, grade, date, credit points, teacher).

Degrees Taken in the University of Helsinki

The table contains one row per a degree taken in the university of Helsinki. Data fields are :

> students social security number, degree code, faculty, date, amount of credits in this student's degree, major subject of the degree, degree program and course alternative.

Degrees Taken Outside the University of Helsinki

The table contains background degrees and also information on the matriculation examination. Data fields are :

> students social security number, degree code, code of the school or university where the degree is taken and date.

Th Study Units

The table contains data on the study units that can be registred in the data base. Data fields are :

> code of the study unit, name of the study unit, dates when the code in effect, institute responsible for this unit, default credits.

Various Codes

The code tables of the data base contain the names of post zone codes, commune codes, school codes etc.

5.3.4. Application Software

The application software of the centralized data base system can be divided into the following subsystems:

1. interface between terminal users and the data base
2. production of reports and lists
3. production of statistical tables
4. various auxiliary programs for the maintenance of the data base
5. query and reporting system used by non-EDP-planners for analyses of the student data

The production data base is implemented using the MIMER software which is originally made in Sweden although the latest version 4 is partly from the USA because of the changes in the ownership of the vendor. The user interface is made using the MIMER/PG program generator by an independent Finnish software firm. The interface is rather complicated, because we have tried to make it optimally fit in the working procedures of the Office of Actuary. At the moment it remains to be seen how we have succeeded.

Reports and lists are made by using the MIMER/RG report generator which seems to be quite efficient. Some tricky listings are planned to be produced with COBOL.

Statistical tables will be made with SAS-software that processes files extracted from the data base by MIMER/QL query system.

The query and data analysis subsystem is based on ORACLE-software. The data base is formed by copying proper data under ORACLE, and at the same time necessary modifications to the format of data is made. The query system is now in preliminary and experimental phase, we are trying to find out the right data content of it.

The reason for selecting two different data base management system software may seem rather strange, but we had several reasons for that. When the decision of the production system software had to be made at the end of 1985, there was no local representative of ORACLE in Finland. During the choice of system software we evaluated several systems (e.g. FOCUS, INGRES, MAPPER, Burroughs LINC, DEC RdB) and found that MIMER gives in our situation the best cost/benefit ratio. The evaluation of software was done along the project which led to the choice of VAX-11/780 for administrative EDP.

The situation with ORACLE was changed during the spring 1986 (Finland got local representative), and we decided to purchase ORACLE, too. The application generator of ORACLE version 4 available at that time was deemed to be insufficient to our purposes, so we continued the work with MIMER. The reason of the use of ORACLE is its standard SQL and other components suitable for "well educated" end-user. MIMER does not have such facilities.

The production data base is separated for the more easily accessed query data base also for reasons of security. It exists a real danger that hackers find it a challenge to intrude to the student file. It is easier to guard the data, if the use of the data base management system software operating on the production data is restricted only for professionals.

5.4. The Department Level Student Information System

The functions of the centralized EDP system are performed by the Actuary's office, and the departments obtain their results and send their data to be fed into the system to the Actuary's office. Only the Department of Computer Science has an experimental system which sends machine format data from the files of the Department to the files of the Actuary's Office.

In addition to the centralized system the typical departments have used manual files for strong student information excluding some exceptional departments who have development EDP systems for their own. There has been no coordinated efforts from the government of the University to establish department level student information EDP system.

Typical departments have manual files on paper cards to store the names, addresses and study results of their "own" students, while some departments have the results stored only on the result lists used when announcing the outcome of the examinations. The "official" procedure deman the departments to send the copies of the study results to the Actuary's Office to be stored into the centralized system, but some results are lacking.

There is now an experimental project going on in order to get a coordinated EDP system for student information processing in the departments. Because of the size of the University it is a necessity to have several variants of this system for different departments. The contents of the first version of the system is now planned, and during this summer we hope to be able to make the schedule according which it is possible to get the first departmental system running to the end of this year.

The first variant seems to be an independent microcomputer system using batch file connections with the new centralized system. Now we are also researching the possibilities to connect the department level systems on micros to the central system on VAX by using the data transmission network and distributed data base with ORACLE software.

The department level system will contain extra functions compared to the centralized one, e.g. the data on participants of courses and their points obtained in the intermediate examinations of the courses.

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THE IMPACT OF INFORMATION TECHNOLOGIES ON UNIVERSITY ADMINISTRATION *

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Introduction

Computerised managemnt has undergone a drastic chhange over the last ten years as two factors in the transition from batch to conversational processing have radically altered information channels for the institutions concerned :

-- There is no longer any intermediary between user and computer facility, and

— Managers are now having to think in terms of the information system.

Previously outside the management function, computing has gradually become commonplace, less confined to the specialist and more accessible to all. The trend towards more user-friendly hardware has been accompanied by the growing sophistication of peripherals and software, requiring users to gain the skills needed to handle telecommunications and networks, relational databases and transactional systems. At the same time, the surge in microcomputing has encouraged all kinds of stand-alone applications.

The universities have experienced and are still experiencing this technological trend at a time when management has to perform in an economic and regulatory environment of increasing constraints and complexity. Realisation of the financial and human implications of computerisation induced management to devise investment strategies and application development and maintenance policies. A number of institutions in some countries set up co-operative machinery to pool their thinking on management organization and to design, maintain and disseminate systems so that each could enjoy economies of scale and benefit from the experience of the rest.

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The new technologies and general institutional operating conditions had the first consequence of generating a certain management motivation, but, whatever form this took, the new technologies initially penetrated distinct functional fields. Soon, if not at once, the need emerged to get back through all these various fields to the unity of the university, to shorten procedures and provide rapid access to information and analysis, both sectoral and general, to meet the needs appearing at the various levels of management responsibility. This integration phase was directly linked to the application of new technical tools and, conversely, direct links were introduced to the system to as many users as possible, apart from which many new applications emerged upstream, downstream and even outside the system as developed.

1. Technological Development and Its Impact

1.1. Limitations of the Batch-Processing System

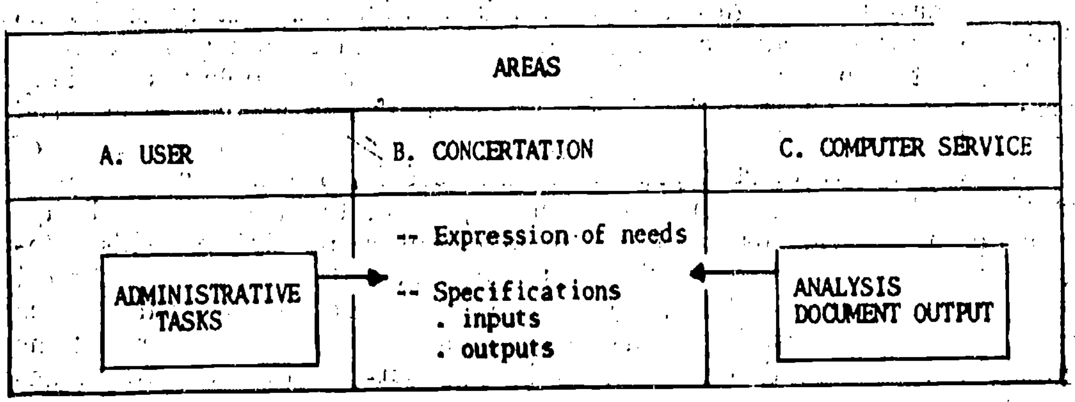
In a non-computerised organization management naturally falls into sectors between which information is passed with a value increment at each stage. Every sector reconstitutes for itself from the data received from the upstream sector the informational environment it requires. This invariably tends to swell staff and impede task fulfillment. It also requires the occasional collation and appraisal of the information held by individual sectors to verify its compatibility. In some fields, identifying and correcting mistakes may take longer than routine performance of the tasks concerned.

At first, computers were used in university management for off-line data processing, their function being to automate repetitive tasks (reclassification of data, production of statements, etc.).

This pattern, essentially linked to the state of the art, offered clear advantages over the traditional approach, but tended to confine applications to a large volume processing. These large-volume sectors were the first to use computers, and this influenced the way the user services were organized with varying effects on their operating processes. While computing provided the user service with some help, it also generated fresh constraints and requirements, thereby illustrating the well-known principle of technological determinism according to which technology is never neutral in any field it enters.

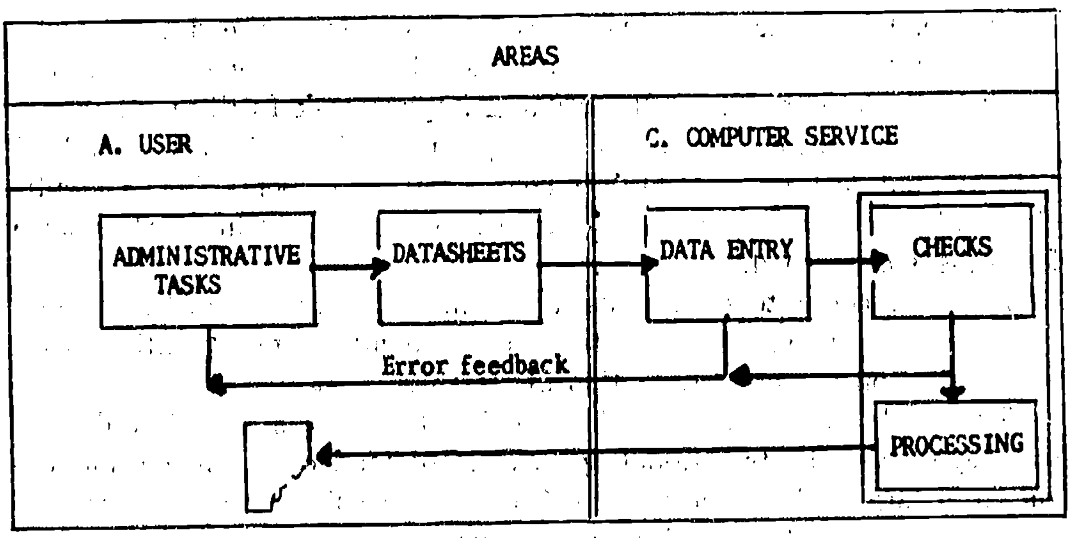
To gauge the scale of the changes wrought by the new technologies it is useful to recall the organizational effects of a computer-management system of this kind.

The table below shows the roles of the various parties at the system preparation stage.



The autonomy of areas A and C is total. Area B is a nexus between customer and supplier where a contract is made.

A batch mode computer system is organized in the following configuration :



In this table the nexus point B is eliminated and recurs only in case of a difficulty or new requirements. Areas A and C are still fully autonomous. However, although the computing function remains outside the administrative operation proper, the sensitive points of such a system, which are all linked to the means of data input, are evident :

1. There is a new workstation on the user side with the twin duties of :

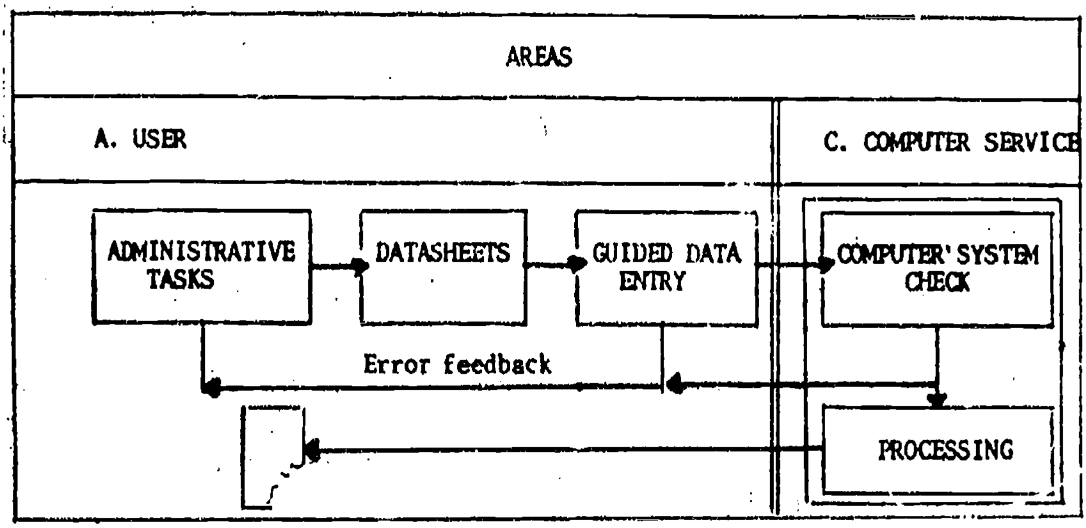
— Codification ;

— Input-document preparation ;

2. The data entry function on the computing side is often a bottleneck, especially when the workload is intermittent with a demanding response time ;

3. Error feedback may lengthen processing times and grow alarmingly if codes are complex to handle or staff preparing input documents and entering data are highly mobile.

With the emergence of transactional systems, the above configuration has tended to change with the introduction of guided and checked entry giving the following arrangement :

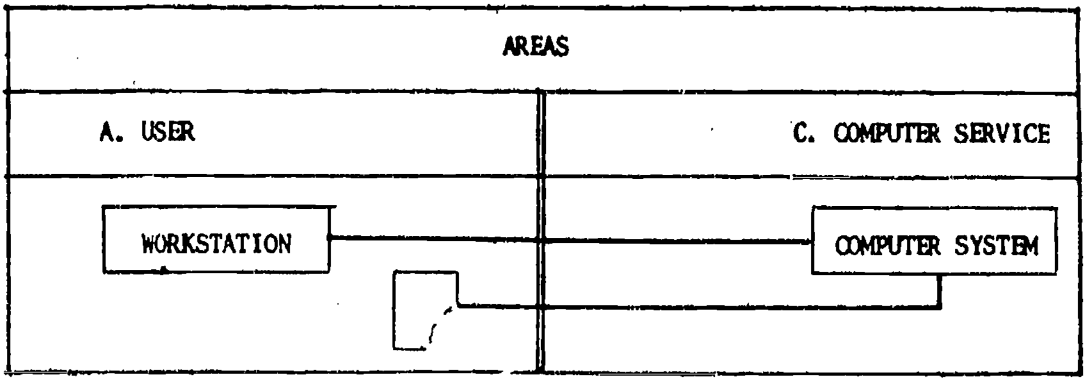


This configuration is a clear advance on its predecessor. The computer service no longer participates in formulating data for input and is now concerned only with operating the system. In addition, some errors are identified and corrected at once, and the reduced feedback is limited to document elements which are not internally verifiable (format, limit values, consistency, etc.). System stops will mainly reflect information gaps relevant to the environment (e.g. an instruction to modify a file which the system cannot identify in its records). There is therefore an appreciable saving of time and increased reliability in data generation.

On the purely organizational level, however, the sole change is that the data entry station has moved from the computing to the user side with a consequent increase in the latter's workload. There has in fact been no fundamental change in the system as a whole.

1.2. The Arrival of Interactive Systems

The arrival of the interactive system results in the following arrangement :



This configuration exhibits two new features :

1. The computer system no longer participates in the administrative operational procedure.

2. A workstation appears on the user side and the administrator is now linked without intermediary to the computer back-up. The user no longer burdens his work with specific system-feeding tasks but is on the contrary supported by the system.

This new configuration has an important bearing on the features of the computer system now available to the user.

1. The system becomes user-friendly i.e., easy for a non-specialist to use.

2. The system is necessarily complex as it has to accompany the user in his management functions and guarantee their consistency while immediately determining the full implications of each action in relation to the total body of managed data.

This latter point reflects the new potential afforded by interactive mode computing. Previously, there were as many computer systems as computerised services and inter-service relations were outside the computer system. The present picture is completely different, and any computer-feasibility study now requires a comprehensive approach to institutional functions, workstation analysis and provision and inter-service links. Computing now applies to functional areas, not to services in isolation.

2. Functional Areas

The decision to use modern information technologies is invariably an act of management policy, and in higher education the decision should serve four basic goals :

1. Provide the most accurate possible picture of the institution's teaching and research system ;

2. Aid in deploying the resources available to the institution for operating the system ;

3. Enable the resources to be adjusted rapidly to altered requirements and environmental changes to ensure their optimum use ;

4. Provide constant control over information flow and hence over the management back-up function.

2.1. The Information System

In a higher education institution, management comprises a range of measures taken by various departments to establish the material conditions and directives necessary for implementation of its teaching programmes and research projects. These programmes and projects are the essence of the institution's existence and every act of management should be related to them.

As a first approach, a higher education institution can be represented by a set of schematic relations between six major basic components :

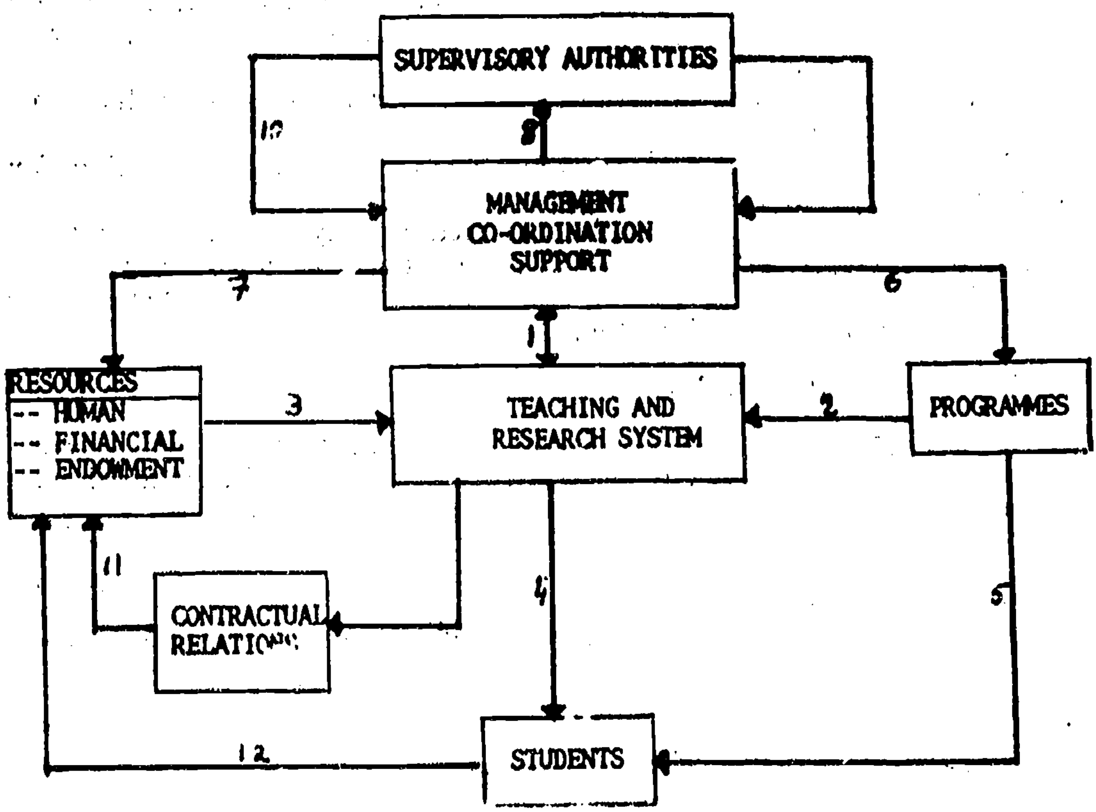
— Supervisory authorities
— Management/co-ordination/support
— Students
— Resources
  · Human resources
  · Funding and endowment
— Contractual relations.

Management : The information system is designed and organized by the institution's administrators (1) performing the functions of management and co-ordination.

Programmes : The programmes component, organized and integrated into the system by management (6), comprises the range of available qualifications, their means of acquisition and the appropriate courses of instruction and also the research subjects and projects approved by the institution (2).

Supervisory authorities : The successful completion of courses leads to university qualifications which, in the case of national awards, have been endorsed by the supervisory authority (9). This authority also reviews the state of the various components of the teaching and research system as reported by the institution's management (8), and applies certain criteria to make available to the institution the human and financial resources (10) it needs to accomplish its goals. Under the term supervisory authorities must also be included the various checks exercised by certain institutions such as national and regional assessment agencies and the auditors.

INFORMATION SYSTEM OF A HIGHER EDUCATION INSTITUTION



Resources : Co-ordination relates to the human resources (teachers, researchers, administrators, technicians and service staff) necessary to conduct the full range of "programmes" (7) and allocates the institution's financial and material resources to operate the system (3).

Students : The student population constitutes the system's beneficiary component (4) and is divided according to the courses on offer which the students are qualified to take (5). By their fees, students contribute to the funding of the institution (12).

Contractual relations : Some of the institution's activities like continuation training and research contracts generate funds and contribute to the institution's financial resources (11).

Management support : The administrative bodies and associated services are able to operate the system properly by frequent if not actually permanent information for the various decision-makers concerned (team work organization and time allocation, ability tests, awards of qualifications, statistics, vetting, budget management, miscellaneous accounting, etc.).

2.2. Areas of Application

Once the institution's information system has been established, one must identify functional areas conducive to the establishment of management applications accessible to the maximum number of users and compatible with the autonomy and responsiblity of each. Two broad areas can be identified :

— Resources

— Activities.

Resources cover a number of operations performed by different services :

— Vetting the allocation of financial resources and their application. This encompasses major system elements such as the budget, administrative accounts, general accounts and fund transfers and is of constant concern to many parties including the institute's various hierarchical levels and all recipients of budget allocations.

— Monitoring the careers of teaching and non-teaching staff from recruitment to retirement and the punctual satisfaction of their entitlements. Institutions are more or less directly involved in this type of operation according to the status of the various staff categories. However, the status and allocation of all staff members are subject to continuous oversight.

— Monitoring the condition, use and performance of tangible infrastructures (premises, technical systems etc.).

Activities basically encompass every aspect of teaching and research :

— Organization of teaching activities with three main objectives :

- Defining the education system, i.e. the types of training and awards provided by the institution ;
- Organizing courses tailored to the various teaching requirements to enable students to gain the knowledge needed to obtain the qualifications they are working for ;
- Practical deployment of all resources needed for the education system to work.

— Organization of research activities :

- Choice of research areas ;
- Introduction of assessment systems ;
- Monitoring of contracts and agreements ;

In all these activities the management's constant concern is the apportionment and optimum use of the resources the institution makes available to them.

3, Integration and Links

An area of application is defined by three elements :

— Its components, within the institution's information system ;

— The participants, i.e. the staff members aware of, and if necessary able to change the component status ;

— General or individual procedures, enabling the participants to exercise their investigative or executive functions.

An area of application therefore establishes constant relations between the components and the participants, if not directly then via the procedures each can apply to the components. This means that the techniques introduced are inevitably conducive to integration : each operation is performed only once, and its consequences are immediately accessible to all participants with the assurance of total consistency.

Introducing a system of this kind does not impose any a priori organizational pattern on the institution but does oblige it to review its functions and performance and to take decisions concerning its organization. The information system, when translated into application systems, requires that the operating rules be clearly defined for each participant. These rules naturally imply the provision of as many links as posible between the system and the institution's staff. Ultimately, conventional inter-service information transfers are replaced by common access to a structured database source.

Two management systems can be described as examples : one for finances and accounts, the other for education system management.

3.1. Financial and Accounts Management

The components selected for this system are :

— Budget
— Credits
— Structures
— Relations with third parties
— Liquidity position
— Audits and consolidation

These various components are organically linked : the structures i.e. the constituent units of the institution such as teaching units, stitutes, laboratories, common services, etc.) receive credits allocated budget decisions and cash revenue as incoming payments are booked. its, like debts, are committed by appropriation users within the es, and the audit and consolidation component ensures that each is implemented according to the rules and guarantees to each ntegrity of the information to which he has access.

participant's access to the system will therefore be limited to the or more procedures he is entitled to use and to those parts of the management data he is authorised to consult or amend. The system thereby links every operation performed to a user, a structure and an objective. While each participant remains a specialist and responsible for his own field of action (not necessarily a management role) he participates in the working of the institution as a whole through the system, which registers operations and relates them to their respective components.

In the system under consideration, access to a common database is associated with a guarantee of total autonomy for each individual in his own sphere of responsibility. The same system has been installed in different institutions with varying kinds of organization, partly or totally decentralised and with a different spread of responsibility between services. The procedural rules are imposed on the system by each institution using procedures only accessible to management.

3.2. Education System

The components of the general information system help to show how the institution organizes its educational activities :

— The degrees it offers ;
— The degree courses it provides ;
— The human resources employed ;
— The composition of the student population ;
— The material resources, particularly premises, available for teaching purposes ;
— The funds available for teaching.

These components form a coherent set of data interrelated as shown in the accompanying diagram.

To use or amend the data a participant can apply various procedures, the most important of which are the following :

— Course introduction ;
— Student enrollment ;
— Timetable adjustment ;
— Allocation of premises ;
— Performance assessment ;
— Degree awards ;
— Storage of course attendance data ;
— General management information, statistics.

Participants fall into two major categories according to whether they are members of the institution or an outside body.

Internal participants include :

— Management bodies ;
— The resource programming and allocation department ;
— Academic registry ;
— Teachers ;
— Students ;
— Accounts department ;
— Information and counselling services ;
— Joint university services (libraries, preventive medicine, sporting activities, etc.).

Once again, when this management system is installed in an institution, it requires close co-operation among different departments — academic registry, personnel, financial services, academic administrators and technical services. Co-ordination is ensured by the "management" component.

The two management systems are coupled by their common "financial resources" component. This demonstrates the fundamental unity of the institution, and is a reminder that the various participant's purpose is to serve the education system, to which every action should be related. This brings us back to the institution's need for integration and liaison in the analytical treatment of the various activities pursued.

The two systems were developed following very extensive study and their introduction on each university campus requires careful prior consideration and decisions by the institution regarding its organization. Another essential point is that, although these systems are structure-forming, they should not render the organization rigid. This should be readily adaptable to changes in structure or statutes. However, this broaches a subject to be dealt with elsewhere.

4. New Applications

Interactive mode and database systems are being installed in higher education institutions with all their organizational consequences : introduction and reorganization of services, simplified circulation of information, procedural definitions, demarcation of responsibilities and increased links between different activity levels. The new technologies have not yet had their full impact, and already other innovations are occurring. The universities have also shared in the latest trends including the wider use of microcomputers and network and videotex developments.

In the beginning at least this proliferation seemed to threaten some confusion, with too many individual initiatives acting centrifugally in a drive for autonomy or independence. In fact, this did not happen. After a honeymoon period it had to be admitted that microcomputing required a minimum training which few possessed. Once this training had been acquired, the need to communicate made it clear that the use of common software standards was essential.

The arrival of microcomputing and the installation of local networks have had the effect of accessing more users to large management systems in which the application of emulation products has made possible the use of microcomputers as system terminals. File transfers enable users to process independently management system data for studies of narrower scope such as statistics dealing with only part of the institution, budget simulations or any other study of concern only to the individual user.

Those with microcomputers seem to make systematic use of off-the-shelf packages like word processors, spread sheets and file managers. Here, too, there is now a trend for software packages of the same kind to be used in any one institution — more evidence that self-sufficiency does not eliminate the need to communicate.

Videotex applications are also spreading very fast. Institutions are setting up internal message systems. Study groups encompassing more than one university etc. keep in constant touch via videotex, especially for the development and maintenance of management systems. The systems also support Minitel connection for user enquiries, so the need for hard copy printouts will certainly soon be reduced.

In many institutions students can use videotex to access details of course programmes and admission requirements. It will become possible for some examinees to see their results on videotex within a few moments of the board's decision, together with the date of their next tests, where appropriate.

Conclusion

Higher education institutions have adopted the new information technologies against a difficult management background, with stagnant if not contracting managerial staff, changing regulations and laws in some countries and financial resources which have at best been flat. For many, the new information technologies have afforded an opportunity to overcome these difficulties and managers at every level have almost invariably been prompter to appraise the nature and methods of management of their own institutions.

AN INTERNATIONAL CENTRE FOR COMPUTERS AND INFORMATICS (ICCI) TO PROMOTE THIRD WORLD DEVELOPMENT

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Introduction

Contributing more effectively to develop and raise the living standards of the 3.5 billion inhabitants of the developing countries (over 70 percent of whom live in rural areas under difficult circumstances), is one of the great challenges of today. Since 1850, mastery of the physical world through science and technology, has helped to bring about a six-fold increase in average global real per capita income. Nevertheless, these aggregate numbers mask glaring inequalities that need to be addressed urgently. Thus, the roughly 25 percent of the world's population in the industrialised countries produce and consume about 12 times more per capita than their third world brethren.

Many of the fundamental structural changes that are transforming the western societies, such as the shift from the industrial to the post-industrial economy are being driven by technological improvements in areas like microelectronics and informatics. These changes cannot be ignored by third world countries, if they are to take their place as equals in the global environment, and compete successfully in international markets.

There is a revolution now under way, that will fundamentally transform human society in the coming years. Fortunately, this particular revolution does not involve weapons and bloodshed — it is the result of unprecedented developments in electronics and information technology over the last 3 or 4 decades.

The biological sciences show that a living organism may occupy a viable niche within the biosphere if it is able to successfully control the three principal aspects of its interaction with the environment, represented by flows of nutrients, energy, and information (Thomas 1974). Analogously, a study of the broad sweep of human history shows that it took many millenia for mankind to evolve from the nomadic hunter stage to the early farming stage (by about 8000 BC). Societies were able to devote more time to relatively sophisticated pursuits, as food gathering became more efficient. The transition from the agricultural to the industrial phase (starting around the seventeenth century), was relatively more rapid, and mainly involved the control and use of energy for manufacturing and production. The most recent era involving the development of electronics and other modern technologies began in the 1950's, and has accelerated even more sharply. It is based on increasing manipulation and mastery of information.

Each age may be represented by a typical tool or implement : the hunter's spear, the farmer's plough, the industrial worker's lathe, and the brain worker's computer. The intrinsic capability of the modern-day computer to enhance and transform our thinking power, makes it a radically new instrument compared to the hunting tools, agricultural implements, and industrial machines that chiefly augmented human muscle power in earlier times. It is this difference which provides the driving force for today's information based revolution.

The recent advances in solid state technology that have given the impetus to the worldwide information revolution, are impressive (Scientific American 1986). Several generations of electronic computers have passed by with increasing rapidity, starting with vacuum tube technology (around 1950), and progressing through machines based on the discrete transistor, and small-, medium-, large-, and very large-scale integrated circuits (today). Consequently, computer hardware that would have filled a room 30 years ago, would now fit into a silicon chip smaller than a pea, while power requirements have also declined correspondingly. Reliability of operation has improved by a factor of 10,000, while maintenance is much simpler. Nominal costs of microelectronic devices have declined by a factor of about 150 over this same period, and the cost decreases are even more dramatic if the effects of steady inflation over the last 30 years were netted out.

Comparable reductions in cost, and improvements in both hardware and software capability are anticipated in the coming decades (Branscomb 1986, IEEE Spectrum 1987). Parallel processing architectures now being developed promise speeds and capabilities (for certain classes of computational problems) that were hitherto only available to supercomputer users and at considerably higher costs (High Technology 1987). A sampling of exciting potential developments for the future include the ultrafast light computer capable of trillions of operations per second, improved very large scale integrated circuits culminating in "molecular" switches which are a billion times smaller than comparabe devices today, and new digital and optical fibre based integrated communications services and systems (IEEE Spectrum 1986).

Meanwhile, computers and communictions are so closely linked that telephone companies are offering new types of computer services and computer firms are entering the communications arena. The advent of the integrated services digital network (ISDN) concept underlines the potential of computers and informatics (Kitahara 1983, NTT 1985, Pitke 1987). ISDN combines audio, data, text and video transmission facilities in a single service, that is both faster and cheaper than comparable services today. At the same time, satellite links and international networks are becoming more commonplace and cheaper, and the developing countries cannot afford to lose the opportunity of gaining access to knowledge and services outside their borders (Quartermain and Hoskins 1986, Balson et al. 1987, Budd 1987). The critical importance of the telecommunications aspects of the informatics revolution, for world development, is becoming widely recognized (ITU 1985).

Software sophistication is also growing, but not at the same pace as hardware. New algorithms and languages are being developed for parallel processors. Expert systems which seek to mimic some of the basic judgemental skills of human experts in various specialised disciplines are already available, and are steadily improving capability. Finally, there is considerable interest in both the theoretical and practical potential of artificial intelligence devices. One particularly promising area of research concerns the so-called neural networks, which consist of large numbers of simple neuron-like logic devices connected in a network. These networks appear to have intriguing and unexpected characteristics, including heuristic behaviour.

In the industrialised nations, ambitious multi-billion dollar initiatives are under way to build fifth and sixth generation computers (ICOT — Institute for New Generation Computer Technology, Japan in 1982; MCC — Microelectronics and Computer Technology Corporation, USA in 1983; and ESPRIT — European Strategic Programme for Research and Development in Information Technology, EEC in 1984). These new systems will have greatly improved performance including quasi-intelligent capabilities (CEC 1985, Feigenbaum and McCorduck 1983, ICOT 1984, IEEE Institute 1987). While the developed countries are already deeply involved in the microelectronics and computer revolution, the developing countries are also on the brink. Whether they like it or not, third world societies and economies will be compelled to live with these new technological advances, and all their widespread implications. Either the developing countries adapt and use the knowledge to enhance their drive for socio-economic development, or they fall back even further — this is the harsh rule of survival in an increasingly competitive world marketplace.

Although the technological advances are breathtaking, our feet must remain firmly anchored on the ground. Thus, policy analysts and planners generally agree with the need to rationally and efficiently allocate the scarce financial and manpower resources available to the developing countries, so that these new technologies can be harnessed to maximize socio-economic development (Munasinghe 1983). The dramatic declines in solid state device costs offer a golden opportunity for third world countries to close the gap between the rich and poor nations, through the wise and effective use of computers.

At the same time, we should also guard against exaggerated claims and expectations — actions must match the rhetoric. Unless the benefits of computer technology are brought to the people, (especially the rural masses), scepticism and disillusionment might hamper further progress in this direction, as the scientific and technocratic leadership rapidly loses its creadibility. Computers need not be confined to the elite — they should be accessible to everyone.

Computer and Informatics Issues in Developing Countries

Computers and information technology provide a unique opportunity for the third world to accelerate their development efforts. The new technology has great potential, but its effective use should be determined by the appropriate development path chosen by each nation. The technology ought to be treated like any other instrument of policy by developing country governments, to achieve national goals, the most fundamental of which is the improvement of the welfare and quality of life of citizens. More specific national socioeconomic objectives to be achieved, include :

1. Increasing economic efficiency, growth, productivity, and employment ;
2. Meeting basic needs and access to minimum levels of essential services (especially of the poor), and ensuring a more equitable income distribution ;
3. Maintaining sociopolitical stability, including national security, unity, independence, self-reliance, and integrity of state institutions ;
4. Preservation of cultural heritage and traditions ;
5. Others (protection of environment, justice, etc.).

However, there are many constraints and difficulties that hinder the early development and effective application of computer and informatics in developing countries. Some of the issues that policymakers will be called upon to address include :

Technical Issues

1. Degree of standardization of software, hardware, databases, telecommunications, etc.
2. Adequacy of service and maintenance facilities, access to standard software and of technically qualified manpower.
3. Quality of infrastructure services and working conditions, including power supply, telecommunications facilities, and control of temperature, dust, vibration, insect pests, etc.
4. Protection of intellectual property, patents and copyrights.

National and Economy-Wide Issues

1. Development strategy, general policy approach and institutional framework, which could range from a market oriented completely laissez-faire attitude, to a rigid, highly planned framework with centralized control.

2. Impacts on economic growth, productivity and employment.
3. Sociocultural effects.

International Issues

1. Transborder data flows.
2. Access to technology.
3. Risks of new forms of south-north dependency.
4. The role of aid donors.

Role of an International Centre for Computers and Informatics (ICCI) to Accelerate Third World Development.

There was a general consensus that developing countries should move quickly to formulate and apply computer and informatics policies for development. The discussion also helped to identify several important reasons why an International Centre for Computers and Informatics (ICCI), based on the network approach, could play a crucial role in the development process.

First, there are many aspects of informatics policy that are common to most third world countries, and ICCI could mediate and catalyse fruitful exchanges of ideas and information among these nations, thereby minimizing duplication and costly mistakes of policy. Second, there are several initiatives and projects that individual developing countries may not be able to undertake on their own, which could be done collectively through ICCI. The Centre would not only facilitate south-south collaboration, but also could actually help to identify and clearly articulate some of the complex issues and problems to be examined. ICCI would provide a critical mass of analysts, researchers and implementers, essential for success in a relatively uncharted and difficult area of study. Finally, ICCI could play a vital role in acting as an intermediary between the south and north, and facilitating the mutually beneficial transfer of information technology and knowledge.

The proposed Centre's primary focus would be practical research, pilot studies and applications on the role of computers and information technology in third world development. On a preliminary basis, ICCI might provide the framework and driving force for third world computer development and application efforts in the following broad priority areas :

1. Policy analysis, formulation and implementation in relation to overall national development strategies.

— comparative studies among countries
— country level studies in selected developing nations
— detailed studies of applications in specific sectors

2. Education and training — a broad range of activities focussed on skilled manpower development and promotion of computer literacy. Institution building efforts would be made especially effective by directly involving developing country collaborators, in the field.

3. Software development, both for domestic use and exports of services, with particular emphasis on rural applications. Some specific sectors with promising scope for applications, include : agriculture, education, energy, health, industry, nutrition, population, transport and urban planning.

4. Hardware and microelectronics development — although competition from the developed countries would be severe, joint efforts based on the pooling of scarce skilled manpower and financial resources of the developing countries, could be very useful. Emphasis would be in areas like use of existing components, computer architecture, basic communications devices, and chip design, rather than advanced chip manufacture.

5. Dissemination of information — act as a clearing house for all types of written and electronic data in this area, produce its own publications and reports, organize and participate in meetings (face-to-face and teleconferencing). One major objective would be to facilitate and encourage the work of relatively isolated researchers in the developing countries.

While there are a number of international and regional organizations in the computer and informatics area, they do not appear to adequately cater to all the needs of the developing countries. This is because the range of issues is so enormous, while constraints and political problems often prevent existing bodies from functioning effectively. Therefore, there would be ample room for ICCI to play an effective role — complementing rather than duplicating the work of existing institutions.

Basic Considerations Concerning the Organization of ICCI

There was unanimous agreement that the new centre should be based on the network principle. ICCI may then consist of a small core group of experts, acting as a coordinating point and central node of a network linking many existing or new regional and national centres in other countries. The advantages of this approach would include :

1. avoiding the high start-up costs (both capital and recurrent), associated with a major new centre :

2. avoiding the need to launch yet another large international organization, given that there may be little enthusiasm for this concept at present, in the international community ;

3. serving the critical needs of the developing countries in this area, in a way that requires only modest initial resources, and permits the centre to build up its programme and obtain additional resources, through proven results ; and

4. using information technology itself to pioneer and prove the value of the network approach for application of science and technology in the third world. ICCI will be able to benefit from the synergistic inputs provided by many institutions and individuals, with relatively low cost and advanced telecommunications, itself facilitating this relatively novel form of collaboration.

The following broad outlines also emerged from the discussions, concerning the functioning and organization of ICCI :

1. The Centre should be an independent, international body like the TWAS, and should draw on the support of existing organizations such an TWAS, ICTP, and United Nations Univ. The autonomy of ICCI would also be protected by having an international charter, and an independent Board of Governors, drawn from the highest levels of the scientific and development communities, and those with practical experience in the decisionmaking process in developing countries.

2. The Centre should respond mainly to the needs of developing countries, but ideas for study could be suggested not only by third world governments, but also non-governmental agencies, universities, bilateral and multilateral aid organizations, and other groups active in the development area. Mutually beneficial collaboration with the private sector may also be pursued, provided the interests of all parties are well specified and understood.

3. ICCI might begin with a relatively small core staff focussing on project and program development, coordination of network research and applications, providing intellectual leadership and guidance, articulation of third world needs, information dissemination, and mobilizing resources (funding and manpower). While, some key activities would be the direct responsibility of ICCI, much of the work ought to be defined and carried out by associated organizations in the ICCI network. Projects and studies could be international in scope, at the national/government level, or involve specific institutions/individuals.

4. Three types of funding would be sought from a variety of sources :

— seed money and longer term core support for the Centre

— programme assistance for activities built around the broad thematic areas identified by the Centre

— funding of a more ad-hoc nature for project of interest to specific donors.

Diversity of financing will also help to ensure a measure of autonomy that is vital for the success of ICCI.

5. Top quality staffing for the Centre ought to be ensured, by providing attractive salaries, working conditions, and other incentives, to attract the best qualified candidates at the international level. Both core (or permanent) staff positions and shorter term visiting assignments for scholars should be provided. The core researchers would provide continuity for long term work, while the fixed-term appointments will give a measure of flexibility to respond to more urgent research needs and help to bring in fresh ideas.

Recommendations for Action

The pressing needs of the developing countries and the rapid pace of technology in the computer and informatics area, strongly suggest that an international body along the lines of the ICCI could play a key role in accelerating third world development efforts. A network based approach for ICCI would be desirable. The following actions were recommended, as the next steps towards realizing this goal.

1. Define more precisely the needs of developing countries in the computer and informatics area and identify the problems and issues that are not being addressed by existing bodies.

2. Prepare a specific proposal that clearly sets out the objectives, scope, functions and organization of ICCI, using in particular, the information from item 1 (above).

3. Organize a meeting of potential donors, at which the above proposal could be presented and discussed.

The ICCI initiative continues to be guided by the Expert Group, and relies on the support of the TWAS, UNU and ICTP. Links are also maintained with other groups working in the informatics and development area.

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GLOSSARY *

ABEL : experimental medical system for diagnosing acid/base electrolyte disorders
ADA : language thus named in memory of lord Byron's daughter, Augusta Ada, the world's first programmer ; conceived initially for internal use by the Defence Department of the U.S.A.
Advisory system : expert system that interacts with a person in the style of giving advice. Advisory systems have mechanisms which explain their advice and allow their users to interact at a detailed level, very convenient for the user
ALGOL : early, general-purpose, high-level programming language
APL : acronym for a programming language. It is very useful by its ability to perform certain mathematical computations extremely compactly
Artificial intelligence : comprehensive notion with several interpretations, of which we mention a few below
1) capacity of a machine to control itself by means of simulated human intelligence
2) way of designating computers conceived to make deductions and draw conclusions based on given facts and information
3) capacity of mutual influence of a computer and human being with respect to dialogue, way of thinking and reasoning
4) access emphasizing symbolic processes with a view to representing and manipulating knowledge so as to solve the given problem
5) implementation of the computer in apprenticeship and comprehension processes, making possible the acquisition and storage of a new "skill" (new knowledge), so as to cope with new situations (to be reacted to promptly and correctly)
Backward Chaining : that problem-solving technique characterized by working backward from hypothesized conclusions toward known facts
BASIC : simple programming language introduced at Dartmouth College
Binary image : black/white image represented by "o" and "1", in which objects appear as outlines
bit : one digit in the binary representation of a number ; it is the fundamental unit of information

* This glossary contains brief explanations of the technical terms most frequently used in the present volume.

bit-map display : display consisting of a large array of tiny, individually controllable dots. Advanced types may have a million or more dots, each of which may be more or less bright or in color
byte : eight bits
CAD : acronym for computer-aided design
CAD/CAM : acronym for computer-aided design and computer-aided manufacturing
CAI : acronym for computer-assisted instruction
CAL : acronym for computer-assisted or aided learning
CASNET : acronym for causal-associative network. Experimental system for dealing with disease processes. Usually associated with a specific application focussing on glaucoma
Causal model : model in which the causal relations among various actions and events are represented explicitly
CBL : acronym for computer—based learning
CMI : acronym for computer—managed instruction
Computerized Vision : visual sense perception achieved by means of a computer making a concise description of a scene, depicted by an image. This is a process based on knowledge and guided by provisions, which makes use of models in order to interpret sensory data
Configuration : the way in which various parts of a computer are to be arranged
Courseware : A package comprising software, documentation and, where appropriate, associated resource material, intended to facilite classroom activities
CPU : Acronym for central processing unit of the computer (i.e. the part that does the computing)
Description : symbolic representation of useful information
Digitalized image : Representation of an image as a mosaic of luminosity values
Digitalized word : numerical representation of the word, in which the amplitude of the wave shape displayed by the word has been registered at regular intervals
Dynabook : early specification for a book-sized computer for education proposed by Alan Kay
Ethernet : local network for sending messages between computers by way of a single coaxial cable that snakes through all the computers to be connected. A coaxial cable consists of a central wire surrounded by a grounded cylindrical shielding sheath
EXPERT SYSTEM : program allowing computers to draw conclusions starting from a knowledge base (contrasted to a data base). It has been structured according to human expert rules for a given domain (i.e. medicine, geology, financial planning etc.). It offers the user the benefit of the knowledge and experience of a number of experts, under machine shape. Most expert systems are able to solve single problems quickly and to explain their own "reasoning", but few are able to break their own rules, to run simulations or to learn

Fifth generation : technological era introducing present and future major technical progress. Includes the new supercomputers, commercial use of artificial intelligence, improved storage systems and integrated circuits on a large scale

Flopping-disk : storage device, having generally a capacity of 256 kilo bytes (1 kilo byte = 1024 bytes); video-disk, hard-disk, video-laser-disk are new storage devices of extremely high performance (it is considered that all dictionaries of current languages could be stored on such a laser disk)

FORTRAN : acronym for formula translation. Early programming language that still dominates scientific computing by virtue of the massive amount of accumulated software that has been written using it

Gate-array technology : approach to integrated circuit design. The circuit designer adds specializing detail to a partially wired array of basic circuit elements

Hacker : person devoted to intricate computer programming, particularly that programming done for its own sake; an expert programming

Heuristic : anything that helps to guide problem solving. Use is generally restricted to those things that are not guaranteed to be successful

IC : acronym for integrated circuit. An individual IC may contain tens of thousands transistors

ICAI : acronym for intelligent computer-assisted instruction

ICAL : acronym for intelligent computer-aided learning

Interface : device used to allow communication between two equipments displaying different functional characteristics

Knowledge base : basic storage of a computer structured according to logic and conclusion rules as contrasted to mathematical rules (based on data). The knowledge base has two essential components : 1) grouping of facts which is not structured and 2) a grouping of rules relevant for determining new facts

Knowledge engineer : person who designs and builds expert systems

Knowledge representation : a vocabulary of symbols and some conventions for arranging them so as to describe things

LED : acronym for light—emitting diode

LISP : acronym for 'list processing language', introduced in 1960 by John McCarthy. It was the first programming language to concentrate on working with symbols instead of numbers. It is preferred by American programmers, because it can easily be programmed and for the surveying quantity it is able to absorb. Main competitor : Prolog

LOGO : education-oriented programming language, conceived by S. Papert and his associates, intended to help people to learn about powerful sophisticated ideas

MACSYMA : large computer system developed by Y. Moses, MIT, for helping people to do advanced applied mathematics

META-DENDRAL : learning system designed to generate rules for DENDRAL (an early rule-based expert system that helps determine organic-compound structure using data from mass spectrometers and nuclear magnetic resonance machines)
Nand : acronym for *not and*
Natural language : part of the artificial intelligence dedicated to the use of commands given in the normal language of the operator. Questions and answers are provided in a conversational style ; a machine using natural language will be capable to understand and solve grammatical idiosyncrasies and other ambiguities
Nor : acronym for *not or*
Object-oriented language : a programming language in which procedures for doing things are accessed through descriptions of the things to be worked on. E.g. : SIMULA, a programming language intended for simulation work
PASCAL : popular general-oriented, high-level programming language, descendant from ALGOL
PC : acronym for personal computer, i.e. a computer that is powerful enough to be user-friendly and inexpensive enough to be nonshared
Pixel : acronym for picture element
PROLOG : acronym for Programming LOGIC : Language chosen by the Japanese for the fifth generation of computers and developed in Europe in the 1960's
REASONING MOTOR : Program capable to substitute a human expert, conducts unfolding of possible deductions to be made with the help of a fact base. The use of such a program implies the prior existence of an adequate knowledge base
Rule-based system : system in which knowledge is stored in the form of simple if-then or condition-action rules
Terminal : equipment for communication between the operator — who is usually at a certain distance — and the computer system
VLSI : acronym for very-large-scale integration, the process of producing integrated circuits containing tens of thousands of electronic devices
Work station : computer system that acts as a partner to a person, in work or play, greatly facilitating productivity.

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