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ABSTRACT

The position papers presented at a seminar held in 1969 at Leeds University are the basis of this report. The papers cover the topics of computers in education, learning systems, planning and management, hardware and engineering, development processes in computer assisted instruction (CAI), and economic problems. The 46 participants at the seminar were from the United Kingdom, Canada, Belgium, Holland, France, and the United States. A summary of the discussion of each topic is presented. Some of the papers have lengthy reference sections. The discussion of a proposal by the National Council for Educational Technology (NCET) for a national research and development effort is also recorded. (JY)

NCET

Proceedings of a Seminar on Computer Based Learning Systems

Bodington Hall, Leeds University,
8–12 September 1969.

NATIONAL COUNCIL
FOR EDUCATIONAL TECHNOLOGY

PROCEEDINGS OF A SEMINAR ON COMPUTER BASED LEARNING SYSTEMS

Bodington Hall
Leeds University

8 – 12 September 1969

John Annett
John Duke
Editors

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EDITORIAL NOTE

This document reports the proceedings of a Seminar on Computer-based Learning Systems held at Bodington Hall, Leeds University, 8-12th September, 1969.

The 46 participants from the United Kingdom, Canada, Belgium, Holland, France and the United States held 7 sessions in which precirculated position papers were discussed. For the first and last sessions the papers under consideration were three documents produced by the National Council for Educational Technology. These are not reproduced here but are available separately from NCET (for details see page 7).

The discussions were wide-ranging and informal. It was impossible to record all the contributions and exchanges in detail. A summary of the discussion in each session was prepared by rapporteurs in which the essential content and some of the original flavour is preserved.

The Seminar was arranged by John Duke, Assistant Director of the National Council for Educational Technology, with the help of the Leeds University CAI project. John Annett undertook the major part of editing these proceedings.

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The Editors wish to acknowledge the helpful co-operation of authors and rapporteurs in preparing these proceedings for publication and to apologize to those whose valuable contributions have been simplified and thus perhaps misrepresented.

John Annett
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January 1970

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SESSION I

WHY COMPUTERS IN EDUCATION?

INTRODUCTION

J.F. Duke,
National Council for Educational Technology

DISCUSSION

Rapporteur, J.F. Duke

WHY COMPUTERS IN EDUCATION?

J.F. Duke,
National Council for Educational Technology

INTRODUCTION

Several years ago there was a short round table conference in London sponsored by ONR on CAI, in which a number of experts from the US came over to share their experiences. That meeting stimulated people in this country to look seriously at the computer as a component of the education system. Since then much has been thought and talked about in Britain of using the computer in the learning situation, but only limited experimentation has so far got under way. Meanwhile developments in the USA have been almost explosively far-reaching, with over 100 identifiable centres now investigating aspects of this field. We in Britain have of course tried to keep up with the burgeoning literature (although this is often more speculatively descriptive than factually informative). We have had the benefit of occasional lectures from distinguished practitioners and there have been sessions at conferences (such as those organized by APLET and IFIP) devoted to CAI and some of us have been fortunate enough to see things at first hand in the States.

It appears to me that the time is particularly ripe to take deeper stock, to pool ideas and experiences and to indulge in that critical reflection that only a few days cut off from all other earthly cares can nurture. When persuading the National Council for Educational Technology to undertake sponsorship of this meeting I was most fortunate in being able to call on the generous support of the US Office of Naval Research, whose additional aid is most appreciated.

This Seminar comes at what may be a critical juncture in the British attitude to investigating computer based learning (of which more later), but I think I also perceive a wind of change blowing through the corridors of the US funding agencies. I would like to thank our American guests for responding so whole-heartedly to our request to pick their brains, and hope that by the end of the week they may not feel the balance of payments has been all one way. Further, through the Centre for Educational Research and Innovation of the OECD, international relationships in this field are being explored. It is thus with much pleasure that, to balance as it were the transatlantic contingent, we have as participants in this Seminar workers from continental Europe. This Seminar will I hope be remembered as a key gathering this side of the Atlantic and be a precursor of many future meetings.

The NCET is a largely advisory and exploratory body, set up by government, but independent of it, to advance the application of educational technology in this country. It is not a grant-giving organization and has to exercise its persuasive powers to exhort action in others. Right from its beginnings two years ago the Council recognized it should take a positive role in respect of the computer's role in education. As a result it set up a series of studies which produced documents containing a preliminary state-of-the-art survey[1] ; a more thorough investigation of the feasibility of R & D work in this field and of the criteria that should be followed[2] ; and most recently a policy statement addressed to government outlining a recommended plan of action[3].

I felt that these documents could provide a useful framework for this conference. They represent a philosophy of approach which I hope will be discussed, although I hope we will not get bogged down on too detailed a debate. They highlight a number of the points at issue and support directions in which we might begin to seek answers. They relate to a peculiarly British situation, but this may have parallels elsewhere.

In this country educational research is something of a poor relation. The total amount spent on research and development is only about 0.1% of the total annual educational budget. Not only are we up against a traditional lack of money, there are also shortages of institutions with adequate staff and resources to undertake major R & D projects. The central Department of Education and Science undertakes virtually no innovative research itself and directly commissions little more. It affects to stand back from influencing both curriculum and method, concerning itself with general policies and plans, but often does not make the wherewithal available to carry these out. At the user end authority is fragmented into units too small to sponsor useful developments. The Local Authorities do contribute towards the NFER, but its work is largely post hoc evaluation. They do now support the Schools Council, whose committees are responsible for new curriculum design and the need for which arose out of the pioneering work of the Nuffield Foundation. The Schools Council only covers the primary and secondary sectors – it has no concern with the further education field. At universities the effect of their educational research on teaching has been infinitesimal. The UGC does not normally provide resources for specific developments, although it did make available earmarked funds for establishing certain audio-visual centres. The SSRC can grant-aid specific projects within its small budget, but it is more inclined to favour basic research rather than applied development.

In the field we are concerned with, there is no suitable mechanism to set work in train such as we see in America, Sweden and France. There is also lack of facilities. Computers are still in short supply in this country. Computing power is inadequate for research into the physical sciences (which have traditionally had the lion's share) and there is no spare capacity for educational purposes. Educationists are generally ignorant of the capabilities of computers and appear happy to remain so. It is against this background that the NCET proposals must be viewed, and any alternative suggested. Firstly, government has to be persuaded that it matters; secondly the ends have to be decided (are we seeking knowledge for its own sake or are we seriously attempting to assist in relieving some of our pressing educational crises); and thirdly the means for achieving these ends have to be set up.

This brings me to the objectives I see for this conference. I would like us first to consider what it is we want of computers in education, and how do we best set about achieving this. What is the justification for exploring this field, and on what criteria can success be assessed? What appear to be the major problem areas and where should the balance of effort lie? This will lead us on in subsequent sessions to consider major sections of activity and the best lines of advance in each. These I have suggested may be arbitrarily divided into hardware and engineering problems – the question of making available a machine system to fulfil educational tasks, the software problems – concerning the development of appropriate learning materials, and the conception and implementation of learning systems through which hardware and software combine with teachers and students to achieve a viable whole.

Towards the end of the week we will look I hope at the economic implications of the problems and solutions we have been posing – who pays and how. And at the question of organizing all the effort that is required, is a disciplined approach possible? None of these topics is exclusive in itself and all have implications for each other. I hope we will be considering these interdependencies for in the final session I would like to piece together the themes we have been following, to reappraise our problems and priorities and look to the opportunities for collaborative action – in this field we cannot all afford to re-invent the wheel.

As to the pattern of the sessions, you will all have pre-printed position papers. To those who I have cajoled, flattered, bullied or downright insulted into preparing them could I publicly display my sincere thanks and appreciation. These will be briefly introduced by their respective authors; then equally briefly commented upon by the session rapporteur who will, I hope, point up areas for discussion into which we can all pitch.

Before I close I would like to record our thanks to our hosts, Leeds University. I am looking forward greatly to this conference, which I hope will be both critical and constructive, open-handed and open-minded, and not I hope too solemn. I would like to think that by the end of the week we have made some real progress to seeing our way through to developing computer based learning to a point where it may have a truly significant impact on our educational systems of the future.

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1 'Computers for Education', NCET Working Paper No 1 Councils and Education Press, London, 1969

2 'Computer Based Learning Systems; a programme for research and development' National Council for Educational Technology, London, 1969

3 'Computer Based Learning; a programme for action' National Council for Educational Technology, London, 1969

DISCUSSION

Launching the proceedings Mr. K. Hill, who with Mr. I McMullen led the team that carried out the analytical study on which the National Council based its proposals, spoke of the rationale behind the approach taken in their report 'Computer Based Learning Systems – A programme for research and development' (NCET, 1969). This was to view computers in education against the whole achievement in education and to consider their potential use by a subjective projection of what might be developed both technologically and educationally. Secondly, they examined the consequences of problems and decisions that would arise from the development, both in the UK and abroad, of the use of computers in education, and derived the nature and hence the likely cost of development both to meet particular educational aims and for a minimum defensive strategy.

Very limited use of the computer was foreseen at present in education up to the age of 16 years except possibly in the computer managed instruction mode. Post-16, and in adult education and training, its use was foreseen in courses with logically structured content and where its simulation and problem solving facilities could be valuable. However careful curriculum analysis was a first essential to determine the place and kind of contribution the computer could make and it was an essential pre-requisite to view the computer as a component of a learning system.

As a result of their analysis of the relevant social and economic criteria Mr. Hill and his co-workers had put forward an outline R & D programme in two main parts: a short term programme aimed at gaining a perspective about the application of computers to education, and incidentally helping to meet immediate educational needs, and a long term programme aimed at exploiting computers and associated technologies to meet the educational needs of the nation and prepare a defence against any threat to educational values by commercial or foreign dominance in this field. The recommended short term programme should concentrate on the development of CAI/CMI courses, mainly in service subjects, in universities utilizing in the main existing computer installations, and that this programme should be centrally organized and coordinated.

In their subsequent submission to Government, the National Council for Educational Technology, while agreeing generally with the underlying philosophy of the study team's report and their analysis of the situation, had taken the view that the R & D programme should be more broadly based, and this was regarded by many as dissipating the available resources too thinly. This point was taken up again in the concluding session. Meanwhile there were a number of criticisms of the feasibility study. In particular it had taken no account of experimental psychology. In accepting the psychologists' role in educational research Mr. Hill did not consider that a psychologist on the team would have added very much. In his view the rate of advance of psychological insight into the learning process was insufficient to allow of an end result in a finite time, and would probably mean that psychological investigations would in the main have to be outside the scope of the short term 'perspective' programme.

On the question of using existing computing resources there was much argument in favour of experimenting with smaller, modern machines rather than with the obsolescent KDF9's, but here again there was insufficient evidence to specify precisely what was required of the computing system and any any formulation decided on today was likely to be outdated by the time implementation was a practicality. Doubts were also expressed as to whether the sums proposed which should be spent on R & D were sufficient, bearing in mind the considerable investment the USA was making in this field. The answer here was that there was at the moment an inadequate basis for investment. Although there were considerable claims for the computer by experts, what insight did they have and was this commendable enough to persuade the policy makers? The object of the 'perspective' programme was to provide a sound basis on which future, and more substantial, investment might be made.

SESSION II

HARDWARE AND ENGINEERING PROBLEMS

TECHNICAL CONSIDERATIONS IN THE DESIGN OF A CAI COMPUTER SYSTEM

E.N. Adams,
Research Division, IBM, Yorktown Heights, New York.

SOME PROCEDURAL LANGUAGE ELEMENTS USEFUL IN AN INSTRUCTIONAL ENVIRONMENT

Gordon Lyon and Karl L. Zinn,
Center for Research on Learning and Teaching,
University of Michigan, Ann Arbor.

A COMPARATIVE STUDY OF LANGUAGES FOR PROGRAMMING INTERACTIVE USE OF COMPUTERS IN INSTRUCTION

Karl L. Zinn,
Center for Research on Learning and Teaching,
University of Michigan, Ann Arbor.

DISCUSSION

Rapporteur, Captain G. Huggett

TECHNICAL CONSIDERATIONS IN THE DESIGN OF A CAI COMPUTER SYSTEM

E.N. Adams
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I. GENERAL INTRODUCTION: CONSTRAINTS

This paper is a discussion of technical characteristics of CAI hardware and programming systems in relation to present or foreseeable future developments of CAI. The aim is to enumerate and put in perspective major considerations that might influence the inclusion of given capabilities in the specifications of a CAI system. No attempt will be made to deduce a relatively unique set of system requirements as, for example, through analysis of the cost-benefit tradeoffs between what is desirable in terms of psychological, educational, and social considerations and what is, or can be, available in terms of state of the art, technological development, and practicalities of support of operational instruction; indeed in the present state of development of CAI the future costs and benefits are still to a considerable extent hypothetical.

The starting point for the design of a CAI system is the set of external constraints imposed by the larger environment in which the CAI system is to operate. Such constraints derive from the purposes of the institutional sponsor of the project that will operate the CAI system and the amounts and types of resources available. A primary constraint is likely to be the computer system to be used, its associated equipment, its satellites and terminals, and its operating system environment. A second set of constraints is the aggregate of courses and services that must be furnished, the operational loads of various kinds, and the schedules and the physical locations of the users and terminals. Finally, there are such constraints as the kinds of staff available for system maintenance, development, and operations, and the administrative organization and division of labor within the system.

Trends in Equipment

Disregarding what might be most desirable from the viewpoint of CAI methodology, the systems capabilities being developed in connection with general time-sharing and remote entry techniques seem likely to provide the frame of reference within which most CAI systems will be developed in the near future. Within that framework we can project the characteristics of equipment to become available in the next years. For convenience we will review these under the headings of terminals, CPU/OS environment, and application programs.

Terminals

A number of types of terminals have been used successfully with one or another kind of CAI. Each has generic physical and logical characteristics that determine what kinds of instructional techniques and/or systems configurations it is suitable for. We will enumerate a representative set of such terminals and review them in relation to the following:

limitations of input messages
limitations of output messages
remotability
special advantages or disadvantages

1. Teletype. Remotable; uses low cost lines; both input and output messages are alphameric, prints in a single case font.

2. Telephone with touch-tone attachment plus voice answerback. Remotable; input messages are keyed alphameric; output messages are voice messages transmitted through an ordinary telephone circuit; advantage is a very low cost terminal with a developed distribution system in place; disadvantages are lack of hard copy records; costly central system features, limited flexibility of output messages.

3. Two-case typewriter with changeable print element. Similar to teletype, but is more flexible in a multiple application CAI system because of capability to quickly change symbol sets.

4. CRT-keyboard. Sometimes called a 'soft typewriter,' both remotable and non-remotable form; input and output messages normally in single font of alphameric. Advantages over printers: lends itself to font expansion at extra cost, in which case simple graphics may be displayed; erasure is possible, a light pointer attachment may be used as an auxiliary input, display format is much more flexible; disadvantages are a relatively small field of output that may be viewed at one time, look-back is usually costly, no permanent output copy.

5. CRT with keyboard, light pen or RAND tablet, and vector graphics. Not remotable, except at great cost of speed or bandwidth; all capabilities of soft typewriter; in addition input messages can include analog data in the form of light pen strokes, output messages can include depiction of relatively complex curves, graphs, display of functional relationships; disadvantages, high terminal and system costs.

6. Electronic blackboard with keyboard, light pen, and stored images superposed on CRT display. Not remotable except at great cost of speed or bandwidth; output display is a composite of stored visuals and digitally generated information; input can include touch pointer that refers to this composite; has special convenience advantages for programming of simple learning tasks; also the composite image permits unique learning tasks; disadvantages, high terminal plus system hardware cost.

7. Plasma tube display with stored visuals. Functionally similar to the electronic blackboard, but at a lower cost; as a storage device presents different addressing, reading problems

from the CRT.

8. Random access, visual projector. Sometimes a supplemental display attached to a printer or CRT terminal; with touch sense capability it can stand alone; remotable; advantages are low signaling rate; disadvantages are limited message set.

9. Random access audio output. Supplementary to printer or CRT display; advantage; low signaling rate; disadvantage; randomly selected audio messages are relatively few in number and/or accessed rather slowly.

10. Other analog attachments can be used as terminals or terminal attachments. Advantages are special functions that can be realized; disadvantage is relative inflexibility; most useful where the specialized equipment can be amortized over many students.

Certain engineering considerations are fairly fundamental in connection with communication between CPU and terminal.

Data Rates

Maximum input data rates for keyed devices are in the range 10-30 bits per second; thus in principle many keyboards could be multiplexed to use a single voice grade telephone channel as a link back to central.

The output data rate required to service a terminal depends both on the average size of the messages sent to the terminal and the form in which the message is transmitted. In existing CAI work output messages might range from less than 100 to 5000 bits in length if transmitted in *symbolic form,* with 1000 being a typical value. If transmitted in analog form, these same messages would consist of 1000 to 50,000 bits and thus are a factor ten larger than when in alphameric form.

The actual loads on the communication channel depend on the frequency with which such messages must be sent, which depend, in turn, on the instructional design of the CAI program. I do not have good statistical information with which to characterize message lengths and frequencies in CAI programs, so I can only offer my personal impressions. Student response times range from a few seconds to a minute, and bear some crude relation to the complexity of the student tasks; as a rule of thumb one can estimate the total student response time as several seconds for each character keyed for very short responses to about one second for each character keyed for long responses. In a similar spirit we may adopt the rule of thumb that the number of characters displayed in an output message ranges from one to five times the length of the student response. (There is, of course, no effective upper limit on the length of output messages if one uses the computer to print out lectures or multiple choice tests.) Combining these rough rules we can estimate that the mean two-way load on a data link is a few dozen bits per second when messages are transmitted as alphameric symbolism; and about a factor ten larger for those parts of the message transmitted as video bits.

Remoting

When terminals must be located far from the CPU, the need to economize on the communications facilities becomes a factor in computer system design. Communication is most often by means of the commercial telephone system voice channels, often on a single terminal per channel basis. Since, however, a voice grade telephone channel will transmit up to 9600 bits per second, in principle it could accommodate a load up to 100 terminals. Thus, where communications distances are large enough, it may become worthwhile to provide multiplexing equipment so that a cluster of terminals can be serviced via a single voice grade channel.

Remoting of typewriter type terminals is straightforward. Remoting of CRT type terminals involves a variety of considerations, depending on how the symbols or other figures displayed are generated and depending also on how the CRT display is regenerated from scan to scan.

In the simplest CRT systems, which use a raster scan, there are actually three processes to be considered: the generation of the video representation of a symbol from its symbolic representation, merging of the individual symbol video into the video for an entire raster, and the process of retaining the information to recreate a display from one CRT scan to the next. The video for an individual symbol may be generated by a table look-up procedure either in the CPU or in any of several types of read only memory located at or near the terminal. The merging of the individual symbol video into the raster video is an electronic procedure done in the terminal. The information to 'refresh' the CRT on a new scan may be retained in symbolic form, in which case new video must be generated for each scan, or it may be retained as video in some kind of synchronized memory, e.g., a delay line or rotating magnetic store.

Remote location of the terminal interacts unfavorably with those system organizations in which the CPU is involved in creating the video, to the extent that it requires a high bandwidth connection between CPU and terminals. Assuming high bandwidth is not available, CPU generation is not practicable unless a slow average rate of video generation is acceptable, and the video for 'refresh' is stored at the terminal.

Special Fonts

The need for special or extended fonts is very common in CAI applications. Language, mathematics, and the sciences, all generate needs for special alphabets or special symbols. With printer type output devices special fonts can be achieved by use of special printing elements; extended font size, however, is essentially impossible.

With CRT type output devices several possible approaches of achieving an enlarged font may be considered, depending on the engineering means by which the CRT displays are generated and maintained. If the means of providing the enlarged font is very costly, it may need to be shared among a number of terminals; thus when large font size is achieved by a *hardware* approach, one must then multiplex the expensive equipment that generates the video symbols; when it is achieved by a CPU software approach, one must arrange to have a single high bandwidth channel service many terminals, and possibly also arrange for a single video regenerator to serve many terminals; when it is achieved by a satellite CPU approach, the small satellite CPU is shared among many terminals. When the physical distance between the computer and the terminal is large (100 miles, say) so that it is too costly to provide video bandwidth channels to individual terminals, the high bandwidth channel must be multiplexed; in such cases the technical approach to generation of displays and regeneration of displays clearly interacts with the multiplexing extending scheme.

Hard Copy

In many situations it is important to have a simple means of preserving protocols of student performance at the terminals. With printer output technology this is reasonably straightforward to do. With CRT output technology there is no solution that appears to be practicable and fully satisfactory: system log records do not provide a convenient means of reconstructing what was displayed; photography and facsimile are neither convenient nor economically feasible.

CPU/OS Environment

Perhaps the single largest constraint for the typical CAI user is the computer system. We expect that the typical system of the future will be a time-shared multi-terminal system. We envision a system having a fast memory of at least moderate size (> 100K bytes), a rather large (hundreds of millions of bytes) amount of disk-type fast access storage, multiplexing and transmission control units as appropriate for its terminals, and various other system components as necessary to operate such a system.

As important as the hardware capabilities of the computer system is the Operating System (OS) environment that it provides. The OS provides the programming system that manages the machine. It schedules all CPU operation. It allocates all system resources. It provides the interface through which programs communicate with terminals and satellites and also with the peripheral storage. Thus the OS provides the communication interface between a program and all of its sources of data, and determines when and whether the program will be executed.

Important constraints are implicit in the languages and procedures provided by the OS for requesting the execution of jobs. Thus the conventions of requesting a job are based on some view of what types of request are routine or typical, what types are non-routine or unusual, what types need not be or cannot be processed at all. Priority procedures in a system are based on a view of how a system is normally operated, what kinds of users there are, what are the responsibilities of various users, etc. The designer's conception of the user that is implicit in the OS, thus has a strong structuring effect on the user.

The OS environment is determined not only by the characteristics of the supervisor but also by those of what we may call the subsystems under the supervisor. For this purpose a *subsystem is a set of routines that control entry and re-entry to a class of programs.* Since the rules for controlling entry to programs are related to user prerogatives, each subsystem may be thought of as associated to, or as defining, a particular class of user. Specific to any subsystem are routines to validate sign-on requests and secure necessary files, effect proper updating of records at sign-off, and error-handling routines.

Important subsystems in a time-shared CAI system include subsystems for use by system programmers, operators, and administrators, a subsystem for application programmers, a subsystem for execution of general applications programs, a special instructional monitor or interactive CAI subsystem.

Below the subsystem level there are *programs. A program is a set of routines that performs a well defined job.* Just as subsystems correspond to users, programs correspond to user services. Among the programs necessary or desirable to have would be, a meta-compiler, a macro-compiler, a number of compilers associated to the various processors available to run under the system, a file manipulation program, a statistical analysis program. Processors might include one or more languages like FORTRAN or PL/1, a conversational interpretive language like BASIC or APL, a statistical processor, a list processor like LISP or SLIP, a CAI author language, special course compilers, etc.

Courses

A last major set of constraints on the design of one's system comes from the courses in which CAI is to be used. While in principle the decision to use CAI in a given course might be thought of as a purely pedagogical one, in practice the decision is arrived at through a process involving many other kinds of considerations, although presumably CAI would be decided on only where it is pedagogically feasible.

Broadly speaking the courses to be taught will be constrained by some set of given instructional objectives, to some part of which CAI methodology is applicable. The overall instructional plan will ordinarily involve the use of resources in several media of which CAI is only one. The plan of how the various learning objectives are to be allocated among the various media and how the media are to be articulated will probably be designed to optimize the use of media resources while meeting pedagogical objectives, rather than merely to optimize pedagogy.

In courses that use a variety of media, the media units will ordinarily have to be packaged in modules of somewhat arbitrary size for logistical reasons: if a learner is to be scheduled on the machine, he must be assigned a quantum of work large enough to avoid excessive losses of student and machine efficiency through various overheads such as student travel time, proctor operations, tardiness, machine time unused because students finish early, etc. This modularization, too, is an external constraint in that it is not generally derivable from pedagogical considerations alone.

II. INSTRUCTIONAL CONSIDERATIONS

The kind of external constraints discussed above define the frame of reference within which a CAI system must be designed; what to do within that frame of reference should be decided on the basis of psychological and pedagogical consideration. Fundamental among these considerations is the nature of the learning process.

The concept of learning as a process of operant conditioning is especially useful as an approach to instruction in that it suggests principles of design for learning programs that are largely independent of the underlying physiological mechanism of learning. The basic model of operant conditioning is:

1. The learner engages in a range of behavior.

2. The environment responds; the topography of response corresponds in some sense to the topography of the learner's behavior.

3. Perceiving the topography of environmental response, the learner is able to assign different values to different variants of his behavior.

4. As the cycle of behavior and response is iterated, behaviors of high value occur with increased frequency.

The differential response of the environment to different behaviors plays a central role in the shaping of operant behavior. The learner learns to differentiate between two behaviors only if some contingency in the environment differentiates between them. One may say that what a learner learns about an environment is precisely its system of behavioral contingencies.

Consonant with this view of learning, instructional design can be approached as the design of a special learning environment in which the contingencies of reinforcement are designed to select and enhance the behaviors that are the goals of instruction. Thus a learning environment is to be designed about the particular class of behaviors it is intended to shape.

The basic building block of a learning environment is the learning task. A learning task is a stereotyped synthetic activity with arbitrary conventions, rules, and objectives. Its principle of design is to create a situation that demands the intensive exercise of a particular behavior on which the contingencies of reinforcement directly depend. The learning task is in effect a very specialized communications medium. Its rationale, rules, etc., narrowly limit what is communicated about and what kinds of messages are exchanged, and create a set in which relatively simple stimuli suffice to communicate a complex topography of response.

The nature of a learning activity may be more or less artificial, depending on the extent to which the behavior being developed is a subskill of the final behavior or a rough approximation to it. In any case the learning task itself has content and involves behaviors that are irrelevant to the final instructional goals, but are necessary for purposes of doing the task; examples of such secondary skills are the use of a keyboard, the format rules of messages, the procedures used in a test administration. Irrelevant as these secondary skills may be they are part of the instructional content, in effect an overhead associated with the use of the learning task. A great amount of student difficulty may be caused by the failure to give enough attention to the design and communication of this kind of content; conversely a major advantage to the iterative use of learning tasks of stereotyped form is to minimize this type of overhead and to achieve good secondary skills on the part of the learner.

Since the effectiveness of a learning task depends on the efficiency of communication it achieves, the focus of learning should be narrow; the learner should not be required to give significant attention or effort to behaviors irrelevant to the instructional goals; and the quantum of learning should be kept small enough so that environmental stimuli can be properly and confidently evaluated by the learner. At the same time the environmental stimuli should be rich enough to convey the appropriate topography.

The keys to the effectiveness of a learning task are three:

1. Stimuli to evoke and reinforce the behavior in question.

2. Means to sense and evaluate the learner's behavior.

3. Algorithms of control to select appropriate stimuli.

A learning program leading to a relatively complex final behavior will commonly consist of the iteration of a single learning task with a continual change of content. Several levels of valuation are likely to be needed in such a case: message processing, task valuation or scoring, valuation of learner state, valuation of learner performance over various periods of time.

Conventional instructional systems depend on humans to carry out the crucial functions of response valuation and/or stimulus selection. Where learning tasks can be devised that use a computer terminal, interactive CAI could *in principle* take over the valuation and/or selection functions if a task valuation algorithm and an algorithm of control can be made. Numerical valuation systems, i.e., scoring systems, are of special value and importance because they lend themselves to mathematical modeling.

It is useful to think of a CAI program as having three separate aspects, which may or may not be clearly articulated in the code. We will refer to these aspects as the *content,* the *communications media (mediation* for short), and the *control* aspects. The content aspects concern the scope of knowledge, behavioral objectives, the sequence of learning tasks, etc. Mediation aspects concern the articulation of media, mechanics of learning tasks, message processing, stimulus generation, etc. Control aspects concern scoring, indices for valuation of the state of learning, criteria of allocating effort, etc.

It is sometimes possible to structure a CAI program so that material relating to each of these aspects is localized in its own separate section of the code. Such a program structure, when it can be achieved, has a number of desirable features, including ease of preparation and revision, and ease of dissemination. A further step in the same direction is the separation of the control programs associated to the learning task into two parts, one which is concerned with message processing, task scoring, and stimulus selection or generation, and a second associated to higher level control, which is concerned with criteria of mastery, indices of mean performance, sequencing of learning tasks, modules, and lessons.

Where valuation must be applied to a complex topography of behavior, task scoring can be multi-dimensional. Correspondingly where it is necessary to construct stimuli that display a complex topography of response, a multiplicity of scores can be combined, as in a multifactor regression formula, to specify values of a number of control variables. For operational reasons it is convenient to cast such multifactor valuation and control algorithms into forms in which adjustable parameters provide means to control and alter the algorithms; a simple example is a scoring formula in which various factors or criteria are combined in a weighted average, the weights being adjustable by the instructional supervisor.

The extensive use of numerical scoring and numerical indices of control facilitates the use of program structures in which response processing routines are clearly separated from the learning task control routines. Programs so structured are relatively simple to prepare. They also provide operational flexibility, since the instructor can readily change the content of a parameterized exercise without changing the algorithms of scoring and control, or conversely these algorithms, but not the content.

A parameterized control program of fixed form is a means of adding quantitative dimensions to the concept of instructional method; different materials can be used with the same control program, different control programs with the same materials, relative effectiveness can be studied as function of control parameter settings, etc. Parameters of a control program can provide convenient dimensions along which to optimize the effectiveness of learning tasks; they can also provide an approach to self-adaptive optimization of learning tasks.

Thus far the discussion has been independent of the nature of what is to be taught. However, it is clear that behavioral goals are of considerable variety, and a learning task must be accommodated to the nature of what is to be learned. One taxonomy (Bloom's) categorizes behavioral objectives as effective, cognitive, or psychomotor and, within the cognitive domain, as ranging from fact recognition, recall, and knowledge of generalizations to comprehension, application analysis, synthesis, and inference. To this wide range of types of behavior there must correspond an equally wide range of instructional strategies or learning tasks.

Almost any academic subjects or courses of instruction includes among its objectives a considerable range of variety of behaviors, so normally requires a composite methodology of instruction. In particular most academic subjects involve a range of cognitive behaviors. Thus it is somewhat frustrating to be asked, as CAI workers often are, "Can CAI be used to teach x?" where x may be sex education, science, art appreciation, "you name it." Clearly, the question does not suggest much understanding of the technical problems of instruction. Nevertheless, one cannot just bruskly dismiss anyone who asks such a question, especially not when he is a Very Important Person; one must somehow give an answer if only in the form of a discussion.

Clearly the first point to make is that the question could better address the *type of behavior* to be learned rather than the *type of information content* the behavior has reference. Second, it seems that in most academic courses a number of phases are involved – call them presentation, practice, recitation, and test – and CAI is not equally applicable to all of these, especially when the economics of its use is taken into account; thus the point may be made that it may be most favorable to use CAI vis-a-vis other media in the practice and recitation phases, which involve the highest degree of two way communication, inasmuch as CAI is the only completely non-human medium that provides for fast flexible feedback.

Finally, one may make the point that the applicability of CAI to various behaviors is limited by the repertoire of existing or readily constructable CAI learning tasks: one may enumerate some classes of learning tasks to give an impression of what kinds of instructional approaches may be possible:

- rote practice or drill
- application practice
- practice with simulators
- presentation and immediate test
- computation
- program compilation and execution
- game playing, decision making
- enquiry, exploration, experimentation
- dialog
- test and prescription

III. PROGRAM FEATURES

CAI makes use of a number of the subsystems of the time sharing system. The features needed in these subsystems are for the most part similar to those needed for general TS use and may not require comment. However, some of the features at the program level deserve discussion.

Author Language

An important system feature is the author language in which CAI programs are to be prepared. In principle the author language might be any of a number of high level languages. However, in fact the need to execute CAI programs under a special student mode subsystem (instructional monitor) and to execute them with high efficiency, implies that it is advantageous to use a special author language for coding CAI programs. The view taken here is that convenience features of the author language itself are secondary to its functional capabilities. Key functional capabilities include:

Variables
- arithmetic, including floating point
- logical
- alphameric strings
- data structures having programmer specified format
- lists

The *number* of variables needed for a single student's use in a single course is *at least* 10 sentence-length ($\sim$ 100 ch) string variables, several dozen numerical variables, and at least 100 logical variables in the kinds of programs we have worked with. We have sometimes wanted more.

Operators
- arithmetic
- logical
- boolean
- character
- pattern operations on strings/lists (see below)
- special operations on data structures (see below)

Control Statements
- conditional: IF
- iteration: DO
- transfers: GO TO
- subroutine: PROCEDURE

storage allocation: DECLARE
restart point
time dependent transfer
log entry

Macro processor within the author language
Library routines written in other languages
which can be used in author language

A CAI language must provide a variety of message processing functions. Messages may consist of natural language strings, data structures, and numerical or logical arrays alone or in combination.

Important processing operations on natural language strings include:

Definition or detection of substrings
- specific substrings
- fields, e.g., first numerical field
- defined by lists or sets
- defined by context

Transformational processing
- edit, e.g., replace, delete, affix
- re-order substrings
- insert substrings

Tests on numbers or strings (vs. reference string)
- character match
- numerical equality
- numerical range match
- degree of match
- pattern tests (combinations of order and match)
- general user defined test

Processing of data structures is useful in connection with coding for learning tasks of stereotyped form, for which the format does not change over a number of learning tasks. The existence of a macro processor provides for a part of the desired capability. However, it is desirable to have flexible means to form such structures during program execution, and to provide in general a compactness of code that will facilitate rapid execution.

The instruction to make a log entry is one with peculiar significance to educational applications, especially where recording of program status and of the occurrence of particular transactions are needed as a basis for research or developmental analysis of the process. The basic operation required is "write into auxiliary storage a record of specifiable form" when a specified condition occurs in the execution of the program. Logging capability should interact with the capability to call for certain routine statistical analysis in connection with program execution, since much subsequent searching, sorting, and other format processing can be avoided if the records can be put into optimal form at the time they are logged.

Logical processing to detect patterns in stored data may become important as the techniques of utilizing more complicated algorithms of control develop. The capability to manipulate and compare subpatterns within boolean vectors or arrays is very desirable; the capability needed is analogous to that needed for dealing with numerical variables in indices of performance and numerical algorithms of control. The capability to assemble rhetorically acceptable natural language statements incorporating various informational elements under a number of constraining conditions is very desirable for purposes of using natural language messages as stimuli.

Program Preparation

Large amounts of stored program are required to support the CAI portions of a course, typically of the order of hundreds to thousands of bytes of machine code per minute of instruction. The process of creating programs of this magnitude that will be satisfactory in regard both to content and pedagogy can easily be a very costly one.

One line of thought is to accept the intrinsic costliness of CAI programs and to seek means to amortise the large preparation costs over large enough number of students. Such an approach implies a high degree of standardization of both systems and courses, a degree which could inhibit the development of CAI both quantitatively and qualitatively and considerably limit its desirability and utility. Thus the alternative of lowering the cost of the preparation of CAI programs is a very important one.

Several of the early CAI workers have tried to simplify course preparation by providing a supposedly simple and easy-to-use CAI author language. This work has been useful, but to the extent that it has conceived the CAI "author" as a "subject specialist – turned – programmer," it has failed to develop all of the kinds of programming aids that are needed.

To elaborate this point: the process of producing completed CAI programs involves the efforts of several different kinds of professional/technical people, viz., content matter authorities, learning program designers, computer programmers, computer coders, computer operators, and media technicians. Nothing prevents the skills necessary to properly perform all of these roles from residing in one creative person; however, nothing makes it likely that a high degree of all skills will in fact be united in one person, or that it is practicable to predicate the preparation of CAI programs on the availability of adequate numbers of such persons. It would obviously be more desirable if program preparation could be approached as a team process, utilizing a division of labor that permitted various specialists to each efficiently exercise his particular skills and do his part of the job without having to become accomplished in the skills of the other team members.

More important even than the variety and heterogeneity of the technical task required for production of a CAI program is that these technical tasks will not necessarily or even usually be carried out at the same time. Thus the learning task designs used in a particular program will presumably have been largely worked out before a program could be designed around them. Similarly a control program design once established as sound may be used in one course after another. Thus the production of an actual course should be viewed rather as the *integration* of various technical elements than the *creation* of them.

The consequence of a proper division of labor is to achieve an essential independence of the form and the content of the instructional program. When such a separation has been realized, the formal aspects of the program are seen as alone constituting the method or pedagogy. The development of methods as abstract forms is therefore a logically separate activity from the development of courses that use the methods; even when the two are carried out at the same time, they should be conceived as disjoint activities.

Certain earlier remarks in this paper about how a CAI program should be structured were arrived at by considering what features and procedures lend themselves to the division of labor in program preparation. To summarize and elaborate these:

> Content should be prepared in a form independent of code and convenient from viewpoint of a content specialist.
>
> The essential control program to administer a learning task should be localized in a routine; this control program should be free of specific content material, which should be furnished to it at either compile or execute time in the form of a data-structure.
>
> The answer processing and conversation handling parts of the control program for a learning task should be separate from the scoring parts; where appropriate the scoring parts should be parameterized and arranged so that the parameters may be readily changed without any recoding.
>
> The control programs governing higher level (module/lesson course) scoring and selection of assignments should be separate from the learning task programs and from one another; they should themselves be essentially content free except for the tables of parameters and other content data needed for execution of the course.

The concept of a CAI program as an appropriate content in a stylized form, is consistent with the goal that the various members of a curriculum team carry out their individual roles with a minimum of mutual interference or hampering contingencies. The key to the proper coordination of the individual contributions in the production of a CAI program is the production director; like the director of a movie, the production director is responsible for the overall concept of the course and for working out with the other workers the broad lines along which technical problems would be solved.

In order to reduce the production costs of such a CAI course as discussed here a number of programming aids can be utilized. The content specialist can use a special text processor that takes manuscript material prepared in a form most convenient to him and puts it in a form convenient for compiling into a "source" program. The computer professional responsible for compiling the program can use one or more special "course compilers" which actually put the source program together. Each such special course compiler is properly viewed as a special user oriented language; these user oriented course compiler languages are the key to eventual successful CAI production and operation.

The system operator will have an assembler or compiler for producing the program in the form in which it is stored when ready for execution. Finally, an author can make use of a special software that permits him to make an on-line examination of the operation of the completed program, to pass control about in the program at will, and to permit on-line entry of corrections to the program.

In some discussion of CAI the source language for coding programs, the programming aids, and various services available within the computer system as well as procedural and other features of the OS environment are discussed under the rubric "language." It is quite important, however, to produce programs in such a way as to make the final product useful to users of a number of systems having quite different features. For that reason one should analyse the production process so that only the source language processors are needed to make use of the final programs.

Operational Aids

A number of different kinds of users make demands on the operation of a CAI system. As a minimum these include students, proctors, machine operators, and supervising teachers. The needs of these users are to be understood in terms of their duties, qualifications, and normal working procedures.

Proctors

Students should be supervised when using the system by someone capable of making at least minimal judgments about, e.g., the probable source of apparent system malfunction as between terminal hardware, system software, or course software; and of taking minor corrective actions in relation to matters in which fully automatic operation of the system is not satisfactory. Proctors should be responsible for furnishing extra materials, tape or visual cartridges, etc., and of getting various routine reports from the system.

In the interest of effective proctoring as well as operational efficiency, the students should be scheduled into the lab so that insofar as possible a number of students are using the same course at the same time.

To keep proctoring costs in control it is desirable that proctors be limited to tasks requiring only a low level of technical skill and that one proctor be able to supervise a number of students. This in turn requires that terminals be grouped in clusters, the minimum desirable cluster size being the number of terminals that a single proctor can supervise.

Operators

In order to maintain a high level of availability for the system an operator needs a number of aids. He needs to have a convenient means to quickly determine at any time what system services are in use, and who and where the users are. He should be made aware of any change in the system service immediately when it occurs. He should have a schedule of system services expected to be required, with suitable information about required programs and data to be loaded.

The operator should have a number of aids for facilitating quick and clean restart of a system that has malfunctioned.

He should be able to obtain summaries of various user records and should on properly authorized request be able to directly enter needed changes into user records.

The operator needs a considerable number of utility programs for performing such functions as starting, loading program; performing various operations on courses such as compiling, amending, reassembling, etc.; registering, purging, listing records; various control operations to terminals or users; etc. The number of such utilities needed depends on the system design, but is of the order of four to ten dozen in the systems we have worked with. Finally, in the common case that the terminals are at a difficult physical location from the machine, the operator needs a means to automatically answer enquiries about the status of the system at times when service is interrupted or is not scheduled.

Supervising Teachers

Presumably the teacher of a course will not have as much close interaction with the system as the proctors and students, but will require certain information to be saved and summarized for him. The operational needs for summaries are primarily for student status information, statistical summaries of use for course administration, and certain special information such as "comments" that may require short term action.

Where research or program revision are teacher objectives, transaction logs may be needed, generally sorted and categorized for the purpose at hand; in addition in such cases there will be a need for programs to prepare transaction logs for processing by statistical analysis programs.

Students

The kinds of student aids needed in a system are a function of equipment used, supervision procedures used, and the operating procedures of the system. However, in general, students need to be able to get certain kinds of information at any time; status of the system, status of his terminal (is it alive?), explanation of any procedural messages he receives (as, for example, when he has violated a format rule), a very simple means to obtain a complete account of any procedures he is expected to use.

It is desirable that the system have only the simplest procedural rules for students and that it be tolerant of student message formats. In this regard procedures for erasure and cancellation should be simple, and the system should automatically edit to avoid confusion from entry of redundant or ambiguous features of messages (simple example: the space-backspace pair within a message).

Terminal operations should make it clear when a message has been accepted, who has control (student or computer), (on a CRT) where a message will appear if input is made, etc.

The foregoing pages are an attempt to indicate the kind of considerations involved in smooth operations. This discussion is necessarily incomplete and fragmentary; good operations are achieved as the result of good management plus providing a large number of small system features found helpful to adapt the system to its users' needs.

SOME PROCEDURAL LANGUAGE ELEMENTS USEFUL IN AN INSTRUCTIONAL ENVIRONMENT

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INTRODUCTION

Caveat

The instructional environment demands of a programming language features not easily satisfied by any one implementation. Some users will program instructional modules central to the system; these require efficient and probably re-entrant machine code. On the other hand a student may be asked to modify a program or write a new one himself as part of an interaction; in this case an interpreter probably serves better than a compiler. Furthermore, the executive system may itself hinder or preclude desirable elements, such as general classes of files. Such a variety of requirements forces a general discussion into a framework of general features for a hypothetical programming language, comparing existing languages against the paradigm.

Of six languages considered here (Table 1) some are compiler-implemented, a few are specifically interactive and well-suited for student use, three are powerful enough for systems-modules, one is an extention of a common scientific language (Fortran IV), and one is the latest (probably last) 'super-language' (PL/I).

Table 1. Short Summaries of Languages Discussed

PL/I:	the newest widespread compiler language – it will probably replace FORTRAN and perhaps COBOL.
APL:	designed by K.E. Iverson, it is an unusually concise and powerful programming language, best suited for algebraic-like problems but extendible via routines.
CATO:	from the University of Illinois is an extended version of FORTRAN IV – especially for programming instructional use of the PLATO system.
BASIC:	the fairly standard and very simple interactive language prepared originally for a G.E. 235 by Dartmouth College. Both compiled and interpreted versions now implemented.
PIL:	Interpretive interactive language modeled after JOSS.
STRINGCOMP:	LISP-like features for string manipulation have been added to a parent language (TELCOMP) which was modeled after JOSS.

Problem-Oriented Languages

The reader may ask, why emphasize procedural features, especially in light of the great number of special (or problem-oriented) instructional languages available. Admittedly there is a multitude, and this very number is the first reason for exclusion since they have proliferated with only superficial differences. Secondly, problem-oriented languages often and in varying degrees reflect the overpowering influence of individual project needs. An outside observer may detect a passive element in the system designer's implementation: The user got *exactly* what he asked for, with little or no examination *if* such approaches were – in the long run – suited for a computer environment for instruction. For example, a design may mimic a frame-by-frame teaching machine, ignoring more splendid possibilities which the customer – unfamiliar with computers – would not have thought to ask for, but which the implementer should have suggested.

Instructional Demands on a Language

Instructional application of computer resources demands its own, distinct set of language powers. The lesson designer is concerned with display information, user input transactions, string manipulations, a data base which may be shared among users, sequence execution, data recording and manipulation for both learning strategy and teacher/author examination, interactive terminal resources, coding convenience and power, supervisor resources and flexibility, and system accessibility.

Procedural Elements

It is of little use to further enumerate instances of specific aspects suggested in the above paragraph, especially if we are trying to stipulate some exact programming mechanisms which will be useful. Specification of functional elements of a language by showing possible instances of use often belies a vague or hastily drawn feature. To avoid overlapping mechanisms in a language some attempt should be made to invert the process: Given a set of functional requirements, what is some small number of language primitives which will meet those requirements; what more can be readily provided, and is the package truly adequate? Having done this for a good number of instructional demands, we conclude that the set of primitives stabilizes rather fast.* The next sections discuss such primitive features while concurrently describing in tabular form related aspects of six currently used instructional languages. The primitives of the hypothetical language are, then, desiderata for contrasting these six languages.

* Various instructional demands are listed in Appendix A.

PROCEDURAL LANGUAGE ELEMENTS IN AN INSTRUCTION ENVIRONMENT

The Basic Choice

Even the recent deluge of problem-oriented computer instructional languages has scarcely disturbed the position of the general-purpose programming language in the field; abandoned by computer users, and non-procedural languages are usually quite inflexible. Against the limited-purpose convenience of the non-procedural or problem-oriented scheme, the general-purpose approach would pit a select, powerful core of basic computer transactions and possible logical organizations. It is then up to the installation and the individual user to fashion those procedures which will best serve them. Specific requirements of tomorrow's users are often – indeed usually – unpredictable today, and this is where a problem-dedicated language can come to grief.

Many general-purpose languages have found their way into computer instructional schemes. Iverson's APL is a concise, flexible and powerful algebraic language; BASIC developed at Dartmouth, is almost a standard in the area of very simple, interactive languages. CATO is an augmented FORTRAN IV prepared for the PLATO System at the University of Illinois, PIL, the Pittsburgh Interactive Language, is an elaborate version of JOSS; STRINGCOMP (an extension of TELCOMP) is BBN's version of JOSS with some LISP-like string operations. For a longer list with brief descriptions see Appendix VI of "A Comparative Study of Languages for Programming Interactive Use of Computers in Instruction", available from EDUCOM, 100 Charles River Plaza, Boston, Massachusetts.

Emphasis of this Discussion

As a starting point emphasis will be given to aspects which bear directly on the known problems in instructional use of computers. For the most part, instructional uses demand nothing particularly unique in interactive systems, but the requisite features are not generally available in older languages which have their origins in pre-timesharing days, Standard elements of procedure statements, such as assignments, control branchings and 'IF–THEN–ELSE's, are simply assumed here. Those features which are discussed we consider especially useful in the instructional environment. These elements do not comprise a universal programming set, but rather, shed a little light on rudimentary features which can be assembled into useful instructional modules. Appendix A lists some instructional requirements.

Names, Data Representations, Variables and Storage Acquisition

DATA. Clearly a language such as FORTRAN IV used alone is quite inadequate for programming most instructional applications. One serious omission is the character string, which in conversational application is pivotal in providing flexibility and succinct code with a modest programming effort. Of course arithmetic is necessary, if for no other reason than to do file analysis and data reductions. List-structures would relieve programming agony in many simulation and inquiry applications; the pointer capability of PL/I provides a rudimentary feature for programming manipulation of lists. The pointer is intimately tied to dynamic storage allocation which is discussed later. Ideally the pointers should be relative indices, i.e., relocatable, but even the absolute addresses would be useful.

Table 2. Identifiers, Acquisition Data Representations, Variables, and Storage

	PL/I	APL	CATO	BASIC	PIL	STRINGCOMP
Identifiers (lengths)	Up to 31 characters	Up to 6 chars. on 1130 unlimited in APL/360	Standard Fortran Names, but also some reserved Fortran	Usually 2 chars. with restrictions	Up to 8 characters	Up to 6 characters
DATA REPRESENTATIONS (arithmetic)	extensive, with conversions avail. from one type to another	there are many powerful operations available. A desk calculator mode exists		a scientific repetair, adequate	adequate. A desk calculator mode available	yes with desk calculator
(string)	limited string lengths, and no pattern matching	could be flexible if built-up from more primitive elements	special string features useful in instructional programming	adequate, no pattern matching	adequate, no patterns	especially designed for CAI string manipulation
(pointer)	yes, but are absolute addresses	no	no	no	no	no
VARIABLES (label)	yes	standard labels are not mnemonic, but optically can be	no	no	yes	yes
(array)	yes	yes, limited	yes	limited	yes	yes
(structure)	yes	no	no	no	no	no
(scalor)	all →					
(event)	yes	no	no	no	no	no
(file)	yes	not implemented	yes	yes	not on some implementations	?
STORAGE ACQUISITION	static automatic controlled based	the allocation is automatic	static (Fortran-like) and also allocation available for re-entrant modules	static, but arrays dynamic	automatic	automatic

NAMES. Identifiers should be practically unrestricted in length, since there is no implementation problem and the mnemonic worth is there. However, since one does not relish typing a 37 character string each time he references a variable so named, an alias declaration would ease life by equivalencing an identifier and its 'nick name', treating both as one and the same reference.

VARIABLES. The usual variable types should be available along with some found now in PL/I. Aggregates of mixed data types form structures. Structures are very useful, e.g. in reading – without format – records from a file into core. If the structure is composed of the same data types as were originally placed in the file record, then the record need but be read into the structure and each field is instantly available without performing a laborious decomposition and conversion of the file record. Another useful item is the entry-point variable, allowing selected invocation of procedures.

STORAGE ALLOCATION. Static variables are given storage locations and initialized at load time. Dynamic storage may take a number of forms: PL/L has automatic, controlled and based. Automatic allocations are made and freed with each block entry and exit as in ALGOL 60. Controlled storage is stacked and popped as requested by the program, and the new stack entries need not be the dimensions of the other stacked allocations. List structures are built up from based storage: at the time of allocation a variable is given the address of the block of storage acquired. A knowledgeable user can build whatever list-structure he wishes from successive allocations.

Introducing dynamic 'GET' and 'FREE' statements into the language, e.g.
GET (X,Y,Z) BINARY FIXED (31) ARRAY (1 : 12);
we can dispense with static, controlled, based, and other distinctions. Dynamic variable typing and dynamic allocation (via GET/FREE) work nicely by stacking or popping incarnations of a variable. For lists one needs a LOCATE (P,X) function to set the pointer P to X's storage block, and a deep-reference facility for the stacked allocations of any one variable is very attractive. Thus:

X = X/–2/;

sets the present value of X to the third-down in the stack. (The one created 3 GET's ago.)

GET and FREE statements determine the scope of variables as does the <block> in ALGOL-like languages, and to this extent we do not need <block>'s. Furthermore, the late binding times, both in variable types and storage allocation, make GET and FREE especially suited for an interactive environment.

Files and Input/Output

PUBLIC AND PRIVATE FILES. An instructional language should include facilities to read and to write in both private and public files. The public files will serve – among other things – to collect run statistics of various users or programs. The files should be flexible and simple to reference with statements in the language. The public files, for example, could includ assorted directories which would (automatically) be used the help reference and analyze associated entries. Suitable file lockout and password mechanisms must be provided along with sequential and keyed access methods. An additional feature, not in the base language but built from it, is a flexible file editor.

INPUT/OUTPUT. Whatever input/output facilities are provided will probably always be inadequate. The specialized and varied I/0 requirements of instructional programs preclude attempting to incorporate everything into the language. Borrowing from PL/I, we might include data-directed input – i.e. an input stream in the form . . . A = 4, BM = 2.1, Z = 65.67, . . . – where the variables are named in the input stream; and list-directed where input values

. . . 3,4.2,8965,3.14159, . . .

are matched to correspondents in the read statement READ I,X,J,PI. Lastly, a formatted input should be available similar to the formatted reading in FORTRAN. If large volumes of data are transmitted, implementation efficiency is gained by allowing unformatted RECORD transactions – the raw data simply are placed in some core buffer which is perhaps a structure.

Processing of strings should remain separate from input. Also, the language should give appropriate control over I/O and conversion mishaps. (See below.)

Table 3. Files, Input/Output

	PL/I	APL	CATO	BASIC	PIL	STRINGCOMP
FILES	an extensive collection of file types, including sequential, and keyed.	files are in the original Iverson language, but have not yet been implemented	has restricted system files for recording student performance	varies with implementation, usually no public files	again, some implementations offer no files. However is in original language	can store a program in a file
FILE ACCESS PROTECTION	lockout mechanisms provided in full language			user's ID determines accessibility in some systems		passwords
INPUT/OUTPUT	wide available range. RECORD– unformatted STREAM– data directed list directed edited	there is a simple automatic I/o or can format into complex displays	here is an example of I/o especially taylored to CAI. Has PLOT, READ, SLIDE, AUDIO, and similar commants	simple I/o or format controlled if desired	both free and formatted options available	free and formatted plus PLOT feature for effortless graphs

Statements and Modules

PROCEDURES. Compound statements and ALGOL-like blocks provide conceptual convenience for the programmer. Procedures types should include both internal, i.e. sharing names with other program elements, and external – compiled separately. Generic procedures allow standard calls for syntactically distinct sets of arguments and are quite useful. Co-routines are procedures which have a 'restart' capability as distinct from the usual call. The checkpoint feature which stores crucial activation information of a co-routine should be optionally controllable; in this manner a procedure could be 'saved' at various progress points and later begun selectively at any such 'save' point. Not surprisingly, synchronized procedures are easily written if each is a co-routine calling the other.

TASKS, PARALLELISMS. PL/I has "tasking". where the main procedure spawns a procedure which then runs asynchronously from the parent. As an example, some aspects of a student's answer may be given a thorough scrutiny by a task while the main procedure continues the usual dialogue with him. Since both main program and task may be awaiting execution or executing in parallel processors together, some method of synchronization may be required if the process is to rejoin paths. In PL/I the WAIT (EVENTNAME) functions in this capacity, holding execution until the task called EVENTNAME is done. The statement AND could also effect a fork in the control path, to be followed by a JOIN which signals confluence. For paths which do not rejoin, the command ALSO would do.

Interrupts

PL/I introduced to the general computing community controllable interrupts for error and global program control, and there is little reason to abandon this valuable feature. Furthermore, the idea of SIGNAL enables the programmer to simulate an interrupt and so capitalize on the global properties of the interrupt mechanism. The block of code executed with a given interrupt should ideally allow 1) arguments, 2) examination of crucial variables, and 3) optionally allow resumption at or beyond the point of interrupt. Unfortunately these stipulations may lead to undefined quantities; it is not clear they are worth the effort.

Table 4. Statements, Modules, Extensions, Code

	PL/I	APL	CATO	BASIC	PIL	STRINGCOMP
STATEMENTS (form)	FORTRAN-like	have strong algebraic flavor	FORTRAN plus extra forms for CAI			
BLOCKS	ALGOL-like with local variable	internal routines may have local variables	program unit	program unit has overlap feature via CHAIN	PART's function as blocks	PART
PROCEDURES	internal, external, generic, and recursive		FORTRAN convention with some reserved words	has simple and compound functions, internal subroutines	DO PART	functions are only single statements
INTERRUPT CONTROL	via ON . . , statement may signal interrupt via SIGNAL	no	may checkpoint program so other programs can run			
EXTENSIONS	pre-syntactic text macros, also run-time mapping macros	via routines and functions	could probably be further extended as has been already	not much hope	perhaps the PART element	
RE-ENTRANCY	yes?	yes?	yes	yes	yes	no?
RECURSION	yes	yes		yes	yes	was designed to teach recursion

Other Points

A useful feature is interface facilities with other languages, especially an assembly language. Because macros offer extensible features which allow fruitful language experimentation, the language should incorporate a macro facility. For example, template macros allow disguised routine calls while checking arguments for correct syntactic type, as in:
WHENEVER A OR B IN STRING, RANGE IS (5, 7)
for the routine SNORT (A, B, STRING, 5, 7) by using the macro definition
TEMPLATE: 'WHENEVER' 1/real/ 'OR' 2/real/ 'IN' 3/string/ ',RANGE IS (',4/int/',5/int,')'TEMPEND;
BODY: 'CALL SNORT ('1', '2', '3', '4', '5')' BODYEND;
The macro checks the types of its arguments and then substitutes them into the body text. All text is enclosed in single quotes. A further example may be found in Appendix C. Additional desirable implementation are 1) re-entrant code, and 2) recursive procedures.

Summary

Obviously nothing mentioned in this framework is really new. Indeed, in instructional computer usage – like so many other applications – there is a need for a wide variety of language powers and almost all of them have arisen before in some other application context. One simply borrows what is needed. In this case, mose of the lending was by PL/I.

THE LANGUAGES

Among the languages considered, BASIC, PIL, AND STRINGCOMP are all similar interactive languages which are

1. easy to use
2. simple to learn
3. fast for debugging small programs.

For student programming and learning, or for a modest research effort, these three languages definitely have something to offer. STRINGCOMP and PIL are stronger in string operations – something to keep in mind.

An actual (production) teaching system should use a compiled language for running efficiency. Within this class, PL/I is one of the newer and more powerful, borrowing as it does from ALGOL and COBOL while trying to look like FORTRAN. And the vast spectrum of programming elements available – the data types, for instance – lend to it an attraction unmatched by any other in this group of six languages. For one who wants to extend a current language for instructional use the details of CATO – viz. intended FORTRAN – should interest him. Here the base language is very well known; the programmer need spend only that time necessary to learn the new features before going to work. Furthermore, since FORTRAN routines are compatible in the system, a system development could be broken into segments, some of which are pure FORTRAN and therefore accessible to regular FORTRAN programmers.

Elegance is APL's calling card. It is concise, powerful and extracts some effort from the would-be user. Having worked into the intricacies, one might very well claim – as many do – that the effort is well spent. Several instructional projects have used APL and the new implementation for the IBM system/360 series machines may further this number.

None of the languages in the group of six share all the programming elements of the hypothetical language. The most glaring absence is that of suitable file support. Curiously enough, files are discussed under various guises in the instructional language literature, but most proposals are limited in scope and often awkwardly implemented. Another plea might be extended for programmable interrupts – they are so useful – and a good macro facility. Macros written by each user enable him to converse in concepts relevant to his field.

IN SUMMARY, why not an instructional language which is general-purpose, flexible, and moderately extendable?

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APPENDIX A

Some Requirements in Instructional Languages (key phrases)

DISPLAY INSTRUCTIONAL MATERIAL
assemble material, display characters, display graphics, display audio, time display.

ACCEPT STUDENT RESPONSES
accept characters, error correction by student, accept graphics, accept audio connect terminals, time response, interrupt response.

PROCESS STUDENT RESPONSES
process characters, process numerics, process algebraic, process graphics, respond to unrecognized.

IDENTIFY LOCATIONS IN INSTRUCTIONAL SEQUENCE
label a statement, identify by condition, establish a restart point, branch to label, branch to condition referenced, branch to subroutine, return from subroutine, conditional branch, select from list.

RECORD AND MANIPULATE DATA
student data, program data, store data for later summary, computations.

STUDENT LEARNING TOOLS
desk calculator, algebraic language, text processor, simulation language, information retrieval.

CODING CONVENIENCE
abbreviation, assign attributes, model conventions, other available languages, implicit branching, automatic data summary, precoded procedures, comment or remark.

AUTHOR OPERATIONS AND UTILITY ROUTINES
preparation of program, format of program, translation, automatic assistance, manual assistance storage author edit.

PROCTOR OPERATIONS
register users, restrict use, on-line assistance, records handling error identification.

Other Factors of Interest

SYSTEM OPERATIONS
translator, operating system, processor and storage, terminals and communication, automatic recovery, retrieval of lost material.

TYPICAL USE AND REFERENCES
subjects, students, levels, strategies, applications, reports of use, stated purpose, a manual documentation.

APPENDIX B

Elements from a Hypothetical Instructional Language (key phrases)

DATA REPRESENTATIONS
arithmetic (integer and floating point)
string (character and bit)
pointer (relocatable so that lists can be filed)

IDENTIFIERS
mnemonic (unrestricted length)

VARIABLES – TYPES
scalar
label
array
file
structure (mapping templates, cf. storages references below)

STORAGE ALLOCATION (typing and allocation are dynamic)
dynamic typing/allocation via GET/FREE
allocations of a variable are stacked with deep-stack referencings available (i.e. can get 'old' values)

STORAGE REFERENCES
dynamic typing and allocation of variables, along with selectable mapping functions for aggregate variables provide a flexible control of storage. Auxiliary functions such as LOCATE (P,X) to establish a pointer P to variable X, DEPTH (X) to return a count of available allocations of X, and '@,' e.g. TEMP3@X for "overlay" referencing of X by template 3, are among the language features. VARTYPE (X), to return the type of a variable, is also necessary.

FILE FACILITIES
sequential, keyed
public and private
access control: passwords, lockout mechanisms

GENERAL I/O
Directed (formatted)
data-directed
list-directed
edited (via a FORMAT statement)
Undirected (no conversion of any sort)
Appropriate interrupts should be accessible in the language (e.g. conversion errors)

MODULARITIES
compound statements
omit block structure
internal/external procedures
co-routines and necessary checkpoint statements
parallel executions

AND (label)	begin parallel paths (fork), join latter
ALSO (label)	fork and no need to rejoin
JOIN	wait for all confluent control paths
interrupt control	e.g. ON OVERFLOW DO;. . .; END;
signal	pseudo-interrupt, e.g. SIGNAL (ERROR)

MACROS, EXTENSIBILITY
interface features with other languages, especially assembly language template macros for subroutine calls (disguise them) perhaps the language could be made available for computation during macro-expansion (a two pass interpretation), in this case the macros could define blocks, and generally carry a much heavier load. Translation-time scratch files would also be required so macros could bookkeep and communicate among themselves.

ADDITIONAL FEATURES
re-entrant code (everything)
recursion (an option)

APPENDIX C

An Example of the Use of Macros

PROBLEM:

An author wants to build a simple file system for drilling students, and he chooses the file format below, which is much like a SNOBOL statement form.

file record	key	question text	answer pattern	answer text (if wrong)	true key	false key

To facilitate building the file, the author constructs an input statement which automatically checks his data and writes it into the file called SNOWFILE. The input lines which the author composes have the form.

```
LINE/34/this is a question/'this', 'question'/not a question/35/34.
```

Each such above entry causes the macro (which the author wrote) to be executed. This macro is given below:

```
TEMPLATE: 'LINE' *1/string/'/'*2/string/'/'*3/string/'/' ......

BODY: IF *I='STOP' THEN DO; WRITE(TELETYP) 'END FILE BUILDING?';
                                        GOTO ENDOFTHING:
                              END;
      ON TRUNCATION DO; WRITE(TELETYP) 'YOU RAN OVER A FIELD';
                                        GOTO ENDOFTHING:
                              END;
      KEY:=*I;QTEXT:=*2;ANSWPAT:=*3;ANSTEXT:=*4;
      TKEY:=*5; FKEY:=*6;
      WRITE(SNOWFILE)RECORD(KEY)KEY,QTEXT,ANSWPAT,ANSTEXT,TKEY,PKEY;
      ENDOFTHING: /* THIS IS A NULL STATEMENT FOR EXIT */
BODYEND;
```

Notice that the macro expands into no text when interpreted. Instead, it causes transactions with the file SNOWFILE.

Having completed the file our hypothetical author would now like to run the exercises. He writes two macros with the calls:

```
        NEXT QUESTION;
and
        PROCESS ANSWER;.
```

These are the two main statements in the author's program. A complete drill might be as below:

```
PROCEDURE: OPTIONS(MAIN); /* DECLARATIONS FOLLOW */
GET KEY CHARACTER(4), QTEXT CHARACTER(80),
START: KEY:=001;/*INITIALIZE KEY TO FIRST KEY*/
CONTINUE: NEXT QUESTION;    /* MACRO CALL HERE */
PROCESS ANSWER;             /* ANALYZE THE ANSW*/
IF KEY = 'STOP' THEN GOTO CONTINUE;/*DONE?*/
END;
```

The macros which the author wrote are given below:

```
macro 1     TEMPLATE: 'NEXT' *1/string/ 'QUESTION' TEMPEND;

            BODY: ' READ(SNOWFILE) RECORD(KEY) INTO (QTEXT,APAT,ATEXT,TKEY,FKEY);

            WRITE(TELETYP) QTEXT; /* ASK THE QUESTION */ ' BODYEND;

macro 2     TEMPLATE: 'PROCESS' *1/string/ 'ANSWER' TEMPEND;

            BODY: ' READ(TELETYP) ANSW; CALL ANSINTERP(ANSW,     ,APAT,SW);

            /* ANSINTERP WILL CK THE ANSW AGAINST THAT IN THE FILE ANSW PATTERN*/

            IF SW='F' THEN DO; KEY:=FKEY; /* WILL BRANCH TO FALSE*ANSWER PLACE*/

            WRITE(TELETYP)ATEXT; /* WRITE OUT ANSWER */

            END;

            ELSE KEY:=TKEY; /* ELSE GO TO TRUE*ANSWER BRANCH */'BODYEND:
```

Notice that neither of the two macros uses the parameter "*I/string/" which simply collects any intervening blanks or other spurious characters. The macro-expansion is thus very simple; the text in single quotes is bodily substituted for the call, e.g. from "READ(SNOW . . ." to "TION */" for macro 1. Both macros still must be compiled or interpreted, of course.

A COMPARATIVE STUDY OF LANGUAGES FOR PROGRAMMING INTERACTIVE USE OF COMPUTERS IN INSTRUCTION

(Excerpts from the final report of an EDUCOM study funded in part by the Office of Naval Research during 1968 and available from EDUCOM, 100 Charles River Plaza, Boston, Massachusetts)

Karl L. Zinn

I. COMPARISON OF LANGUAGES

A. By common aspects

The forced juxtaposition of two or more languages whether by a list of aspects, characteristic samples or measures of author performance and satisfaction cannot help but improve the capabilities of each for common purposes.

The comparison of languages by common aspects emphasizes similarities by presenting together the way in which various languages accomplish the same function. It has prompted some languages designers to fill in a few blanks in the columns describing their languages, that is, they have provided their users with capabilities described for other languages in the table. A means for translation from one language to another is also implied.

A summary table arranged by common aspects cannot be complete and free of error: the languages are changing rapidly; the designers are slow to provide current documentation; first-hand programming experience in each language is not possible. Different approaches to summarization favor one language or another; different approaches to instructional use of computers require essentially different language characteristics.

Languages explicitly intended to do different tasks should be described by different sets of attributes in different tables.

When making decisions about languages and systems the relative weighting of various criteria must be determined by each project or user upon considering: a) the age and background of the student, b) the relative importance of research, development, implementation and operations, c) the interest of the project staff in general system characteristics versus programming languages versus instructional materials, and d) the availability of funds and of a general-purpose system.

Some standard format or common notation is needed for writing an individualized description of each language. In order to communicate with potential users of computer-based systems, a notation for description should be readily interpreted by those who have little experience with languages and systems.

B. By characteristic samples

Each language has unique features, and any small number of test programs will favor one or another. It is difficult to represent the capabilities of any language in a few pages of sample programs.

Without agreement on optimal strategy for computer-based instruction, any small number of test programs will favor one or another kind of language. In fact, it is difficult to represent the capabilities of any language in a few pages of sample programs. Many of the languages under study continue to be changed, and the samples obtained one month may not be characteristic of what is being done with the language six months later.

C. By usefulness: effectiveness, convenience, reliability, etc.

A major problem for evaluation is the definition of a measure of accomplishment which voids reliance on how long the student spends at a computer terminal. Studies of cost-effectiveness could proceed if the experts in some subject area would agree on measurement of concepts acquired or skills perfected, which would apply throughout the domain of concern. There is little hope for relating results from use of new media to conventional-instruction-equivalents because curriculum designers will and should exploit the new medium to improve and expand the content and skills taught, and will use the occasion of revision to drop some material which is obviously useless.

Criteria for measurement should be more objective. Words such as reliability and flexibility are used as if everyone agreed on what they mean. In some cases very different measures of the implied concept have been employed. It is not necessary that all agree upon any single definition for a term or unique measure for a criterion, but the various uses must be made explicit.

Journals should adopt a firm editorial policy which requires clarification of the referent or measure 'power', 'elegance' and other such terms when used in published reports.

II TYPES OF LANGUAGES

A. By user

(2.) Those involved in operational uses of computers for instruction in the schools should not pay for computer time and equipment that is not part of the immediate task. A system designer may increase operating costs as he adds on various optional features.

(4.) Staff on a curriculum development project require convenience and low error rate for writing and testing the material. This is not the same as economy and convenience for student use day-to-day in the schools: terminals may be more expensive, the speed of compilation of new materials more rapid, priority is given to revision of materials, etc.

A project working on development of system features and language characteristics should invest in flexibility. Furthermore, the curriculum writers who choose to work with such a project must be willing to give up some convenience for the sake of experimentation, eg., learn new language features frequently, modify or discard programs which used outdated procedures, accept errors and unreliability in the system, etc.

B. By strategy of curriculum development and/or description

1. The most straightforward approach to serving the needs of an author may be to provide a *format* into which he places elements of the curriculum. The computer program successively presents the question frames, provides a hint when the student asks for it, provides the right answer when needed, and records performance data for later inspection by the author of the exercise.

2. *Frame-oriented description* of testing or instruction is a kind of computerized programmed instruction. The similarity of the code and conversation to a programmed text is apparent. In fact, translators have been written to accept linear (or simple branching) programmed text and derive CAI interaction with a student.

More author hours have been invested in the computerization of programmed instruction text than other instruction modes.

"Frame-by-frame programming with an author language is on the way out. A few years from now less than one tenth of any computer-based course will be programmed by an author or his technical assistant in languages such as COURSEWRITER and PLANIT."

Materials which now are prepared using these languages include a number of pre-defined frames or "paragraphs" in an instructional sequence, each one written in some detail and on an individual basis. This approach cannot succeed; too many writers are required to generate enough instructional material in this format to provide for the needs of our increasing educational populations and to justify large scale, computer-based systems dedicated to this mode of operation.

3. *Task-oriented notation.* Whenever one or more authors have a singular instruction task, determined in part by content and in part by instruction strategy, a special language or dialect may be useful. Eg., PLANIT is particularly suited to tutorial and problem solving in statistics; MENTOR was developed at Bolt Beranek and Newman (BBN) especially for "socratic dialogues."

4. *Procedure-oriented languages.* All of the languages or notations in the first three categories had to be programmed for the computer in a regular computer language which could be interpreted by the machine. Any of these languages could have been used directly, but some are especially convenient for writing procedures for interactive use on a computer, or for conversational instruction in particular.

The author adopts a logic or pattern or strategy which can be conceptualized in a procedure statement. The programming of the logic may have been done by the author or by a programmer experienced with the system. The author then applies this and other strategies to curriculum files of indefinite size.

Increased use of procedure-statements and (separate) curriculum files will be beneficial for the field, and increasing use of computers in large curriculum projects will require this approach for economy.

Procedure-oriented languages are for computer programmers and for educational technologists specializing in computer applications; these persons should produce the user-oriented languages or data formats which maximize convenience of the curriculum expert.

It would not be advisable to promote only development of generative procedures. Some instruction packages have been demonstrated to be useful as they stand; and more is yet to be learned about computer aids from pushing the limits of a frame-by-frame approach to programming. However, a significant proportion of resources for research and development will be put into more flexible approaches to designing learning environments.

One could have too large a library of strategies and too much individuality among students and topics for standardized techniques to be useful.

Subject areas will not see much development of prescriptive curriculum for individualized instruction (controlled by the computer program) until instructional objectives are rather well defined in terms of practice in using facts, concepts, and simple skills which can be described and administered by standard procedures.

The practical application of standard procedure programs and generative techniques applied to curriculum files on any specific subject area or training situation raises the following questions: How are information structures to be described by the subject expert and stored in the computer for use in such procedure statements? How are materials to be assembled according to general rules? In other words, do we know *how* to process language in this general way? Can student answers be processed *except* by empirical procedures derived by the author from experience with student responses to each individual question?

How do we process input from the student in some general way which determines a suitable reply? Can we identify patterns or sequences which indicate certain treatment for the student on succeeding learning experiences?

5. *Interactive student programming.* If an on-line problem solving language is suitable for simulation and model building, then that language certainly is of interest to designers of computer-based learning exercises. First, the subject expert may want to build models on which to base games or simulated practice for students to try. Second, he may wish to guide some students through revision of the models and construction of new ones. In general, he wants to show students how to use the computer for information processing in his discipline; as lesson designer he might produce a

"mentor" which advises each student on how to get maximum value from the computer as a problem solving and scholarly aid.

Given limited computer resources and very few expert personnel to design learning exercises, projects are advised to use the computer more as a learning tool than a presentation device. The relative benefits are apt to be considerably greater when the computer does things which could not be achieved in other ways; students of reasonable study skill can learn rather well from textbooks, workbooks, and other non-computer learning formats.

The most significant contribution of simple, interactive programming languages may be through increased student use of computers for problem solving and scholarly endeavor on individual initiative.

Much of the enthusiasm for conversational computing languages may relate to non-essential features; quick response and understandable diagnostics can be provided in batch systems. Now that commercial services are being offered to (and purchased by) public schools, it becomes increasingly important to isolate the essential contributions of interactive programming languages, and to determine effective cost conditions.

The computation facilities of the interactive languages are useful in many computer-based learning exercises, and convenient computation is conspicuously absent from nearly all languages specially designed for computer-assisted instruction. When an author uses an interactive language the program is more accessible to the student. This increases the opportunity for a student to become involved in the redesign of an exercise, and this is especially important when the curriculum writer has incorporated mathematical models or simulations.

The problem-solving mode will be over-valued and misapplied, as was COURSEWRITER five years ago. However, more instructional materials of significance are likely to survive in this mode in the next five years, than have been seen in the computerization of programmed instruction in the *last* five years.

III UNIVERSALITY OR UNDERSTANDABILITY

A. Universal language

Strong forces will be encountered against standardization, but one common language is not the important goal. Because of the great variety of purpose and process in instructional programming, less progress will be made toward standards than in business or scientific programming.

B. A few common languages (eg, one of each type)

COURSEWRITER will continue to be used, as FORTRAN continues to be used, not because of general utility, but because it handles a few jobs well, it is available on a number of different machines, and users have some hope of translation from one dialect to another.

Five years from now neither COURSEWRITER nor PLANIT will be the standard, although there will be some efforts in that direction. Hopefully some guidelines will be achieved for talking about language, and more important, for describing and documenting instructional procedures. Such a communication medium will promote design of more reasonable instructional tasks, and serve also as a significant tool for advancing instruction research and strategies of curriculum development.

C. Translatability

New languages and systems will have greater capacity for translation of instruction programs from present programming languages in which they were implemented. Translatability is possible without imposing any restrictions on innovative ideas for language or strategy.

D. "Publication" language for documentation and communication

Documentation has two main functions, that of information transmission and work simplification. It transmits information to potential users concerning: (1) the contents of the instructional program; (2) the proper use and application of the program, and (3) how the program was constructed. It simplifies work by: (1) enabling the user to find actual or potential trouble spots; (2) assisting the user to eliminate problems which may arise, and (3) simplifying revision.

Representation of a procedure statement for a curriculum expert not accustomed to computers requires an approach different from standard flow charting.

In most cases the essential information about a computer-based learning exercise can be derived without executing the program; careful study of proper documentation should provide all information about the materials and logic short of operating system characteristics. One obtains relevant information more efficiently through organized exploration of the program description than through reading individual records of student-machine interaction or through blind searching on-line at a student station for the eventualities for which the author has provided coding.

Actual experience with a computer-delivered exercise may be an important contribution to understanding and evaluating an instructional unit, especially if certain knowledge and technique are supposed to unfold or develop during the learning experience. An important component of some learning experiences is effective, that is, success depends on an impression or feeling of pleasure, satisfaction or possibly surprise. Negative experiences might also be identified in on-line experience more readily than in a statement of specifications.

IV GENERALITY AND SCOPE OF INSTRUCTIONAL SYSTEM

A. Hardware limitations

Uses of auxiliary memory for updating formatted files of student records and making decisions in real time on the basis of certain aspects of the data require direct access to specific portions of the information. It is disappointing to find the disk and drum storage on conversational computing systems used in a tape-like fashion instead of as the direct access file devices they really are.

B. Software limitations

When the subject expert and educational technologist become distracted from their real purposes by the peculiarities of current computer systems and programming languages, work should leave the computer for a time until the essential parameters of the learning situation are determined. If specifications for human tutoring are prepared as if for a more sophisticated computer system than now available, techniques developed off the computer will more readily be adapted for computer implementation later.

A broadly conceived instruction system probably should begin with a general-purpose system and add facility for moving from the tutorial mode into other user sub-systems and returning when an exercise is completed. Some authors need to maintain contact with the student through some means of monitoring his work on a problem, to bring him back to the tutorial mode because of elapsed time, number of problem attempts, or even an anticipated error which requires special attention.

Instructional systems should incorporate other programming capabilities which can be used by both author and student. In addition to simple computational aids, some lesson designers will want to provide an algebraic language, a text-processing language, a model-building or simulation language, perhaps a specific system or model written for student use, or information organization and retrieval capability.

A task-oriented language may serve well those purposes for which it was originally designed, but authors in other areas of study will need to have the translator adapted for their own special needs. For a long time, users who seek ready-made specific aids and generality at the same time will be disappointed.

Revision of materials should be encouraged by automatic summarization and selection of data on computer cost and student time as well as student performance to be put before the author.

Capability for processing quantities or algebraic expressions typed by the student is useful. The author may wish to attempt to match a number within numerical limits, or as an integer multiple or negative inverse of the anticipated number, or match values in spite of an error in units. Some languages already provide for evaluation of an expression by the translator; but in some instances one wishes to recognize an expression as equivalent to or in some definable way different from the expression anticipated by the author.

C. Cost limitations

Techniques for preparing curriculum files must be more powerful in the sense of fewer hours required of the subject expert to write and revise materials which achieve the objectives intended of the learning experience. Authors cannot often afford the luxury of individually shaping or tailoring each line of text in each frame for each kind of student.

It is today cheaper, and in some instances perhaps more convenient, to handle some desirable translator features manually with clerks and writing assistants. The next important step is careful development and evaluation of language features which adapt to the needs of authors and subject areas.

Conversational languages emphasize convenience, and sometimes require considerable additional cost in computer time during execution. The number of operations for interpretation of a symbolic program is always greater than for execution of a program already compiled into machine-level statements. Of course a user may be willing to pay more for execution if his results will be available immediately and without complication, along with quick diagnostics and opportunities for changes in the program at stopping points throughout.

D. Design procedures and/or limitations

One way to extend a language to handle additional applications is to provide linkage to other programs. No one language now available can handle the variety of applications efficiently, and some useful subroutines may already be available in other languages on the same system. The major problems seem to be: 1) transferring data, 2) returning control to the calling program, and 3) leaving the user in control in spite of program or system errors.

Facility for definition of functions should be extended to provide for definition of a) character operations as well as numeric ones, and b) distributed operators which apply throughout one or more statement lines. The latter would allow for definition of new operations with convenient formats for specifying answer processing. More than one line should be permitted in the definitions, and the possiblity of an operator being distributed among two or more variable names must be allowed in the parser.

The problems with extending a language through definition of new operators and statement types concern the internal representation of the language, simple rules for describing new features, and the ability to recognize operators distributed throughout a list of variables even on more than one line or program statement.

New features defined as functions for execution as needed must be reinterpreted each time the function is used, and little economy of execution results. The ability to compile or assemble a routine, link it to the interpreter, and specify its execution in a statement form natural to the user will increase the convenience of conversational computing languages while making certain information processing operations more economical to perform.

One way to accomplish some economic advantage is to re-assemble the interpreter, adding the new statements, functions or operators to the language. This delays availability unless an informed system programmer is always at hand. Reassembly for one user also raises some questions of proliferation: should he then have his own special version; do changes in the basic compiler take effect for everyone?

Variety and flexibility in programming capability of an instruction system are not necessarily incompatible with economical operations. Early decisions by system designers about specifically what is needed by users inappropriately limit the scope of applications.

It is not obvious what the elements of programming should be. The basic statements and operations need be elementary enough to permit building the variety of processes desired by programmers. However, high level commands should be assigned to frequently used routines constructed by programmers in a way that the syntax can be readily used by curriculum designers.

The potential author who does not have access to a specially designed educational system, or the school which wishes to gain some experience without large investments in space, leasing arrangements or committed user time, will find the rental of one terminal for limited use of a general-purpose, time-sharing system to be a satisfactory interim arrangement. Through suitable modifications, some of these languages and systems could serve most of the needs of instructional applications.

Interactive programming on a general-purpose system is not likely to include the proctor operations and other systems support which may be important to educational experiments and operations.

V. INTERACTIVE MODE CONTRIBUTIONS

The essential contribution of interactive programming must involve responsiveness of the system which holds special benefits for the casual and infrequent user. He may be well advised, when unsure of the proper syntax, to try various likely ways until the interpreter accepts one and does what he intended. Better yet, the processor should tell him what form to use the first time an uninterpretable statement is entered, or refer him to the section of a reference manual which is likely to explain away his confusion.

Interactive programming languages incorporate aids for program testing in a very natural way. The same statements with which stored programs are written can be used as direct commands to print the values of selected variables to see what went wrong, assign new values to test other parts of the procedure, and resume execution with any line or segment of the program.

If diagnostics, provided at the moment, and backed up by references to readily available literature, can relieve the user of concern for the means to describe his procedure, he will give more attention to solving the problem. A shorter elapsed time between problem definition and solution, and the time savings attributable to continuous working sessions provide another bonus.

A cleverly written processor should have some auxiliary memory and decision rules which generate special user assistance. A rather deep search for the locus of a syntax error and some attempt to interpret the intention of the user in spite of ambiguity has already been mentioned.

The processor might also keep some record of the types of errors made by the current users and, according to rules set up by the designer of the training and support system, initiate some conversation with the user in order to clear up his probable confusion.

The processor might save previous versions of statements and segments which are replaced, until it becomes less likely they will be used again. Already the user can store alternate routines under different names, using one or the other during testing, until he feels ready to discard all but the most effective one. A careful design might automate part of this process, increasing the power available to the initial or infrequent user.

There could be considerable convenience in a memory feature which reduces the distinction between the indirect mode of stored programs and the direct mode of commands. For example, statements would be executed as entered, with changes in sequence (branching) requiring confirmation by the user. The translator would monitor selected variables and indicate when they exceed acceptable ranges defined by the user. Entire conversations would be saved so that part of an earlier attempt at problem solution could be retrieved for examination; a program listing could be extracted for execution or permanent storage. Alternatively, the user could request an automatic but selective saving of alternate versions of statements or short routines.

Incorporation of training into the use of an interactive language introduces some problems. One consideration is the time required for typing full diagnostics, remedial material or tutorial lessons. A training version of a processor could be available in addition to the regular operational version. A training mode could be incorporated throughout the regular processor if a convenient convention is provided for requesting additional clarification or diagnosis as needed and no more. For example, the documentation for the language might be stored in the computer in a tree structure referenced by pointers in the translator. Whenever the scanning routine ran into difficulty, it would point to some place in the (on-line) manual to which the processor would refer the student. Additional indications of confusion would cue increasingly detailed responses from the processor to some reasonable depth. If the interactive mode is fully exploited, and the manual reasonably arranged, the availability of help should impose no delays or distractions on experienced users.

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Zinn, Karl L., "A comparative study of languages for programming interactive uses of computere in instruction," Final Report under ONR contract N00014 - 68 - C - 0256 (Feb., 1969) and available from EDUCOM, 100 Charles River Plaza, Boston, Mass., 02114.

DISCUSSION

Captain Huggett said he felt that this was perhaps the most dependent of the sessions since the design of a CAI system and its attendant software should be the outcome of other wider factors starting with a statement of the education or training goals, a knowledge of the capabilities of the population that is required to achieve them, a knowledge of the ways in which the material might be learned, and so on. The position papers had fully recognised this point and it was interesting for him to compare the general aims, consciously arrived at or not, of a number of centres where computer based learning facilities existed and he instanced the case of PLATO at the University of Illinois where the aim appeared to be to produce a community service in which many different approaches to learning could flourish. He remarked on the very stimulating environment this eclectic environment produced. This sort of aim would lead to a very different specification of hardware than aims of a more specific nature.

The design of CAI systems is limited by the factors that limit communication in any form. Fundamental problems of size and cost are posed by the data demand on the system, the rate at which it may be supplied and the costs of transmitting this data. A range of terminal devices had been listed with broad assessments of their capabilities and cost. Captain Huggett pointed out the imbalance in the state of terminal development. Thus the ways in which the student may respond to the system are narrower and less flexible than the ways in which the system "talks" to the student. This restriction would not impair certain types of learning but there are many that it would. He also pointed out that students also expect machines to have machine like characteristics and there are indications already that even quite modest delays in machine response are unacceptable. The system employs a teaching strategy but this must be of a sort which is in harmony with the way the student wishes to learn. Dr. Adams put it in a particular way when he said that "The designer's conception of the user is implicit in the operating system of the machine and thus has a strong structuring effect on him (the user)". This seemed a very important consideration that ought to be discussed. Those author languages that he had seen reflected the designer's view of the user but they appeared not to have been conceived as entities and the guidelines adopted early on sometimes proved to be an embarrassment later on when developments were necessary to a language that had become too big and complex to be altered without being rethought. CAI was characterised by its highly interdisciplinary nature and the success of CAI ventures would depend on good managers who could direct and blend these disciplines severally developed in others.

Captain Huggett ended his summary by saying he would like to hear discussion on the degree to which CAI systems should be developed to simulate/emulate human student/teacher interaction, the degree to which the universal author language should be developed, what learning model should be used to define language, and the question whether comparatively free unfettered hardware development would throw up these answers anyway.

Professor Pask said the author language should reflect a learning model but the trouble was there were many of them. The 'black box' model was very convenient and would work for simple highly structured tasks but it was not a larrning model and could not be used to predict. He emphasised that teaching was control of the learning process and that because of the complexity a complete CAI system would be a hybrid of different forms of control system and that a possible approach was to try partially to isolate subject areas and to try to optimise with respect to the several parts.

Professor Mitzel commented on the *ad hoc* nature of work in the United States so far and the fact that CAI needs theoretical definition. He called for a study of educational objectives and pointed out that examinations test what each student has obtained from some set of experiences but if this was looked at in terms of his later achievements a different pattern of education might evolve. He also touched on the nature of a conversational mode between student and machine. Did this involve only the exercising of options by the student or was it possible for the teacher to retain some degree of control. He saw the machine being used to attend to the delivery and continuity of material leaving the teacher free to deal with the affective issues.

Miss Ash welcomed this turn in the discussion and said that care was needed to prevent too much emphasis on fitting the student to the system and there must be more on making the system flexible enough to fit itself to the student. She called for a terminal development programme which would accept freely constructed student responses either in words or graphically as seems most appropriate to him. She also asked for a definition of the role the teacher would be expected to play in preparing material and operating a system.

Mr. Broderick developed this line of discussion and said that the acceptance of this mode of learning by the teacher was vital to its fruitful development in the English educational system. It was also vital that the real contributions that teachers are willing and able to make should be given fair consideration. Many of them had a wealth of experience and were conscious of practical day-to-day problems and techniques which could play a vital part in the development of a CAI programme (c.f. the designer's concept of the user mentioned by Dr. Adams).

He said that the teaching profession was a conservative one and had been known to take a hard line against seemingly logical innovations for reasons which had their roots in lack of trust and insecurity. He felt that CAI could easily be presented as a threat to the whole status and livelihood of the teacher instead of as an additional educational resource to the teacher's armoury. He felt that the inclusion in teacher training courses of a detailed study of the ideas underlying the structuring of learning material could have a beneficial effect on the students both as regards their potential as teachers and as regards the readiness with which they would accept computer based learning systems later.

The discussion now turned towards hardware and **Professor Hansen** said that the operational educational requirements were going to be difficult to define. Generally he advocated an economic approach with a limit set to cost within which the customer's requirements should be optimised. As regards the debate about large systems or small his preference was for the development of small ones. He was optimistic about what could be done with terminals and predicted the development of cheap graphic displays. Professor Hansen pointed out that computers have not hitherto been designed for CAI work, their logic was cumbersome where, for example, character manipulation was concerned. Only one peripheral was served and more overlap was needed. Disc files were organised for random access whereas the type of access structure required was reasonably well known.

Mr. Hodgson said that conversational interaction in CAI was somewhat counterfeit in that the student freely constructed a response but key word analysis was a simplification of a freely constructed tutorial diagnosis – as Dr. Adams pointed out, the students were very perceptive of the real operational constraints imposed on them by the terminal. The Centre for Structural Communication group together with GEC Hirst Research Centre had developed the "Systemaster" terminal concept. They had a simulation of a computer terminal which involved a combinatorial matrix response system which used overlays of subject statements, a code index output and a set of operating buttons. This gave "on-line" dialogue with a looseleaf book format. The approach made, by its form, the conventions of "dialogue" explicit for the student. The game he was playing was not made to look like something else. Since complex subject data could be symbolised by one bit of computer data, the system would enable several hundred terminals to be controlled by a medium sized computer. Normally available curriculum materials could be integrated into the system.

Mr. Duerden said that reference had been made, in both Dr. Adams' and Dr. Zinn's papers, to the importance of the terminal problem, and both had mentioned the plasma panel display. He wished to emphasise the importance of an integrated design approach, bringing in engineers and even production engineers at a very early stage where engineering economics are recognised as crucial to system design. An engineering evaluation of the plasma panel initiated at Marconi some fifteen months ago had indicated that the panel itself was a well-engineered device basically suitable for quantity production, and with interesting design features likely to give it a very long in-service life. However, the penalty for these features was that there was a voltage incompatibility between the panel and normal computer logic circuits, which seemed to preclude the possibility of an economic design. Since he regarded the plasma panel as a device suitable for filling the gap until the advent of fully solid state matrix displays and taking into account rapid advances in the latter area, he felt that effort to solve this compatibility problem was unwarranted.

He mentioned other interesting display terminal developments. The Direct Vision Storage Tube showed promise – selective erasure was now possible, and the problem of running cost had been overcome. His estimate of running cost of the early MIT terminals was about \$1/hour for tube life. Long life tubes were now available from UK sources, and this particular cost factor was now vanishingly small. However, cost might still prevent the DVST terminals getting down into the price bracket required for extensive CAI use.

Another interesting trend was the advent of cheap local storage as a result of MOS technology and medium scale integration. This led to fundamentally cheaper production processes, giving rather slower logic circuits; but speed was not important at the man/machine interface.

The possibility of a major decline in cost was in the price of bandwidth. He thought that eventually a coaxial cable connection would be as standard as a gas or electricity supply; and this led to the concept of cheap terminals based on T/V technique. Indeed the terminal might well be a T/V display, and the only cost to be considered would be that of the add-on interactive facility. There was much to be said for integrating the approach as between the requirements of educational technology and the general developments in the communications industry.

SESSION III

DEVELOPMENT PROCESSES IN CAI
PROBLEMS, TECHNIQUES, AND IMPLICATIONS

Professor Duncan Hansen
Florida State University

DISCUSSION

Rapporteur, John D'Arcy

DEVELOPMENT PROCESSES IN CAI PROBLEMS, TECHNIQUES, AND IMPLICATIONS

Professor Duncan Hansen
Florida State University

INTRODUCTION

Computer-Assisted Instruction (CAI) is now more than a decade old. Having moved from a conceptual ideal, CAI has both proven its operational feasibility and revealed all of the complexities of the educational world. Moreover, it has confronted the educator with the diverse requirements of a technological approach to instruction. Thus, the field of CAI has by necessity addressed itself both to models of the learning process as well as to issues dealing with efficient techniques for curriculum development within the requirements of available computer technology.

For the purposes of this paper, a brief introduction to a learning model for adaptive instruction will be presented in order to clarify the difference between the instructional process and the curriculum development process. In turn, more specific remarks will be made in regards to instructional strategies as these form the primary intersection between these two theoretical and empirical domains. And finally, the major portion of the paper will describe our experiences at Florida State University in developing an autonomous multi-media computer-based collegiate physics course. In this final section, a "systems approach" model to CAI curriculum development will be presented. In order effectively to evolve and utilize the systems model in the development of the FSU physics course, ten significant professional roles in multi-media CAI curriculum developments will be described. The paper will then conclude with a set of summary propositions concerning the area of curriculum development within the CAI world.

INSTRUCTIONAL LEARNING MODEL

For the purposes of clarification, it is important when developing CAI materials to have some conception about the learning process being utilized by the student. Moreover, as has been redundantly asserted, CAI is justified by its individualization of the learning process. In conceiving of the individualization of the learning process, most educators have tended to define the process as one of supplying appropriate instruction to satisfy the student's needs. This assertion is ambiguous at best. For example, are the needs to be defined in terms of the student's frame of reference, especially in terms of his wants? Or is it to be defined in terms of some benevolent power who controls what the student should have? The concept of needs is an integral behavioral construct evolving out of research within human motivation. The problem of its definition can be witnessed within the literature of human motivation and personalities process. As an alternative theoretical approach, one can specify a simple input/output model for the student and utilize this model to consider some of the preliminary factors in CAI curriculum development.

Turning now to this simplified model, individualization of learning can be thought of as a process by which the student maximizes his informational input, mental processing, memory storage, and response output. In psychological terms, this conception of learning behaviors specifies the stimulus array, the cognitive processes, and the response requirements. Breaking the behavioral processes of learning into these three components will bring into focus some of the potential CAI curriculum development factors to be discussed in a later section of this paper.

In regards to stimulus input, investigators such as Briggs and Gagné assert that greater learning gains can be achieved by appropriate assignment of instructional media. Matching appropriate films, audio lectures, or printed material to individual characteristics should, it is claimed, lead to better learning results. Current work in the area of Individualized Prescribed Instruction (IPI) and our own experience with CAI indicate that the assignment of appropriate media within CAI is a highly complex problem. For example, there are research findings indicating that cathode-ray tube presentations to low ability students may in fact deter the learning process, or that audio lectures in some cases prove superior to film presentation, even though there is an obvious reversal in terms of information characteristics of the two media. As a consideration within a CAI research project, it is therefore important to prepare a design which allows for an assessment of the various media being utilized. As a feature in the adaptive nature of a CAI curriculum, alternative media approaches will ultimately provide useful insight as to range and optimality of each in a given curriculum.

In regards to internal processes, the middle component in this simplistic model, the manipulation of the level of difficulty of the learning materials has proven to be a powerful variable. In research at Stanford University, as well as at a host of other CAI Centers in the United States, it is clear that optimal matching of the level of difficulty of the learning materials to the student's performance level leads to improved processing as well as enhanced long term retention. As an example, a recent study in our laboratory indicated that the use of concurrent memory retention indices provide enhanced learning in comparison with more general individual difference variables such as an IQ score. While a large array of alternative psychological models can be proposed for this internal processing by the student, it is important to consider within CAI curriculum development such simplistic factors as the scaled information load as evidenced by a readibility indices, the complexity and sequential structure of solution algorithms, and finally the fostering of long-term retention.

Turning now to the response side, the third component in the model, it would seem that most CAI curriculum development projects have constrained themselves by the availability of computer/terminal equipment. Encouragingly, though, most students indicated a quick adaptation to the response requirements of the student/computer interface with little or no detrimental effects from one alternative device as opposed to another. To be more specific, very young students have clearly demonstrated the ability to master the typewriter keyboard, or no evidence exists as to the superiority of an electronic blackboard as opposed to a more inexpensive keyboard device. As a wider array of curriculum materials are developed, it may become clear that more appropriate matching of response characteristics of student/ computer interface may foster more optimal learning. CAI curriculum projects may desire to be more exploratory in the area of alternative response devices.

While acknowledging that this input/output model for individualized learning is extremely simple, it provides a CAI curriculum project with the essential considerations in thinking through each specific stage in the curriculum development process. A failure to consider the student and his related behavioral processes has been one of the major flaws in many of the CAI developments to date in the United States. It is also important to indicate that there has been little experimental investigation in regard to appropriate matching of learning, computer, and curriculum characteristics. Until this void is eliminated, major CAI curriculum developments will be limited in regard to their implementation and implications.

INSTRUCTIONAL STRATEGIES

The major intersection of a model of the learning process with that of a CAI development model comes under the rubric of instructional strategies. This term was first referred to by Stolurow in terms of the logic flow of the instruction, that is, the branching structure utilized within the context of correcting error responses or applying remedial procedures. As a contrasting conceptual frame of reference Smallwood proposed a quantitative model by which to define instructional strategies that lead to optimal solutions for the learning outcome. From my point of view an instructional strategy is one that allows for selection from the alternative plans of instruction the one that hopefully will lead to an optimal performance level. These instructional plans involve the characteristic of the learner, the structure of the curriculum material being developed, the behavioral processes being utilized by the student, as well as the student's coping behavior that results in maximizing his rewards and minimizing his efforts. Thus the student, from my point of view, will always try to maximize his rewards and minimize his efforts in terms of either playing an "interesting game" or contending with the problems posed by an educational system.

The primary issue concerns who selects and controls the instructional strategy. At one end of the continuums Stolurow, Smallwood, and Atkinson would suggest that we prescribe the optimal selection of learning events for the student. They claim that having once understood the student's basic behavioral processes that we, as an outside decision-making mechanism, can best decide his prescription for instruction. At the other end of the continuum, Grubbs has suggested that a student, given his better self-awareness of all of his internal mental processes and immediate state of understanding, can best select his own strategy for acquiring a set of complex concepts. For my part the process for the selection of instructional strategies should be considered one of negotiation between the instructional system be this a teacher or a computer and the student. This negotiation should allow for more student initiative and self-selection given better desire performance, that is, the better the performance by the student the more we offer him self-selection among the learning topics, alternative media, and criterion levels of performance. Recent work in the area of social learning contingency games indicate that allowing for student initiative leads to at least these two results: (1) more student accomplishment of the desired performance defined in terms of behavioral objectives in less time, and (2) more motivation by the students to move towards the category of superior performance. Thus CAI curriculum projects must constantly consider the social learning contingencies if a successful overall instructional course is to be developed. The frame by frame issues typically discussed within programmed instruction appear to be marginal in their impact on CAI learning. In essence I am recommending that a wider and richer approach to instructional strategies with more student involvement will provide better payoffs in learning. We turn now to the specific issues in CAI curriculum development.

SYSTEMS MODEL FOR CAI CURRICULUM DEVELOPMENT

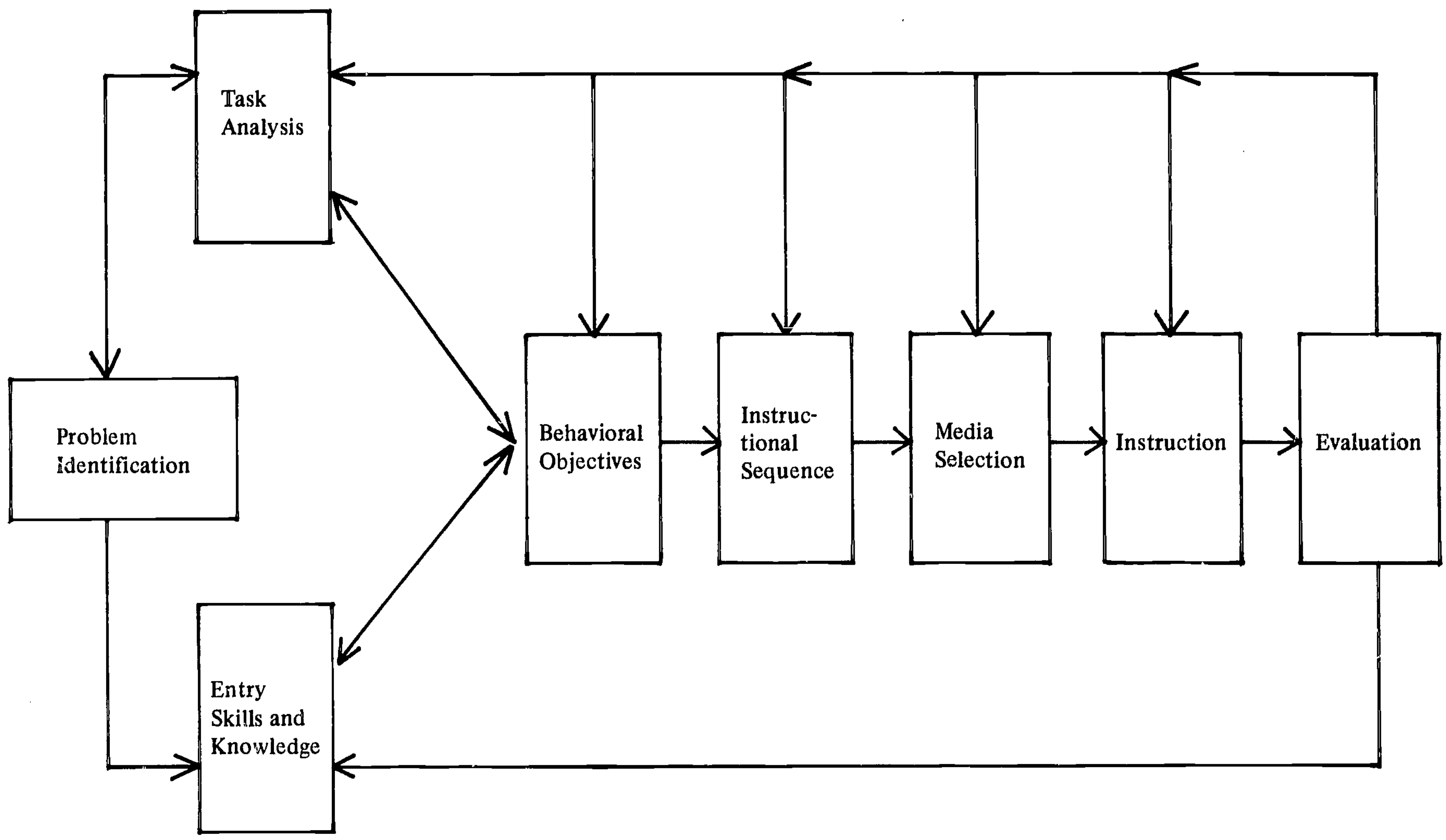
The systems approach has evolved as a set of ideal analysis and implementation procedures that can be followed in order to develop effective learning materials which in turn maximize the conceptual development of the students. The essential features of the system model are schematically presented in Figure 1. The first step in the process is the exploration and description of the instructional problems plus associated context constraints of the instructional setting. Concurrently, a task analysis of the conceptual requirements, as well as the behavioral processes, should be performed. A thorough assessment of the entry skills and prior knowledge of the student population for which the course is intended is also required. These sub-analyses then culminate in the course behavioral objectives which form a description of the criterion performances which are desired as outcomes for the student. In turn, the behavioral objectives are sequenced and structured into instructional strategies for given segments within the course. As a consequence, appropriate selection of media and instructional contexts provides the implementation prior to the first field test. The empirical results obtained in the field test provide the basis for evaluation and subsequent revision cycles.

While this is an overly simplified representation of the process, each of the system's components will be described in more detail below. The adaptation and utilization of this model by the FSU project staff will be emphasized.

1. Problem Identification

In the process of identifying the existing instructional problems within the physics course, it was found useful to employ a number of techniques by which to reveal specific problems upon which the CAI approach could focus. If con-

Systems Development Model



ceptual learning problems can be identified in terms of behavioral phenomena such as prior test scores or responses on homework assignments, etc., a CAI project will be much further ahead in its formularization of appropriate behavioral objectives.

Four techniques were utilized to identify problem areas within the physics course. First, a thorough literature search of the physics education area provided information about the needs of students for prerequisite quantitative abilities, for high order abstracting and concept formation abilities, and for sophisticated problem-solving skills. In the last analysis, it was apparent that one learns physics to the degree that one can solve physics problems. The primary behavioral focus on problem solving for physics courses should not be minimized.

The second technique involved a number of conferences between members of the FSU physics faculty and the project staff in order to gain case study information about learning problems revealed during class discussion periods as well as faculty office hours. These conferences pointed up the need for good conceptual development and associated problem-solving skills plus the deficiency of student motivation for certain aspects of the course. These motivational factors seem to determine class attendance, work effort, and general intellectual commitment.

In terms of the third technique, all of the prior test results over the previous three-year period provided a clear indication that the later portions of the course, namely electromagnetic phenomena and atomic physics, provided the greatest difficulty for the students in terms of items failed on final examinations.

The fourth technique for identifying difficult concept topics leads to a set of CAI physics problems which were presented on four different occasions to samples of students enrolled in the conventional physics course. The performance of the students on these CAI instructional problems provided performance data upon which all future comparisons for revision and improvement purposes were based. The availability of baseline data is an extremely useful technique and should not be minimized.

All of these efforts clearly indicated that throughout the physics course there were specific learning or conceptual problems that influenced the overall performance into a gradual decline as the students proceeded through the course.

2. Task Analysis

A task analysis of the curriculum concepts to be taught to the students provided an overall structure of the course content in a manner that delineates the relationship among topics in both sequential and hierarchical fashion. In terms of introductory physics, the integrating conception of particle and wave phenomena provides a recurrent and increasingly complex set of theoretical propositions as the student moves through the topics on measurement, optics, mechanics, electromagnetism, and modern physics. This relatively stable conceptual structure has evolved over a long period of time and is easily inferred from a review of existing textbooks.

For the purposes of the project, the task analysis of the content was performed in two ways. First, a video recording was made of the twenty-nine conventional classroom lectures and demonstrations. These video tapes provided an opportunity to study both the detailed presentations of concepts, but more importantly to identify the language and representatives utilized in the conventional setting. Parenthetically, it is highly recommended that video recordings of a professor who is highly successful in conventional teaching provides many important insights into the pedagogical techniques and language appropriate for instruction in a given course area. Moreover, the video recordings allow one to identify the characteristics of concept presentations which will be of value when consideration is given to media assignment. And, lastly, it provides an invaluable tool by which the professor can compare and reconsider the sequencing of portions of the course.

As a second task analysis technique, four currently popular physics textbooks were analyzed. Interestingly enough, the topic sequence in all of these textbooks was exactly equivalent; that is, the authors employed the concepts of particle and wave phenomena in order to integrate the topics within the introductory physics course. As an additional benefit, the analysis of the homework problems required at the end of each chapter indicated many of the behavioral requirements currently considered important in introductory physics.

3. Entry Behaviors

An empirical assessment of the skills and performance level of the student population as they enter a course is an absolute prerequisite for the preparation of optimal learning materials. These performance levels are commonly referred to as entry behaviors. Entry behaviors represent a characterization of the heterogeneity of both cognitive and affective processes and prior knowledge levels on the part of the students. Obviously, as gaps or deficiencies are revealed, these impinge directly on the conceptual attainment as represented in the task analysis. In essence, entry behavior should indicate both the aptitudes and abilities of the students at the beginning of the course and the appropriate entry points into the conceptual flow identified within the tasks analysis of the course.

The entry behaviors of the FSU students were assessed in terms of scores on the Florida Collegiate Entrance Examination, performance on midterm and final examinations in the conventional physics course, and most importantly the performance on the CAI problem sets. These CAI problem sets were a fair representation of each of the sub-concepts presented in the conventional setting. The students typically came to the CAI Center prior to each examination for one to two hours of instructional interaction. Each CAI item poses a physics problem; if the student could not answer it, help was provided until a successful answer was emitted. The preparation of this type of CAI complementary problem set is highly recommended in order to identify specifically the performance level of students both prior to and during a conventional course preparation.

Problem sets have great merit in that they save a great deal of time and energy in terms of preparing desired remedial materials and delimiting professors' and authors' intuitions about potential learning problems. The area of CAI curriculum development has been fraught with extensive remedial material preparation which is rarely used by any of the targeted students. It was discovered that utilizing the CAI homework problem results saved considerable time and focused the preparation of learning materials specifically on difficulties demonstrated by concurrently enrolled students. Thus empirical techniques provide an efficient approach to specifying student entry behaviors.

4. Behavioral Objectives

Information from the course analysis, task analysis, and entry performance levels was utilized in formulating the behavioral objectives of the CAI physics course. Since a direct comparison with the conventional course was desired, the concepts and related behavioral objectives were arbitrarily divided into twenty-nine segments referred to as lessons. These closely parallel the presentations in the conventional lecture-demonstration course. The behavioral objectives were treated as hypothesized propositions which could be and ought to be achieved by the students given an effective instructional treatment.

For each lesson the behavioral objectives were broken down in terms of prerequisite skills and concepts plus the behavioral objectives for that given instructional segment. It was observed in the process of stating the behavioral objectives that the availability of prior test items as well as the video recordings of the conventional class presentations proved an invaluable data source from which to formulate precise performance related statements. These precise behavioral objectives assist one in the next step, namely, forming instructional strategies.

5. Instructional Strategies

Since the conceptual structure of the collegiate physics course did not pose major sequencing problems because of the constancies within existing text books as well as the equivalent structure or reverification from the CAI task analysis, the instructional strategies focused on the conveyance of appropriate learning expectancies to the students via various types of media presentations. Distinctive instructional strategies were utilized for each of the subsections of a lesson.

First, each textbook reading assignment was followed by a detailed CAI quiz which had a specified criterion performance level. If a student failed to meet criterion, he was given a remedial reading assignment and recycled through the quiz items. This strategy insured that the students' comprehension of the text was more than sufficient. In regard to the audio lectures, a set of typed notes and diagrams were utilized in conjunction with the audio tapes. The concepts presented in the audio lectures again were evaluated in terms of CAI quizzes. For remedial purposes, students were required to repeat the presentation if their performance did not meet criterion. For both the physics conceptual film presentations and the laboratory film loop presentations, there were related CAI quiz items. Again, students were directed to return to the presentation if their performance was not at or above the desired criterion level.

In each of the lessons, the final assessment of the behavioral objectives was in terms of a CAI problem set. Students were provided detailed remediation within the structure of each of the problems. As a follow-up, a parallel form of the physics problems was presented as review material prior to both the midterm and final examinations. These CAI review problems again assessed the long-term retention of the behavioral objectives for each of the lessons.

In essence, the instructional strategies were created in order to relate hypothesized sets of psychological states through which the student would pass while completing various tasks in each of the physics lessons. In this regard, the students were provided a recognition of the learning expectancies to be covered within each of the sub-sections of the physics course. This was accomplished via explicit directions plus criterion quizzes at the end of each sub-section. These psychological expectancies provided involvement and commitment on the part of the student to obtain the desired behavioral objectives. Without this psychological commitment, there would be a low probability that the CAI instruction would produce the desired optimal learning outcomes.

Having gained the student's involvement, the new information of each lesson must be sequenced in light of the prior knowledge and problem-solving skills gained in prior lessons by the student. The algorithms of these problem-solving skills are clearly related to the specific sub-concepts of each topic in the physics course. For example, the solution of kinetic energy problems related back to considerations of the sub-concepts of force and matter. If a student had mastered the sub-component elements of each concept, then the more complex algorithms could be applied.

As a last feature of the instructional strategy, an attempt was made to provide frequent conceptual closure and the self-realization by the student of having gained competency over each specific topic in the course. This psychological requirement for frequent closure is one of the most overlooked aspects involved in effective instructional strategies.

6. Media Assignment

As a related aspect of the development of the automated physics course, the process of assigning appropriate media for each concept is critical. Most of these decisions are typically based on relatively unexplored research conceptions. Obviously, the media utilized for a given presentation has to be as contiguous or as similar to the response modality as possible. The physics course utilized a wide variety of multi-media modalities. Rather than restricting the presentation only to the CAI-CRT terminal device, the most appropriate match between the media and the information features of the concepts was attempted. This use of multi-media within the physics course offered an opportunity to analyze the learning impact of these media types.

The following guidelines were used for media selection. First, when attempting to facilitate acquisition of conceptual material, the use of multiple sensory channel inputs was maximized. For example, in presenting a complex demonstration of physical phenomena like kinetic energy, either PSSC films or film loops were used in order to maximize the richness of the sensory characteristics. Second, when allowing for both acquisition and intellectual problem solving, the information source was focused within restricted sensory channels. For example, many problem-solving routines were illustrated within the audio lecture through the use of accompanying graphic presentations. Third, when attempting to build problem-solving skills for long-term retention, the use of feedback and correction via CAI was maximized. The interactive feature of the CAI system was utilized in order to individualize the feedback, the correction, and to insure sufficient practice. Fourth, when faced with evaluative decision-making, especially in determining successful attainment of the behavioral objectives, the real-time student history feature of the CAI system was utilized in order to scan over a number of learning tasks in determining an appropriate decision about criterion performance. And lastly, the logistics of the instruction from the student's point of view in moving from one media device to another was considered. While interruptions may break the monotony of the instructional process, it has been found that interruptions within learning processes can interfere with acquisition and retention. Thus, an attempt was made to match appropriate media in order to have a smooth flow through a given lesson.

7. Field Tests

In conducting the field tests and subsequent revisions, the following factors seemed important based upon our experiences. First, appropriate selection of students who vary according to aptitude, prior knowledge, and other psychological characteristics is difficult to obtain but important. The forming of special sub-groups to assess their reaction to the materials formed the substance of all future revisions in the CAI physics course. Secondly, the importance of looking at learning frame statistics as well as overall course performance became quite contingent upon our ability to process and analyze the CAI data encoded within the computer system. As will be explained in a subsequent section, a computer data analysis and management system was developed in order to perform these analyses. Various reports proved invaluable to the course authors in the revision process and should be considered an essential part of any computer approach to instruction. Third, good interview techniques should be employed constantly, not just at the end of the course, but throughout the instructional process. Informal comments from students can be treated as hypotheses which need to be checked out as to their validity and potential implications for course change. The informal comments from students concerning scheduling and the reliability of various media devices indirectly formed the basis upon which certain equipment and scheduling changes were made in the CAI physics course. Lastly, a pool of experienced personnel with clear understanding of their functions is required when one is pursuing development work in computer approaches to instruction. For example, the primary function performed by the student proctors was one of assistance to the students, but more importantly they served as input sources by which important information was gained both through direct observation of and interactions with the students.

8. Field Study and Project Development Schedule

Table 1 (see next page) presents a brief quarter by quarter description of the primary project activities. It can be observed that most of the first year was devoted to developing the course. The first field study was conducted in the fall of 1967. The second field study, the most complete of

Table 1

Developmental Schedule for the Project

	First Year. (1966–7)	Second Year, (1967–8)	Third Year, (1968–9)
Fall	Project Initiation Staffing, CAI Problem Exercises, Course Analysis	First Course Field Test, CAI Problem Exercises	FLEX Field Test
Winter	Video Recording, (1967), CAI Problem Exercises, Task Analyses Entry Behaviors	Data Analysis, (1968) Course Revision	Data Analysis, (1969) Final Report, Project Ended
Spring	CAI Problem Exercises, Behavioral Objectives, Film Preparation, Course Authoring	Second Course Field Test CAI Problem Exercises	
Summer	CAI Coding, Audio Loop Preprations, Graphics Preparation, CAI Problem Exercises	Data Analysis, Course Revision	

the experimental versions, was presented in 1968. The final field study that focused on individual difference outcomes was completed by December, 1968. This project schedule offers at least one example of the time requirements to develop a collegiate CAI course.

MANAGEMENT TECHNIQUES

The primary task in the management of the project consisted of evolving and redefining the functional roles for staff personnel. As new needs and related functions were identified, a staff member assumed the responsibility and in essence created the role. The primary mechanism for planning and co-ordinating was a weekly staff meeting. While more formal project planning techniques like PERT might have improved the project's development, the unknown nature of the CAI course development process resulted in the use of more informal planning and communication techniques. However, the use of the Systems Approach as a model for CAI curriculum development guided our efforts.

Any CAI project utilizing a rich array of technological equipment requires a complex functional organization that differentiates roles and related competencies. This section of the paper describes the various roles which evolved within the physics project.

1. Content Scholars

Foremost within a CAI project is the requirement for excellent subject matter scholars who have complete command of the concepts to be taught. The project was fortunate to have the involvement and professional commitment of four professors from the Florida State Department of Physics. While the project did not create a major new sequencing of the concepts of physics, each of these men provided excellent insights within the following phased steps.

First and foremost, these professors devoted innumerable hours to the preparation of a detailed conceptual outline of the course. In addition, they allowed us to video-record their classroom presentations over two successive quarters. These video recordings were used to study the language and demonstrations utilized in these lecture presentations. As various segments within the CAI course were developed, each of the four professors provided valuable contributions in terms of critiquing and editing the course materials. Since these materials were automated, these professors went through them in a student mode in order to detect any misconceptions or inaccuracies. In addition, the professors provided invaluable service in the continual preparation of new sets of midterm and final examination questions as well as the homework assignments for the physics class. It should be noted that a common set of examinations and homework problems was utilized in comparisons between the conventional and CAI versions of the course.

Informally, these physics professors also contributed to the development of the field studies by lending professional support to the process of gaining permission to teach the CAI version for full university credit. While this may seem like a minor point, one should not minimize the time and energy required to gain permission to offer credit for an experimental instructional course. Typically, the university administrators wish the assurance that the "new" course will be equivalent to or better than the existing course. Prior to the first field study, as many arguments as possible for accrediting the course were assembled with the knowledge that the empirical outcomes might in fact refute some of the claims.

2. Behavioral Scientist

An equivalently important talent is represented by the behavioral scientists who provided insights into the overall creation and implementation of the systems approach. Being "behavioral methodologists," the behavioral scientists provided reasonable criteria for the behavioral consequences of the instruction. They also analyzed the issues dealing with the topics of entry behaviors, task analysis, behavioral objectives, and instructional strategies. Concurrently, the behavioral scientists contributed the major structure of the research design as well as specific hypotheses which are reported within the field studies. Since they had prior experience with experimental data analysis, the responsibility for analyzing the instructional outcomes and interpreting them also was assumed by the behavioral scientists. Perhaps most importantly the behavioral scientists provided the managerial leadership and the training of other personnel within the project in order to achieve the project goals.

3. Physics Writers

Since the talents of both the professional physicist and behavioral scientists are in exceedingly short supply the project recruited a full-time physics writer. After being trained in the nature of CAI and the desired instructional strategies, plus viewing the video tapes for appropriate language, the full-time writer, as well as three part-time physics graduate students, proceeded ahead with the detailed writing of the instructional materials. Thorough command of the physics content and an understanding of the overall systems approach and computer capabilities were required. The majority of the writing was performed by these authors. It can be recommended that such full-time writers form an essential ingredient in a reasonably large CAI developmental project.

4. CAI Coders

After the instructional material has been edited, a CAI coder entered it into the FSU-IBM 1500 CAI system. The CAI coder had a thorough understanding of the Coursewriter II language, the uses of switches and counters for real-time data analysis, and the role of macros which provide a method for more quickly encoding curriculum materials. The CAI coders, who are excellent typists, typically performed both the entry and copy editing functions; that is, many minor mistakes were picked up by these coders and referred back to the physics writers and the physicists. This type of informal editing can be exceedingly important within the implementation phase of CAI.

5. Media Specialists

In terms of the physics project, part-time media specialists were employed who helped in the preparation of the concept films as well as the audio tapes. Since a random access audio system was available for this project, instruction in the preparation of tapes was required. While no special or unique functions evolved for these media specialists, they did prepare all of the final version of the curriculum.

6. Computer Operators

As the physics course was being encoded by the CAI coders, a computer operator had to be available for supervision and normal back-up operations on the computer. The primary contribution of the computer operator was in terms of solving linkage failures within the CAI courses. These linkage failures are computer errors which drop required indices that correctly link up various branched parts of a CAI course. In addition, the computer operators kept a very extensive set of records as to the nature of the CAI operation and scheduled work loads, so that appropriate materials were available for all students.

7. Computer Systems Programmers

In the process of developing the course, it was necessary to employ a computer systems programmer who developed the FSU Data Analysis and Management System. In addition to designing overall systems for CAI operations (e.g., more effective ways of encoding materials for data analysis, or more effective reports for authors and investigators), the computer systems programmer focused on the logistics of the total computing system. Resolving certain logistics problems, such as the requirement for extensive course listing, etc., has been very important within the CAI context in order to insure prompt processing of all requests. Moreover, the systems programmer has developed special Coursewriter functions that allow an author to gain the kinds of information and branching flow desired within the instructional sequence. Thus, the overall computer system was vastly improved by the computer systems programmer.

8. Data Analysis Programmer

Repeated data analyses, especially in terms of item frames, were required as a critical part of the project. This function typically involved taking data from the CAI data management system and processing it on any of the computers on the FSU campus. While many of these statistical programs such as items analysis and linear regression were available, the preparation of new input/output statements were a special requirement for the project.

9. CAI Proctors

As mentioned in the description of the field study, a proctor is necessary to supervise the actual mechanics of CAI instruction. The primary activity in the physics project was assisting students in preparing various media devices for actual utilization. Proctors had competencies in physics so that they could assist students with conceptual problems. However, these problem-solving requests were so infrequent as to be almost non-occurring. In addition, the proctors kept extensive observational notes and performed interviews which provided a great deal of information related to the student's adaptation to the multi-media CAI physics course.

10. Graduate Students

Within any large CAI curriculum development project there should be an array of graduate students who can provide at least two significant contributions. First, the graduate students represent excellent back-up personnel and superior problem-solvers. The physics project was inundated with a multitude of small problems and our graduate students learned a great deal by resolving them. More importantly, though, the graduate students continually raised questions about the overall systems approach and generated small research experiments related to major questions revolving around instructional strategy and media selection. This small-scale experimental research performed on other content topics provided important information during the formative stage of this project. Thus, it is felt that the support and active involvement of graduate students is an important ingredient in the overall mix of functional roles in a complex CAI project.

DATA ANALYSIS AND DATA MANAGEMENT

As a result of the need for data analysis in the CAI physics project, a general file structure system was developed that allowed for the organization of each student's behavioral responses into a clearly identifiable file array. This general file structure is an exceedingly important feature in data analysis for a number of reasons. First, authors tend to be primarily interested in item or frame statistics. The file structure must be manipulatable so that item and frame statistics can be printed out in a number of ways in order to characterize performance and allow for easy inference making in the revision process. As a corollary, the quick availability of this information for the authors is exceedingly important. Secondly, the file structure must be amenable to comparative analysis for various portions of the course, or various media presentations. These comparative analyses permitted the project team to decide whether certain hypotheses were in fact valid and worthy of further pursuit.

In terms of more sophisticated analyses, a number of factorial and linear regression techniques were utilized in order to obtain both with and across group comparisons. The data file structure was organized in a matrix fashion in order to generate variance and covariance matrices which could be utilized within these regression models. These linear regression analysis techniques are extremely useful in gaining insights into the identification of variables which are important in terms of positively influencing the performance levels resulting from the instruction.

One of the great potentials of CAI data is the sequential tagging of each student's response. The sequential analysis of responses has proven to be of considerable difficulty and the FSU CAI Center is still developing programs to allow for more adequate analysis of sequential responses as well as latencies. Ultimately, it is hoped that these analyses will eventuate into quantitative models that characterize the learning process. Unfortunately, the complexities of the analysis have prevented this avenue from being pushed much beyond the linear regression models. Thus, it is felt that the investment in and development of the Data Analysis and Management System was an important ingredient for the successful completion of this project.

SUMMARY

This paper has primarily described the CAI curriculum activities of the FSU Physics Project. Unfortunately, there are few empirical reports from other CAI curriculum projects in the United States that describe their developmental procedures. Informal discussion and communications with these other CAI projects indicate close similiarities to our efforts at FSU. In light of these similiarities, the following eight factors seem critically important in determining the rate of development and success of a computer-based curriculum project:

1 The use of the systems approach and the clarity of the behavioral objectives derived for the CAI curriculum will determine the rate with which a project will be developed.

2 The variety and frequency with which varying response modalities such as speech, light pen, keyboard, etc., are required in a course can affect the rate at which a CAI curriculum can be implemented.

3 Terminal criterion performance levels for the CAI course will determine both the instructional sequence as well as the complexity of the instructional strategy. In turn, the complexity of the instructional strategy will determine the developmental rate of the project.

4 The variety of multi-media utilized in the CAI course will determine the implementation rate and the logistic ease of the instructional process.

5 The number of revision cycles required to develop an "optimal version" of a CAI course remains an unanswered question. However, the use of CAI problem sets to determine baseline performance and video recordings of excellent instruction in a conventional setting allowed for restricting the number of revision cycles.

6 The degree of sophistication of the CAI operating system is highly critical in determining the rate of development. The availability of an efficient coding language with macro techniques plus an operative computer data analysis and management system is highly essential for a favorable rate of development.

7 The number of experimental versions of the CAI course will determine the rate with which the project successfully reaches closure. However, investigation of experimental issues is necessary for the full evaluation and validation of the curriculum.

8 Since it is recognised that CAI curriculum development is a highly complex process, the use of multiple role differentiation techniques and specific functional assignments for staff members leads to more effective and efficient rates of development.

DISCUSSION

The session divided into two distinct sections; the first dealt with points arising from Hansen's paper, the second consisted of prepared statements describing developments in Louvain, Glasgow, the Centre for Structural Communication and H.M.S. Collingwood.

Professor Hansen spoke briefly enlarging on the thinking behind his paper and in particular spoke of the value of having a generalised learning model. All the instructors had some conception of student processes but the model adopted gave some common framework and was particularly useful in explaining the work to anyone not directly involved. He outlined three possible strategies for task analysis:

1. interviews with successful students.
2. building up modular flow diagram of course.
3. starting with desired objectives and then moving backwards until entry points were reached.

He also emphasised the importance of getting the system in operation quickly, then revising by using data collected through the system, although he warned against collecting too much data at first.

In answer to questions he replied that the course covered ground that would usually require 30 hours of conventional instruction (3 hours a week for 10 weeks) but that the average time saving on this was of the order 10/15%. In addition there was a further 6 hours of revision material. Full details of the entire project had been published and was available, in 3 volumes, from Florida State University. There was the possibility of extending the material to other universities and there had been four formal requests for the entire course and altogether about twenty others were interested in some of the problem papers.

Mr. D'Arcy then thanked Professor Hansen for his paper and pointed out that most CAI projects in the States were built up piece-meal and that one of the objects of this seminar was to enable us to benefit from their experience. He thought that the paper gave us, in effect, a very concise and clear do-it-yourself CAI kit, covering the learning model, the systems model, management techniques and data processing. He wondered if we could start by looking at one of the central themes of the work which was the interaction of the learning model with the systems model in the area of instructional strategies and in particular at the primary issue of selection and control.

Dr. Annett stated that this was an area in which he was particularly interested and thought that it was one in which the computer could do well something that could not be done satisfactorily by other means. He wondered if Hansen would enlarge on his work.

Professor Hansen explained that this matter of student choice was one that had interested him considerably and that he was still engaged in further work. (Among choices allowed to the students had been additional exposure to work and complete control over review material). He indicated that this work, and the work on the physics course, gave a clear indication of the gain to be made from allowing student choice to take place. These results were confirmed by work done in the University of Texas. He also stated that they were exploring the possibilities of multi-person experiments with two, three or four students using one terminal.

Professor Pask outlined the continuum that existed between the learning strategy that allowed the student to explore freely his learning environment and that which used some feedback to control him. In between the two extremes was a 'conversational' system that allowed the student a choice of strategy.

If the machine thought it necessary to override the student it could do so but the student was told why and the general effect was to obtain a compromise between the strategies preferred by the student and those preferred by the machine (there are more details of this position in the paper presented by Pask). There was evidence to show that the very good students did benefit in the free environment and that there was an average gain in the restricted one with the good students being slowed up. However, in the conversational systems there had been a dramatic increase in learning.

Mr. Duke then asked if the discussion could be brought round to the areas of attack; should one choose simple or complex areas if one expected a good return. In particular he asked Hansen why he had chosen physics.

Professor Hansen replied that he thought the really important thing was the people involved and that he himself believed in finding bright exciting people who would then select their own area. In doing this he had a very broad view of what constituted CAI. In Florida, for example, there was a group using a computer to study poetry. They used a batch processing system and the response time was several hours. He maintained that this was still CAI and that the important ingredient was the people who wished to work in that area.

Dr. Adams looked for criteria to justify using the computer and thought this could be that the work must contain something that the computer could add and that responses at the terminal must be relevant to the objectives of the course. It was also important that student responses could be processed.

Mr. Hodgson raised the question of cost and in particular the payment to Faculty members in the Florida project. He thought that reducing costs was a critical issue in CAI.

Professor Hansen replied that it was difficult to apportion costs in a large developmental project and referred to the 3 volume report which detailed this. He suggested that anyone interested in this should contact the university for these reports.

Mr. Hartley thought that the difficulties of implementing and using a CAI system were consistently underestimated particularly on the educational side. He thought this might be because evolutionary processes in education favour the teacher so that through the years a system of classroom organisation, book methods, set syllabuses and public examinations had been developed. Computers would favour different more individualised methods but the present system seems reasonably efficient – and it is the one in which computers must find a place. This has led to a way of implementing computer-based learning in which experienced teachers were found, quizzed about objectives, educational content and structure, the responses which they expected from students and the decisions they make. These were stored within the computer and all instructions duly carried out. He believed that such methods may be useful and necessary at the start but there are disadvantages. The material is expensive to produce because all the work had to be done by highly trained personnel, and although courses will benefit and be more efficient than conventional methods the teaching strategies will have been of the 'ad hoc' variety. Many variables were undefined and uncontrolled so that it was difficult to see how it could be improved. Because of this expense the material is not likely to be tampered with and the project would acquire much inertia. In addition to this all difficult decision-making and production of material had to be anticipated so that the educational use of the computer was rather trivial; it merely stored and presented information. He advocated that within large scale projects there should be smaller projects that allowed the computer to take over more of the teaching decisions, to help in generating material and adapting to the individual student.

He thought it may be necessary to set such experimental projects in areas which present particular difficulties to the teacher and tackle those functions in which the size of classes made him less efficient. He then postulated three phases of teaching; initial teaching in which the learner is introduced to certain ideas, concepts or techniques, supporting practice for this, and finally, problems in which the student applies what he has learnt.

It was unlikely that the computer would be acting to its full potential in teaching pure content as the physical constraints of the interfacing equipment often made it less congenial than conventional methods. However, the computer could have a useful role to play in practice exercises. The notion of practice implies rules so that if these and the elements used together with levels of difficulty are specified then the computer could generate material, adapt to individual performance and provide close monitoring and control. Teaching in this way was economic, and typically, quickly produced learning gains over conventional methods. At the same time the computer could be used as a calculator and relieve the student of monotonous low level tasks.

A much more interesting use was in problem-solving and simulation techniques and at Leeds such work was being carried out in aspects of science, mathematics and clinical diagnosis. Teaching material was stored so that the student could refresh his memory but it was assumed that he had had initial conventional teaching. Computer-based learning projects in problem-solving were being prepared to make the student seek out and use information and ideas to solve particular problems. The resources of the computer would be used to help and at the same time monitor progress. If an area for experiment was chosen so that the elements and underlying rules are known, e.g. electric circuitry, some types of chemical reactions or clinical diagnosis (assuming relations between diseases and symptoms can be stated in probabilistic terms), then the computer could teach adaptively. At Leeds there was now a framework for experiment, they knew what variables to work with and, hopefully, the instruction would be improved. Student performance data was on a scale which could be handled and which should give insight into the learning process.

He finally expressed a hope that attention would be given to such small scale 'depth' projects for they may well provide a base for second generation CAI projects.

Miss Ash thought that Mr. Hartley may be right in suggesting some limitations in setting up research projects but that his description of the teaching responsibility was a gross over-simplification. Teaching and learning involve far more than initial exposition, drill and practice and problem-solving. His approach would tend to place constraints on the educational processes and make them more rigid. She believed we should aim to extend the learner's experiences, to broaden horizons rather than restrict them and that computers could help in this process.

Mr. Broderick agreed with Miss Ash and suggested that one of the most rewarding applications of computers may be in the enrichment of the learning environment through simulation and game playing. For example, tremendous insight into chemical reaction could take place if a student were able to define two compounds and a set of physical conditions and observe the reactions taking place in slow motion on a graphic display. If we could add to this the facility for the student to manipulate the parameters of the system (the physical conditions) it could lead him to a better understanding of this aspect of chemistry.

The Royal Liberty School had produced two gaming programs for experimental purposes, a business game and a town planning game. This work is preparatory to a deeper study of this aspect of CAI and whilst work is only at the early stages the teaching staff concerned were encouraged by the usefulness of the system and the students found it developed a better understanding of an otherwise 'abstract' area of the curriculum by enabling them to learn heuristically.

Dr. Adams pointed out that the machine was in fact well suited for teaching mechanical skills and that many of the problems facing society were at the level of people requiring such skills. These mechanical skills were the things that teachers claimed they could teach but the evidence was against it.

Professor Hansen gave three instances of fields in which the computer could play a major role.

(i) Counselling work – he knew of cases where students preferred to use a computer because they could rely on obtaining accurate information.

(ii) Computer Managed Instruction was becoming more prominent. It was certainly an area where information may be too much for teachers to handle.

(iii) As a resource in complicated problem solving.

Dr. Adams thought that the report of the N.C.E.T. study team had not taken enough notice of the design potential of the computer and instanced some work in lens systems that was being done in the States.

Dr. Eraut brought the discussion back to the question of costs again and asked if the 6 hours of problem solving could justify the expense.

Professor Hansen replied that the 6 hours problem solving could be taken separately and some students had done just this. Students who did the entire course did better.

Dr. Rothkopf said that the costs of producing an hour's instruction for Bell Telephone Company were about $10,000 and thought that Hansen's figures should be examined very carefully.

Professor Jones then introduced a short paper describing the system developed by him and J. M. Zelis at the University of Louvain and also used by le Corre in Paris. The system was part of a more general project intended to improve the study of mechanics in a General Physics course and altogether 80 students are involved. Each student works through a sequence of questions, answers and comments and these are linked together on a matrix so that they can be presented to the student in any order and in any way that is wanted. The answer the student gives leads to the next question or comment and the logic of the system ensures that no question which has received a correct response will be asked again.

The work is done on the Bull-G.E.C. time-sharing system and the following data is collected:

For each student:	order of questions
	number of questions
	time to respond to each question
	score for one sequence
	mean score for all sequences
For each sequence:	frequency for each question
For all students:	a mean value of the time for each question
	the time required for each sequence

Time is also provided for each student to discuss his work with tutors.

Miss Wallace presented a paper describing teaching undergraduate biology and medicine at the University of Glasgow. The most advanced work is a series of self-instructional units on endocrinology and renal disease involving the use of 35 mm. slides with synchronised audio-tape. The student makes his response on a prepared response sheet. The team producing the work feel that although certain concepts can be taught by traditional programmed methods there is a strong case to be made for using a computer in the second stage of the process – transfer of knowledge to new situations. What is being proposed is a self-instructional system in medical education consisting of traditional lectures, tape/slide programmes (self-instructional), computer assisted instruction (self-instructional) and tutorials.

The educational approach to the CAI presentation is algorithmic so that there will be several tracks through the work but there will also be certain 'gates' which must be passed. It is hoped to have a random access slide projector linked to the teletype which will supply the visual element. The slide projector will present summary captions from the tape/slide programmes and these captions will provide remedial loops. There are no plans at present for linking a random access tape-recorder to the system. The cost of producing the educational content of one hour of instruction will be close to £1000 – somewhat more than five times the cost of producing the first copy of tape/slide programmes.

An investigation into the possibility of using the COTAN on-line desk system was being carried out and there would be co-operation with Culham laboratory in this field.

Mr. Hodgson read a paper on the work of the Centre for Structural Communication. The researchers at the centre believed that computer-based learning systems suffer two major areas of neglect. These are:

(a) Unrealistic estimates of the difficulty and magnitude of the task of computer compatible curriculum design and development – the 'software' gap.

(b) A confusion in relating the sophistication of computer data processing to the actual level of educational significance which that data processing possesses – the 'blinding by technology'.

Work at the centre could make significant contributions to these areas and they felt that Structural Communication enabled the computer to be applied to areas of higher complexity in Bloom's cognitive domain rather than to just knowledge, comprehension and application. The modular design of Structural Communication is easily implemented in CAI and CMI and several U.S. organisations (I.B.M., Westinghouse and the U.S. Navy) had used units. It had also been established that teachers and lecturers could be trained to write study units in a time ratio of 10 to 50 hours per student hour and that these units were meeting their objectives. Furthermore, the units already produced covered a number of academic fields (ranging from art appreciation to management and engineering) and for a variety of ages and abilities.

Captain Huggett then described the system at H.M.S. Collingwood for training electrical technicians. The approach could be described as a systems approach with a measurable input and output and the procedure adopted for evolving the work followed similar lines to those described in Hansen's paper. There had been a considerable amount of work with programmed learning but this was applied where it seemed appropriate rather than as a blanket device, i.e. they had a complete training package. Out of a twenty-five week course about half was programmed and there was considerable scope for revision as a new course started every two weeks. They were interested in using their present scheme as a testbed into which CAI could be fitted and in redeveloping their course so that the modules could be seen as a whole, i.e. they did not wish to go through the course, rewriting each module in turn but would like to develop the CAI aspect of all modules at the same time.

SESSION IV LEARNING SYSTEMS

COMPUTER ASSISTED LEARNING AND TEACHING

Gordon Pask, System Research Limited

DISCUSSION

Rapporteur, Professor Harold Mitzel

COMPUTER ASSISTED LEARNING AND TEACHING

Gordon Pask

Director of Research, System Research Ltd.
Professor, Institute of Cybernetics, Brunel University

IN their recent report on computer based learning systems the NCET working group introduced the happy neologism "learning system analyst" to designate a person with an inter-disciplinary approach to the matters they discussed. I shall put on the hat of this new profession in tackling the more restricted topic of the present paper.

From this point of view, it is evident that teaching is a form of control and that Teaching systems are built to control a learning process. This idea is developed in Section 1. However, any controller is designed on the basis of a model for the controlled process. Hence, in Section 2, we take up several issues to do with learning and teaching models and relate these notions to the business of system design.

To limit the scope of the discussion, it is assumed that the reader is familiar with the salient concepts of programmed instruction and systematic training which, in many respects, are precursors of the ideas involved in the (chiefly) computer assisted (CAI)* systems treated in the paper. It is also assumed that the reader is conversant with the main CAI display and response facilities (teletypewriters, CR tubes, light pens, function boards, computer controlled slide projectors) and the currently available response modes (multiple choice, constructed, word matching against synonyms, open ended etc.). Although programming languages and programme organization are vital constituents of CAI (and though many questions of this nature are relevant to the present argument) these matters are not considered since they lie in the province of other authors.

Within this restricted field, the paper touches upon much of the research going on in Great Britain and the USA. No attempt has been made to review European and Russian developments, many of which are on a par with and some of which are in advance of the work that is mentioned.

1. TEACHING AS THE CONTROL OF LEARNING

1.1. Introduction

A computer assisted teaching system (CAI system) is intended to control the learning process in an individual (the usual case), in a team or in a community. Proper as it is, this use of the word "control" has often led to crass misconceptions because "control" is rather narrowly interpreted. The required connotation is "guidance". Control is not necessarily authoritarian. It may equally well be co-operative or catalytic. Moreover, tutorial control can be exercised even if the educational goal is underspecified (a point we take up in 1.5. For the moment consider the commonest case, where the educational goal *is* well defined).

Now the symbolic instrument of control is a strategy; when it is lodged in a computing machine I shall call this a teaching strategy. But the influence of a teaching strategy is always contingent upon its acceptance by the student and the *actual* control of learning is frequently bilateral. Students learn continually, even in the absence of educators or their artifacts. In particular they direct their attention, choose goals to achieve (problems to solve) and partition them into subgoals (subproblems). This activity is governed by one or more of a class of learning strategies, certain qualities of which constitute the student's learning set. Thus, any teaching strategy is in competition with learning strategies that already exist. It may be possible and expedient for the teaching system to suppress the student's learning strategy and to introduce its own strategy as a surrogate. In other circumstances the teaching strategy is co-operative,* insofar as parts of it replace defective or missing segments of the student's learning strategy. In other conditions again, the strategy followed by the coupled student-machine system is a compromise between the inbuilt teaching strategy and the strategy the student would have adopted if left on his own. To illustrate these points, let us consider the sorts of control exercised in a number of teaching systems.

1.2 Representative Systems

(1) *Direct Individual Control.* The computing machinery is equipped with a single teaching strategy. Excluding the trivial case, where the computer is used as a page turner** the execution of this strategy calls for more or less detailed performance information gleaned from the student to whom the machinery is coupled. Typical instances are CAI systems with history dependent branching programmes (decisions at a choice point may, perhaps, depend upon long sequences of past responses) and simple feedback controlled training systems such as Gaines's,[1–2] Kelly's,[3–4] Hudson's,[5] Sime's,[6] or my own.[7–10b] Here the level of task difficulty (for example,

* Computer Assisted Instruction.

* It is worth making a distinction between the strategic co-operation, noted above, and the co-operation which goes on in any of the systems cited in 1.2.(1), (2) or (3). Even with a fixed strategy any of these systems perform an operation which we class as "increasing the task difficulty" or conversely "decreasing the task difficulty". In reality, this is often a complicated operation based upon a model for the student's learning process (as in Section 2 of the paper) and "decreasing task difficulty" is reducible to the canonical form "simplifying the problems posed by the task" or (equivalently) "partially solving these problems on the student's behalf". Such an operation is clearly co-operative though *not* in the strategic sense. Since all of the systems in 1.2. (1), (2) and (3) perform this operation all of them are partially co-operative systems.

** Trivial only in the present context. Such arrangements may be quite useful but their value depends upon factors beyond the scope of this discussion; for example, the ease of recording responses, getting statistical data or updating administrative files.

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the mean amplitude of a forcing function input in a tracking task, the pace of operation in a perceptual motor skill, the withdrawal or delay of cueing information in an intellectual skill) is increased as the student's proficiency increases and vice versa. The overall result is to balance the student at an operating point (in terms of task loading) that is predetermined to favour learning.

(2) *Adaptive individual control.* Performance information is used directly as in (1) but, in additio. , this information is evaluated and used to change one or more parameters of the teaching strategy. For example, the adaptive loop may change the operating point of (1) or it may change the weighting attached to several different variables which are adjusted to alter task difficulty or, as noted in (3), it may even change the form of the strategy. This category of systems is exemplified by Smallwood's teaching programme and by more sophisticated training systems for perceptual motor and simple intellectual skills. (Gaines, Sime, and Pask.[10–12])

(3) *Conversational Systems.* * The machine is provided with a *class* of strategies based upon a preliminary investigation of the learning strategies adopted by a population of students; this class is open ended; new strategies can be added as they are discovered. The machine is also furnished with information about the appropriateness of these strategies (for example, that Z_1 is effective if the student assembles the solutions to subproblems in the context of the problem as a whole, Z_2 is effective if the student solves problems like a puzzlist by stringing the subproblems', methods into a more or less linear sequence).

For his own part, the student also has a class of learning strategies from which he selects one at any moment. In a conversational system the student's and the machine's strategies are described and discussed (at a higher level of discourse than the problem and solution dialogue of straightforward instruction) and certain propensities of the student are specifically tested (for example, his ability to see problems as a whole, his ability to adopt an algorithmic approach or, at a more pedestrian level, the interference characteristics of his intermediate memory). Often the test data evaluates properties of which the student is either unaware or imperfectly aware. Other things being equal, the machine allows the student to employ whatever strategy he has selected but (a) the student may have doubts about how to learn, in which case the machine makes a suggestion or (b) the chosen strategy may be quite inappropriate insofar as (in view of the measurements just made) the student would be unable to handle the task in the way he prefers. If so, the machine overrides the student, tells him why it is doing so and enforces a substitute strategy. Naturally, this process is repeated throughout the conduct of teaching so that, on average, a compromise is achieved between the strategies preferred by the student and those preferred by the machine. It is also possible to envisage the evolution of hybrid strategies. This comment delineates an important area for research.

Several systems have a genuinely conversational calibre. Some of Stolurow's[13] systems do so (the conversation is phased into parts that determine the student's characteristics, parts involved in strategy selection, and so on). Kopstein and Seidel,[14-15b] at HumRRO are designing their system, IMPACT with the required properties (a pilot version has been put into operation); programmes like TASKTEACH[16] and PLATO[17] in its enquiry mode have many conversational features; Uttal has devised a system of this type. Conversational systems have been used for skill instruction in my own laboratory (Pask,[18] Lewis and Pask[19]) and we have completed a study of conversational interaction in simple problem solving which unequivocally demonstrate the efficiency of this mode of control.

In one way the distinction between the adaptive system (Type 2) and the conversational system (Type 3) is fairly tenuous. If (as in Type 2) the parameters of a strategy are altered by the control loop, then a family of strategies is generated. Thus both Type 2 and Type 3 systems are based on a *class* of strategies. However, Type 2 strategic control depends only upon the machine's interpretation of the student's behaviour. In a Type 3 system the student's *interpretation* of his own state is also taken into account (this is quite crucial) and the machine is required to "interpret the student's interpretation" as well as his behaviour. Indeed, the cycle of student-machine "interpretations of interpretations" has no theoretical limit and the total system is, in principle, akin to a system of interpersonal interaction. (Bateson,[20] Laing,[21] Brodey[22]).

(4) *Game like systems.* All of the systems so far considered are game like if they are properly instrumented; game like in the sense that the student plays with or participates in discourse with the machine. However, certain systems are game like in a different sense; the student is invited to participate in a game which (like a business or management game) simulates a situation he is required to learn about. Two categories of system are worth distinguishing (a) The game is a fairly veridicial representation of reality. Though it often constitutes a useful training device this fact is incidental to its primary function. Some examples of the category are aircraft simulators, the Leviathan simulation of Sidney and Berenice Rome[22–24] at SDC (a very large, computer controlled, system) the medical diagnosis game[25] at Harvard and the SIMPOL system used, in my own laboratory, to simulate the managerial and resource allocation aspects of a police unit.[26–27] (b) Games which are rigged up in order to teach someone (say an economics student) about the symbolic structure of his discipline (economics). Here, the paraphernalia of the game is specifically devised for instruction; economists are not generally required to play such games in real life (though, in the computer oriented environment of the future, they may be). Perhaps the best known system of this type is the Sumerian game[28] in which history students learn about the socio-economic structure of Mesopotamian civilization in 3500 BC (there are several less colourful examples).

(5) *Group systems.* The idea that students can be used to teach one another is by no means novel, and the concept has been refined in terms of group dynamics by Abercrombie[29] and by Ackoff.[30] Broadly, the adaptive and self organizing capabilities of the students are used as part and parcel of the teaching system. In many ways it is very convenient to mechanize the interaction between the students by providing

* Here, I am using the word "conversational" with its full logical meaning. Thus a quasi natural language computer terminal is not necessarily a vehicle for conversation just because it permits direct online communication with a human being. Conversation involves discourse at several levels; the higher levels accommodate statements that evaluate, arbitrate, criticise, command and select whatever is designated by the lower level discourse.

interfaces via which they communicate with one another or via which they gain access to data sources. In this context it becomes perfectly evident that the tutorial process must be catalyzed and guided (a) by assigning roles (such as A instructs B or C co-operates with D or E is the subject matter expert on X, F on Y); (b) by providing the channels of communication necessary to these roles; (c) by varying certain economic parameters of the system (in particular, the cost of communication and the gain obtainable as a result of successful performance).

Quite a lot of small group psychology, from Bavelas onward, is relevant to this theme; for example, Lee Christie[31] has for many years been alive to the potentialities of group learning systems (see Kelly for a useful review, slanted towards this point of view). More specifically, Osgood has used the PLATO system for group tuition; Glaser and Klauss[32] have examined reinforcement schedules for teams and Lewis and I have carried out a series of experiments on machine controlled group learning.[33-35]

The last system will be briefly described, since it illustrates the group teaching paradigm in a simple but realistic form. We were teaching inductive inference. For this purpose we used an iterated form of Bruner, Goodenow and Austin's[36] conjunctive concept attainment task (a) the group had to tackle a sequence of over 100 "concepts", i.e. any member had to handle a subsequence of evidence and to give a description, keyed into his console, of an unknown conceptual class; (b) the roles were (I) transmitter of information (concept exemplars), (II) receiver of the information (the man who sees the wood for the trees); (c) the communication channel conveying knowledge of (conceptual class) membership information was perturbed by varying amounts of "noise" (misinformation) so the students had to learn inference in noisy conditions; (d) the students sat at consoles in separate cubicles in which they received or transmitted concept exemplars and knowledge of membership information and via which they keyed their hypothesis and conclusions into external registers; (e) after each concept had been dealt with the controlling automaton (I) delivered knowledge of results, proficiency measures and updated a variable called "Bank Balance", (II) allowed the students to express their preferences for different roles, (III) weighted these preferences as a function of the standing "Bank Balance" and allowed the receiving students to purchase co-operative communication links, (IV) assigned roles and sequenced the next set of moves, (V) set the level of misinformation so that a certain level of success could be reached.

An initial study revealed that some groups learned better than others; indeed, a few failed to learn altogether. The successful groups could be characterized in several ways. For example, they engaged in an initial phase of objectively detectable co-operative activity; they traded off variety of behaviour (reduced by learning) for variety of communication and role structure; the entire group acted as a self-organizing system in the sense of von Foerster.[37-39] Later in the series we introduced teaching strategies that acted upon the economic and role selection parameters of the system so that the conditions conducive to success obtained in any group, i.e. the controller was given a set of *group* teaching strategies and used these to catalyze favourable aspects of the developing *group* organization. The controlled groups were significantly more successful than the uncontrolled. Similar results were obtained in training a trajectory interception team but, although the latter work was done in the early 1960s, the results are only available in report form.[40]

1.3. Areas Omitted

There are two major omissions from the list; both are important but neither is fully within the compass of this paper. (1) The computer is used as a tool (or laboratory) for teaching the student mathematics or programming. Notable instances are Feurtzig and Paperts LOGO[41] and James Thomas's[42] work with TELCOMP (both addressed to schoolchildren 10-12 years upwards). Here the computer only controls the student in the rather esoteric sense that any environment controls its inhabitants. Of course, the subject matter is irrelevant to the comment. The systems mentioned above are facilities (environments) that extend the student's programming experience. By way of contrast, Seidel and Kopstein's system at HumRRO is a computer controlled learning system that also (incidentally) teaches COBOL programming. (2) The computer is used to control community or school activities by differentially routing individuals through various educational tasks (for example, practical work, reading, programmed instruction). This is a promising field, so far chiefly represented by Flanagan's PLAN project.[43]

1.4. A Couple of Common Myths

Even with these exclusions the systems listed in 1.2 provide sufficient evidence to destroy the common myth that CAI is wedded in principle to the rather tedious paradigm of a question and answer routine. It is not.

Before going on, I would like to discredit another myth (mentioned in 1.1) which does a great deal to hamper development in CAI. The myth in question is that the educational goal of the control system must be fully and formally specified. Of course, the goal of the controller itself must be well defined: but that does not mean that we have to know the "right" answer to each question. There need not even be a "right" answer. It is still perfectly possible to design a heuristic device that encourages learning.

The following hoary and whimsical example demonstrates the point. Suppose you make utterances $x_1, x_2 \ldots$ (all of which are members of a set X) to a friend and that the friend replies with utterances, gestures or grimaces $y_1, y_2 \ldots$ (selected from a set Y). A very simple minded control scheme amounts to rewarding certain of the x, y relations with a nod of approval, i.e. you choose a mapping $\emptyset_o: X \rightarrow Y$ and reward all y such that $y = \emptyset_o(x)$. Here, the mapping $\emptyset_o$ is the crux of a fully specified educational goal. Equally well, however, you might choose to reward any consistent relationship, i.e. your friend could, unknown to you at the outset, select *any* $\emptyset$, not your $\emptyset_o$ and you would reward him provided his usage is regular thus encouraging him to learn *some* relation. Of course, you, as the controller, have a well-defined goal (mathematically it is of the form: maximize $-dH(X, Y)/dt$ where $H(X, Y)$ is the contingent entropy of the selections from X and Y but you do not have a fully specified education goal as you did in the first variant of the experiments.

The principle involved is neither restricted to trivial systems nor to simple minded reinforcement procedures. For example, it is easy to set up an adaptively controlled system in which the student is provided with more items to classify as he shows evidence of producing *any self consistent* and *informative* (efficient) scheme of classification (the student's reaction is interesting in its own right; people who *like* to innovate find life in this libertarian teaching system exhilarating; those who do *not*, find it thoroughly disturbing).[44] There is no reason why the same ideas should not be applied to much more complex teaching situations and a moment's contemplation indicates that similar notions are implicit in the operation of any open ended conversational system.

1.5. The Evaluation of Control Methods

The categories of control listed in 1.2 have psychological cogency; they correspond to recognizable situations or relations between the student and the machinery. They are also quite realistic. Given a skill or a body of subject matter to be taught, and given a description of the student population it is possible to come up with estimates of the cost of each sort of control in terms of hardware and software. Further, a good deal is known about the behaviour and relative efficiency of systems Type 1, 2, 3, and 5 (when a skill and a student are specified).*

Evaluation is possible because the control methods are specified relative to models for learning; hence the methods may be evaluated in respect to real systems with which the model in question is identifiable to form a theory of learning. The nature of these theories is taken up in Section 2. But we comment, at this juncture, that these theories are *educationally* relevant insofar as they treat subject matter organizations and modes of cognition that are characteristically in the human domain and with which all teachers are familiar. Hence they are not amongst the simplest sorts of learning theory which appeal to experimental phychologists because of their elegance and structural parsimony; the simplest theories are often (and perhaps rightly) discounted on the grounds that they have little relevance to education. The present batch of theories are proof against this criticism (and so are the system evaluations derived from them). However, both the theories and the evaluations can be attacked from a different quarter.

The fact is, the theories are most readily testable when the corresponding learning models are identified with laboratory situations. There are several reasons why this is so; the models themselves are workable with respect to small (though, as above, representative) chunks of mental activity. At an experimental level, the effect of individual differences (between subjects) becomes embarrassingly large if the experiment is unduly prolonged (by "pure" psychology standards the experiments are fairly lengthy; even so they do not often last more than a day or two). Finally, there is a purely practical reason why the control systems have been tried out in miniature. Most of the work in this field has been conducted in laboratories which (until recently at any rate)** have had special purpose on line control gear rather than on line equipment controlled by a general purpose computer (as a half-facetious, half-serious aside, workers having "big" CAI interfaces seem to have been preoccupied with getting them going rather than finding out what they do). Under these circumstances the cost of experimentation is appreciable and it is necessary to choose experimental situations that are as small as *possible.*

Because of all this, it is perfectly possible to maintain that the theories and consequently the control methods attached to them have been tested in conditions that are educationally picayune. That is a caveat which must qualify all of the comments in the next few paragraphs and it may or may not be viewed as a damning one. My personal conviction (supported by the argument in Section 2) is that the educational relevance of the theory and the test situation are of primary importance and that the time scale of the experiment and the precise character of the problem solving activity do not matter too much.

The following notes are grossly generalizcd summaries of the main findings.

If ^ skill or body of knowledge is unstructured, i.e. if studer..s are unable to say how they learn it after careful interrogation, apart from a statement to the effect that they engage in practice, then a fixed training routine (a feed forward procedure) appears to be as good as any other. Acquisition is just a matter of repetition. Type 5 control is useful in maintaining the student's motivation and may be used to check his perseverance.

Rather few skills are completely unstructured. Presumably, the skills (if any) acquired by simple conditioning are of this sort. In the later stages of learning (but *not* at the outset) many perceptual motor skills are unstructured. The same comment may apply to the later stages of learning computational skills (mental arithmetic) and possibly (though probably not) to the later stages of language acquisition. Rote learning, if it really took place, would be a matter of repetition but, unless precautions are taken to prevent him doing so, the student structures almost any list or catalogue, however meaningless it seems to be.

In contrast a skill (body of knowledge) may be structured in the sense that (I) it can be represented as an hierarchy of subskills *or* (II) a goal-subgoal hierarchy *or* (III) an hierarchy of TOTE units *or* (IV) an hierarchy of concepts *or* (V) if learning can be conceived as the elimination of a finite number of Error Factors. If the skill is structured (and the student can be persuaded to see it in this way) it becomes possible to talk about the existence of learning *strategies.*

Suppose that one such strategy has been selected on logical or psychological grounds as a good strategy. Now, a Type 1 Feedback control system designed relative to this good strategy is more effective than either (1) a fixed (feed-forward) routine based upon the *same* strategy or (2) Free learning. The advantage becomes marginal as (a) the acquisition of each component of the skill (body of knowledge) approximates "one shot" learning or (b) the set of *possible* strategies are uniformly "good".

Consider a *family* of learning strategies derived from a single good strategy and a Type 2 control system based upon this strategy family. In general, the Type 2 system is more

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* The evaluation of Type 4 control depends ceitically on the material Sometimes a game like mode of instruction is mandatory. When a game is optional there is evidence to suggest that Type 4 control is a relatively effective method of instruction.

** The picture in this country is as follows: Kay and Sime have recently set up a computerised installation at Sheffield. Annett and Duncan at Hull, have an interface linked to an Eliott 903 which is just becoming operational. Cook, Hartley and Sleeman have a system with multiple hardware (KDF9, Modula R.I.) at Leeds. Gaines still relief chiefly upon special purpose equipment. So do I, though we are considering the economy of using a general purpose machine. It should be emphasised that the experimental requirements are fairly quirkish. A simple on line terminal is virtually useless for this purpose.

effective than the corresponding Type 1 system, if either (1) there is interference between the acquisition of one part of the skill (body of knowledge) and some other part of it or (2) the student needs to build up a learning set in order to secure competent performance ("interference" and "learning set" may be interpreted within any of the frameworks (I), (II), (III), (IV), (V)).

Suppose there is a class of learning strategies which may be adopted by different students (or the same student on different occasions). It may not be possible to single out a strategy as "good"; for example, because some student uses each strategy effectively, i.e. we could only say "that strategy is good for a student with certain characteristics". In this case a Type 3 conversational control system is more effective than either a Type 1 or a Type 2 system designed on the basis of an arbitrarily chosen good strategy and is very much more effective than free learning. The merit of Type 3 appears to be greatest when the influence of cognitive fixity (getting stuck with an inappropriate strategy or selection) is most obtrusive. As noted in 1.2 Type 5 control may be used to achieve Type 3 control, either in the context of a group of otherwise independent individuals or in the context of a team.

The majority of evaluations are expressed in terms of trials or time to reach a criterial performance with some check upon retention. A few are expressed in terms of uncertainty reduction. A more telling measure might be the time to reach a given level of understanding as indicated by the extent to which the knowledge in question is locked into a cognitive network. Tests for such a property have been devised but have not been extensively used.

1.6. Control Methods as Educational Facilities or Educational Subroutines

There is little difficulty in isolating skills such as list learning, relation learning, series completion or concept attainment for which one of the control methods listed in 1.2 is better than the rest, and to determine the cost of instrumenting it.

However, the majority of curricula—in mathematics, statistics, history, etc., call for the inculcation of several skills. This comment also applies outside the academic sphere; in the instruction of many complex tasks. Here, the picture is a good deal clearer since the subject matter is not so conventionally (perhaps arbitrarily) ordered.

In COMCEN operator training, for example, it is possible to justify the use of all five control procedures (listed in 1.2) at various stages in the process.[45] This is true, even if we confine our attention to the code teleprinting skill which is one ingredient of a COMCEN operator's repertoire.

At the outset, there is a strong element of problem solving. The student has to form concepts to do with different parts of the keyboard and the acquisition of one demonstrably interferes with the acquisition of another. A similar situation occurs at a later stage, when the student is mastering the many to one relationships entailed by upper-case and lower-case operation. With the "difficulty" variables chosen as cueing and pacing, a Type 1 feedback control (Section 1.2) is empirically superior to mere practice and, in certain circumstances (if the student's behaviour goes outside a limited range), the Type 2 (adaptive) control is still better. In our own system, COMOPTS 1, the demand for Type 1 and Type 2 control is met by providing an overall feedback control teaching system in which the student is normally situated and an adaptive system into which he is routed for remedial practice.

Up to 30 hours of conventional training (about 10 hours in the mechanized training system) there are several possible learning strategies. Since this is so, a conversational system (Type 3) is required (if only because we are unable to determine an appropriate teaching strategy on behavioural evidence alone). It is provided in a partially mechanized form, by a "programme" or "flowchart" in which the student substitutes values derived from the feedback trainer after each exercise block. Further substitutions are made to indicate the student's preferences and to point out aspects of the skill that are causing peculiar difficulty. Following through the substituted flowchart, the student is directed either to alter parameters of the feedback machine, to rehearse the skill on the adaptive machine or to engage in other activities (which will, in the final version of the system, involve working through segments of a programmed text).

After 30 hours of conventional training, the task is substantially homogeneous (from the student's point of view) and the acquisition of further competence depends chiefly upon practice. Here, an open loop training system would be as good as any other (given only a minimum monitoring of performance). The main problem is to keep the student motivated as he grinds away. For this purpose, COMOPTS 1 will make use of control methods Type 4 (simulation) and Type 5 (gaming), i.e. students will be periodically presented with realistic communication situations and periodically required to play partly competitive and partly co-operative games with one another via the teleprinter interface (augmented by a board that delivers commands and synchronizing signals). The frequency and the nature of these interventions are automatically scheduled as a function of performance which is measured during the communication act. These measurements provide sufficient information for monitoring purposes. At the moment, the monitoring is manual but it could be automated without difficulty. In a programme such as TASKTEACH (which is capable of teaching quasi intellectual skills, typically fault detection and maintenance), an instructor sets up the list which gives the system a structure akin to COMOPTS; within this framework the student is free to choose his own fate (conversational Type 3 control) or to invoke more restrictive procedures (resembling Type 1 and Type 2 control).

Similar comments apply to PLATO, Kopstein and Seidel's IMPACT and other large CAI systems. However, since these are generally used to instruct academic skills (statistics, computer programming and the like) the simple pattern is obscured. Statistics, for example, already has a conventional order imposed upon its instruction so that the plan for teaching the subject matter as a whole contains phases in *each* of which the control methods of 1.2 are called into operation, generally with different parameter settings to achieve specific subgoals. In the context of a large CAI system the control methods of 1.2 thus have the status of tutorial *subroutines*.

It should be emphasized that the distinction between a tutorial subroutine and a full CAI system is made on the grounds of organization rather than size. To see this, notice that the Stanford System (Suppes and his colleagues) consists in a series of isolated subroutines which are called into operation at the discretion of a teacher or supervisor. Thus the "drill and practice" mode, used for teaching children to carry out arithmetical operations, is a large but simply structured feedback (Type 1) subroutine; the "tutorial" system employed for logic instruction (and other purposes) is a mixed conversational and adaptive subroutine (a hybrid of Type 2 and Type 3). The Stanford system has, nevertheless, massive provisions for recording and evaluating data and the system itself is one of the largest and most liberally interfaced* in existence. Of course, if the external supervisor uses the data to select the subroutines or to adjust their parameters then the system (*including* the supervisor) *is* a full CAI system. Without the supervisor it is not.

1.7. Evaluation of the System as a Whole

It can be stated with some confidence that a full CAI system is no less effective than a system of programmed instruction or a system of classroom instruction. The more cautious commentators, seeking a general evaluation of the art, have gone no further than this and have still managed to justify CAI on economic grounds for higher education, special civilian and military training (where instructional costs are high in any case), and for many industrial and governmental purposes. When relatively inexpensive systems (such as Bitzer's) come into operation the cost of CAI will fall from about \$2.4 per student hour to about \$0.35 per student hour due, in no small measure, to large-scale production techniques and hardware innovation; this change will place CAI within the economic compass of the school system.

But all of these estimates, predicated on "CAI is no worse than . . .", may be unduly pessimistic. In view of the information available about the basic control methods (educational subroutines), it is not unreasonable to suppose that CAI may be "a great deal better than . . ." other techniques and, if so, any cost benefit argument in its favour should be more readily acceptable.

Unfortunately, the evaluation of a total CAI system is beset by a number of difficulties. Some of these have already been mentioned; for example, the problem of coping with individual differences. However, there are five obstacles which deserve special attention.

(1) Providing it has been competently designed, any CAI system whatever is bound to give a saving in time and effort. For example, we can claim that COMOPTS will train teleprinter students (up to 3 or 4 week level) in half the time taken by a conventional training routine. But we have a relatively vague idea about how much of this effect is due to the tutorial action of the system. Some of the benefit stems from an incidental rationalization of improvident training techniques; in specifying any CAI system an efficient planning procedure is forced upon the designer. In particular, the CAI system is far more flexible and individualized and the greatest organizational advantage is gained when it is possible to get rid of the class attendance concept (so that the system can be used optimally with respect to the pupils). The Army Operational Research Group[46] in a much earlier study, predicted a similar enhancement in training efficiency (for morse training) on these grounds alone; without reference to CAI as such.

Needless to say, the same comments apply with even greater force to CAI systems used in the academic sphere. The enhancement due to organizing instructions and avoiding time wastage is particularly great if, with Eide,[47] we count the students' time as one of the most costly educational resources (there is a very strong case for doing so at the national level).

(2) Any competent CAI system will work because of the Hawthorne effect. It is difficult to discount the influence of novelty in an experimental situation. Desirable though the improvement may be, it is not directly relevant to the tutorial influence of CAI.

(3) Whereas it is easy enough to find standard conditions for controlling small-scale experiments (free learning or a fixed training routine) it is not so easy to select a control condition for a full CAI system (glibly CAI performance is compared with the performance of "conventional teaching", but what *is* "conventional teaching"? It is fairly well defined for perceptual motor skills but not for academic skills).

(4) Individual differences are not only large (a point made already in 1.5) but specific to the motivational variables that appear in the fully-built CAI system.

(5) The final and fundamental difficulty is that no one really knows what to measure (as evidenced by the fact that vast amounts of latency and response data have been collected on tapes, though very little of it has been used for evaluation). Just as the functional evaluation of an educational subroutine calls for a learning theory (which, amongst other things, tells the experimenter what to measure) so the evaluation of an entire CAI system calls for an educational theory. At the moment no adequate theory exists, though several relevant developments are noted in Section 2.

Thus, at the moment, we are in the position of a programmer equipped with a collection of working and evaluated subroutines who is anxious to evaluate a programme (the full CAI system) constructed from these components. It would be naive to suppose that the evaluation of the whole (in the educational case) is the sum of the evaluations of the parts. In some instances, useful limits can be set up in terms of subroutine evaluation but a general appraisal of CAI seems to rest, as suggested above, upon an educational theory. We return to this point in Section 2.8.

1.8. Critical Statement

It is true that computers have often been used (under pressure to use the things somehow) in an unimaginative, narrow or downright stupid fashion. But this should not lead to a condemnation of the entire field: computer control of learning has great and diverse potentialities, some of which have already been realized.

The general development of computer control does, however, entail paying more attention to psychology and logic than it is currently fashionable to do.

To take just one aspect* of the psychological point, most of the varieties of control listed in 1.2 call for an adequate interface (which is certainly not a teletypewriter) and an adequate language. These questions are really in the province of other authors at this symposium; I only wish to make two points which illustrate a broad contention: (1) any conversational system must have an interface and a language which allows the student to state what he intends to do, not only as a plan for action but also as a plan for learning; (2) by the same token, the interface and language must allow the student to evaluate prescriptions and descriptions *either* to do with the task itself *or* with the process of learning it. One of the most useful evaluations is a subjective uncertainty

* For example, the student receives spoken messages in addition to visually displayed material.

* We return to it in the section on learning models.

measure, preferably obtained with a Shuford[48] type of scoring function as mechanized by Baker.[49]*

These facilities are mandatory adjuncts to quite simple studies of teaching and it is disheartening to find elaborate computerized systems which lack them altogether. Needless to say, the systems cited in this paper, especially Seidel and Kopstein's system, *do* have such facilities. So do many European and Russian systems which are excluded from the survey.

On the issue of logic, there is an understandable tendency to see things through the eyes of computation technology. Logic is parochially (and naively) identified with propositional and first order predicate calculus. But, insofar as a logic of teaching is a logic of conversation, this is an insufficient framework. It is at least necessary to synthesize a scheme from the framework as it stands and (a) a logic of relations (the higher order predicates); (b) a logic of commands (Rescher[50] and von Wright[51]); (c) a logic of parallel (rather than sequential) organizations, for example, using Holt's scheme;[52] (d) a context logic (in the sense of Kotely[53]); (e) a logic of distinctions and form (Spenser Brown[54]) and (f) a logic of games and metagames in the sense of Howard.[55] Some efforts have been made in this direction, notably by the social anthropologists who face much the same problem as "learning system analysts". It is plain silly to pretend the problem does not exist, to give up in despair or to bludgeon away with techniques that serve well enough for describing mechanical computation (as carried out by present-day computers) but are unfitted to adumbrate the dynamics of mentation.

2. MODELS FOR LEARNING AND TEACHING

2.1. Overview

Any controller is designed according to a model which can be interpreted and identified as a theory of the controlled process. In the case of teaching (the control of learning) this theory is a learning theory and it represents either the student alone or the student coupled to a specific teaching system. We emphasize that the underlying model is the *designer's* model *of* the process; it is *he*, the designer, who interprets it as a theory. Furthermore, it is *he* who carries out experiments to verify the theory and it is *he* who, if necessary, alters the model to fit the facts.

In contrast, models may also be used inside systems. Here the teaching device is provided with an internal model which it is built to interpret as a theory of the student with respect to the educational goal. It uses the model to determine its next move, it performs experiments to validate the model, and, if necessary, it modifies the model. In other words the system learns about the student and builds up an internal representation of the student state. The distinction between (designer's) models *of* the system and (system) models in the system is non trivial when the system acts in this fashion. All conversational systems and most adaptive systems do so. (It is of interest to note that the system might start from scratch and build up a student model *de novo*. In practice this process would take far too long and even if it could be instrumented would clearly constitute an uneconomic design.)

* Other techniques, such as a mechanised version of the Kelly grid, could be introduced with advantage.

2.2. The Scope of the Models

We have talked of learning theories and student models as though these things were neat packages. In fact, there are several separate representations which form part of any model and which are given varying amounts of emphasis.

(1) A representation of the subject matter to be instructed.

(2) A representation of the educational goal. In the simplest case this is a statement of the looked for terminal behaviour but frequently there are cognitive components in the specification.

(3) A representation of the initial state of the student when he enters the teaching system i.e. of his current level of competence, his attitudes and possibly his personality.

(4) A representation of the current state of the student (3) above providing a statement of the "initial conditions") Generally, this part of the model is far more detailed and is mainly restricted to a representation of the student competence and his learning strategies (if attitudes, personality etc. appear in the model at all they are assumed to remain unchanged by learning).

(5) A representation of the teaching system including its teaching strategies.

All of these representations are present (perhaps in an embryonic form) within competent (designer's) model of the student and his instruction. Models *in* the system are set within the framework afforded by (1), (2) and (3) but (insofar as the internal model is changed as a function of experience) the internal model itself is restricted to components (4) and (5).

2.3. Some Types of Learning Theory

Confining our attention to components (3) and (4) of 2.2, there are several types of learning model available to the designer of a CAI system. (Many of these are only interpretable on the "subroutine" scale considered in Section 1.2).

In order to appreciate the state and potentialities of CAI it is necessary to review the major types of learning theory and to comment upon their ranges of application. As a prefatory remark the various theories are often complementary to one another; the differences are mainly philosophical. At a pragmatic level the recommended teaching strategies tend to be quite similar (as they should be! the theories are theories of the same system!). Nevertheless, one point of view may be very much more useful than the rest when it comes to modelling a particular situation.

(1) *Behaviouristic Models.* The operant conditioning approach of Skinner was largely responsible for "linear" small step programming (a teaching paradigm still at the roots of many CAI systems). More liberal concepts of behaviour shaping have led to the "Mathetics" type of programme[56] (which consists in large frames, eliciting many covert and overt reponses, each one resembling a well planned advertisement).* The S-R-operations (apart from basic conditioning and association) are chaining, discrimation and generalization and these operations are evoked in sequence in

* In terms of this paper, both Skinnerian and "Mathetical" techniques are "feedforward" techniques. The *student* received a reinforcing feedback but feedback signals are *not* employed to modify the sequence or type of instruction.

order to produce (by hypothesis) such a juxtaposition of associative connections that the criterion behaviour can be achieved.

The main attraction of this theory is its simplicity, atomicity and quasi physical calibre. Its main disadvantages are (a) that the structuring of the task (representations (1), (2) and (3) of 2.2) is *outside* the model and is catered for *informally* (the matter is left to the designer's discretion). (b) The representation of such entities as concepts, rules and plans ((4) and (5) of 2.2) is exceptionally cumbersome and may even be impossible.

(2) *Stochastic learning theories,* especially the stimulus sampling theory of Estes and his colleagues.[57-58] Stochastic models are admirable predictors of the statistical properties of simple behaviour, for example, of response probabilities (strictly, these are properties of an ensemble of students but they may be interpreted as properties of processes which are ubiquitous and thus represented in any student). Some typical and interesting applications to teaching are Dear and Atkinson's[59] model for concept learning and Matheson's[60] use of a stimulus sampling model in combination with the technique of dynamic programming to prescribe optimal teaching strategies for certain (more or less repetitions) tasks. The control and evaluation procedures in Smallwood's[61] CAI system are based, primarily, upon stochastic learning theory and this scheme, though not so highly developed as Matheson's, is applicable to a much wider range of subject matter. Hence the stochastic models have much to recommend them. Their disadvantages are those voiced in connection with the behavioural models and, in addition, the limited tutorial relevance of the statistical properties they predict so well.

(3) *Error Factor Theory.* Within this (more or less behaviouristic theory) learning to do something is regarded as the elimination of the influence of Error Factors which prevent it being done and which are responsible for classes of mistaken responses. Error Factor Theory[62] is particularly well suited to designing feedback and adaptive control systems for perceptual motor and problem solving skills. It has the great advantage of imaging the response process as potentially multidimensional and the vector of difficulty variables (Section 1.2) can be placed in direct correspondence with the set of Error Factors. The forms of learning predicted by Error Factor theory and simple reinforcement theory are somewhat different but the recommended training strategies are much the same (Error Factor theory yielding consonant but more detailed recommendations).

(4) *Functional Theories.* Enough is known about certain of the subsystems involved in learning to model them meaningfully as mechanisms (rather than "Black Boxes").* This is especially true of the functionally demarcated subsystems "Immediate" (short term) "Working" (Intermediate) and Long Term memory, of which the first two are fairly well investigated.

* In Ashby's sense; modelling the input output characteristics or transfer function of a system.

The characteristics and limitations of immediate memory are familiar from work in pure experimental psychology; clearly these limitations should be respected in the design of any CAI system (as in the design of any other man machine interface). The working memory system is less well documented but is especially germane to teaching since it is in this system that skills and bodies of knowledge are integrated into structures and it is here that interference and positive transfer of training take place.

There are various models for the system, but Atkinson and Shiffrin's[64] is well validated and is stated in a form applicable to CAI. The working *memory* is akin to a programme embodied in a working *storage* which serves as a general purpose computer that may be programmed in several ways. Each way is an information control procedure; for example, one procedure is a rehearsal buffer, another is a sort of push down list processor, another is a procedure for transfer to long term memory. Fiegenbaum's EPAM programme,[65-66] a computer simulation of working memory viewed as a discrimination and association network, is a further model of this type and is also well validated. Given a theory based on one of these models, it is possible to recommend very detailed teaching strategies. Several of these have been tested as part and parcel of the experimental effort connected with the modelling. It should be noted that the teaching strategies derived from functional theories are generally compatible with those derived from behavioural theories. But the functionally derived strategies are far more sophisticated.

(5) *Objective Informational Theories* (Wattanabe,[67] von Foerster,[73] Pask[68-72]). The word "information" is used in its technical sense (selective information, measures of information) and learning is viewed as a reduction in relevant uncertainty which is influenced by such variables as the student's information loading and the informational redundancy of the materials presented to him. "Objective" implies that the informations, uncertainties, etc., in question are those of an outside observer, not of the student. On the one hand such objectively measured uncertainties are clearly related to statistical indices such as response probabilities (regard stimuli as signs selected from an input alphabet and responses as output selections). Thus the informational theories of learning are related to the behavioural theories. On the other hand, the information measures, though obtained over sets of behavioural alternatives, may be held to estimate the student's uncertainty. Insofar as they do so a bridge is established between behavioural theories and subjective information theories and via these between behavioural theories and cognitive theories of learning.

(6) *Subjective Information Theories.* The information measures are computed from subjective estimates of degree of belief (or doubt) obtained by the methods of Shuford, Baker and others.* These workers have developed a learning

* Essentially in a game like situation where the student is assigned a score dependent upon his numerically *asserted* degree of belief in several alternatives. His assertion is constrained to secure "probability" numbers which sum to one over all of the alternatives. The scoring function employed is such that, over a sequence of trials, the student's mathematical expectation of score is maximised if, and only if, his *asserted* degree of belief equals his *real* degree of belief.

theory which is comparable with an objective theory and have used it to prescribe various teaching strategies.

(7) *Structural Theories.* The developmental psychologies of Piaget and Luria[74] are structural theories insofar as they postulate certain mental structures which dominate the psyche at different ages. At the level of individual learning (rather than development) there are several theories of a like kind; Gagne,[75–76] for example sees the acquisition of a skill as the assembly of an hierarchical structure of capabilities. Learning occurs when a pair or more of subordinate capabilities are wedded together by an instructi n that combines them in some way; but the instruction will only be effective *if* the requisite subordinate capabilities *are* already established. For dealing with a body of knowledge (rather than a skill) the "capabilities" are replaced by "concepts" (given a behavioural emphasis a concept is a capability to classify and respond).

(8) *Organizational and Cybernetic Theories.* These are structural theories in which the basic units built into an hierarchical structure are goal directed, problem solving or control systems (either contained within the organisation or acting partly through the environment. The theory has a cognitive aspect; since "aiming for a goal" or "solving a problem" explicitly involves a state of knowing. Miller, Gallanter and Pribram[77] proposed a TOTE (test operate test exit) unit as the goal directed building block; essentially this is a piece of *programme* which corresponds to a contingent of IF, THEN, ELSE, statement. A plan or a concept is conceived as a nested structure of TOTE units.

I have pointed out that in order to build up or modify such an hierarchy (i.e. in order to talk about learning) it is necessary to invoke an independent *hierarchy* of control (or problem solving of problem solving). Because of this any Cybernetic learning model is *heterarchical.*[78–79c]

(9) *Programmatic Cognitive Theories.* In general these turn out to be Cybernetic theories although the basic units are specified simply as information processing programmes, the execution of which may be expected to produce a state of knowing and the consciousness of a plan, hypothesis, concept or strategy.* All artificial intelligence models which purport to simulate human learning belong to this class. Since the models are very complex and varied, it is impossible to convey the gist of them in a few words but the subject has been reviewed in another paper.[80] Bennett and Hodges "Structural Communication" or "Systematics" type of programming is based on a cognitive model;[81–82] informally so at the moment, but a formal treatment is clearly possible. It is also quite clear that although systematics programmes can be administered by textual methods, they are really fitted to CAI administration and have the status of CAI systems.

(10) *Other Cognitive Theories.* Several perfectly respectable cognitive theories do not fit easily into the currently popular programmatic framework. Two good examples are Festinger's[83] cognitive dissonance theory and Kelly's personal construct theory.[84] Both of them have potential value in connection with certain aspects of learning and teaching (notice for instance the close relation between the "cognitive fixity" of 1.2 and "cognitive dissonance").

(11) *Statistical Cognitive Theories.* Guildford[85] and Bunderson's[86] factor analytic studies of learning showed that different mental processes (aptitudes) are important at different stages in learning the same task. Clearly, these "processes" have a statistical calibre akin to the response "processes" in a stochastic model apart from the fact that they are cognitive rather than behavioural entities. A body of hypotheses frames in terms of there variables can be usefully interpreted as a theory (such a construct is used in the IMPACT model).

(12) *Theories of representation and learning type,* notably Bruner's[87] theory of ikonic, mnemonic and automatic representation and the linguistic theories of Vygotsky,[88] Luria and their pupils.

2.4. Models and Theories of Learning

The learning theories of 2.3 are concerned with the components or representations (2) and (4) of Section 2.2 (namely of the student's initial state and his current state). Given a specific task or body of knowledge it is fairly easy to adjoin a representation of the subject matter (component (1) of 2.2) and of the educational goal (component (2) of Section 2.2) to yield a *descriptive* and predictive (or explanatory) theory of *learning the task in question.* Clearly, the representations employed for this purpose must be *compatible* with the type of theory chosen and it is almost platitudinous to remark that the choice of a learning theory will depend upon the subject matter and the educational goal that an investigator has in mind. For example, the behavioural theories are simple and thus (in one sense) preferable. But it is difficult if not impossible to set up a subject matter representation which is compatible with such a theory if the subject matter entails plans, concepts and the like, in anything more than a naive fashion.* In general, it is necessary to reach a compromise between theoretical simplicity and realism of subject matter representation and the structural and Cybernetic theories are peculiarly useful in this respect.

Although the models of Section 2.3 are chiefly descriptive (and predictive) models, they can all be used in a *prescriptive* fashion** to yield recommendations for teaching; either a set of teaching strategies or a teaching system. Thus, we enquire what operations would be necessary to achieve the educational goal (with respect to a given body of subject matter and a given student model) and specify a teaching model capable of performing these operations. The requirement may, of course, be more or less refined; for example, we might demand a set of operations to achieve the goal as fast as possible or set of operations that lead to a generalized rather than a specialized competence. But, in any case, the teaching model constitutes component (5) of Section 2.2 and, when

* Unless the entity is specifically tagged as a reflexive or autonomous unit.

* This is a personal bias. For instance, I *do* believe it is naive to regard a concept as no more than a class of stimuli that evoke some common response.

** The distinction between the descriptive and prescriptive use of models was originally drawn by Kopstein. It has been employed extensively by Stolurow and myself. Stolurow also consider models that have little predictive power. Thus, my usage is somewhat different. All of the models cited in this paper, for example, have predictive or explanatory power.

r Hansen gave three instances of fields in
ıe computer could play a major role.
unselling work – he knew of cases where
ıdents preferred to use a computer because they
uld rely on obtaining accurate information.
mputer Managed Instruction was becoming more
ominent. It was certainly an area where
formation may be too much for teachers to
ndle.
a resource in complicated problem solving.

ms thought that the report of the N.C.E.T. study
d not taken enough notice of the design potential
omputer and instanced some work in lens systems
being done in tne States.

t brought the discussion back to the question
again and asked if the 6 hours of problem solving
stify the expense.

r Hansen replied that the 6 hours problem
could be taken separately and some students had
t this. Students who did the entire course did

ıkopf said that the costs of producing an
ıstruction for Bell Telephone Company were about
and thought that Hansen's figures should be
d very carefully.

r Jones then introduced a short paper
ıg the system developed by him and J. M. Zelis
niversity of Louv~in and also used by le Corre
The system was part of a more general project
l to improve the study of mechanics in a General
course and altogether 80 students are involved.
dent works through a sequence of questions,
and comments and these are linked together on a
o that they can be presented to the student in
er and in any way that is wanted. The answer the
gives leads to the next question or comment and
of the system ensures that no question which
ived a correct response will be ask again.

k is done on the Bull-G.E.C. time-sharing system
following data is collected:

ı student: order of questions
number of questions
time to respond to each question
score for one sequence
mean score for all sequences
ı sequence: frequency for each question
tudents: a mean value of the time for each question
the time required for each sequence

also provided for each student to discuss his work
ors.

llace presented a paper describing teaching
aduate biology and medicine at the University of
. The most advanced work is a series of self-
ional units on endocrinology and renal disease
g the use of 35 mm. slides with synchronised
audio-tape. The student makes his response on a prepared response sheet. The team producing the work feel that although certain concepts can be taught by traditional programmed methods there is a strong case to be made for using a computer in the second stage of the process – transfer of knowledge to new situations. What is being proposed is a self-instructional system in medical education consisting of traditional lectures, tape/slide programmes (self-instructional), computer assisted instruction (self-instructional) and tutorials.

The educational approach to the CAI presentation is algorithmic so that there will be several tracks through the work but there will also be certain 'gates' which must be passed. It is hoped to have a random access slide projector linked to the teletype which will supply the visual element. The slide projector will present summary captions from the tape/slide programmes and these captions will provide remedial loops. There are no plans at present for linking a random access tape-recorder to the system. The cost of producing the educational content of one hour of instruction will be close to £1000 – somewhat more than five times the cost of producing the first copy of tape/slide programmes.

An investigation into the possibility of using the COTAN on-line desk system was being carried out and there would be co-operation with Culham laboratory in this field.

Mr. Hodgson read a paper on the work of the Centre for Structural Communication. The researchers at the centre believed that computer-based learning systems suffer two major areas of neglect. These are:

(a) Unrealistic estimates of the difficulty and magnitude of the task of computer compatible curriculum design and development – the 'software' gap.
(b) A confusion in relating the sophistication of computer data processing to the actual level of educational significance which that data processing possesses – the 'blinding by technology'.

Work at the centre could make significant contributions to these areas and they felt that Structural Communication enabled the computer to be applied to areas of higher complexity in Bloom's cognitive domain rather than to just knowledge, comprehension and application. The modular design of Structural Communication is easily implemented in CAI and CMI and several U.S. organisations (I.B.M., Westinghouse and the U.S. Navy) had used units. It had also been established that teachers and lecturers could be trained to write study units in a time ratio of 10 to 50 hours per student hour and that these units were meeting their objectives. Furthermore, the units already produced covered a number of academic fields (ranging from art appreciation to management and engineering) and for a variety of ages and abilities.

Captain Huggett then described the system at H.M.S. Collingwood for training electrical technicians. The approach could be described as a systems approach with a measurable input and output and the procedure adopted for evolving the work followed similar lines to those described in Hansen's paper. There had been a considerable amount of work with programmed learning but this was applied where it seemed appropriate rather than as a blanket device, i.e. they had a complete training package. Out of a twenty-five week course about half was programmed and there was considerable scope for revision as a new course started every two weeks. They were interested in using their present scheme as a testbed into which CAI could be fitted and in redeveloping their course so that the modules could be seen as a whole, i.e. they did not wish to go through the course, rewriting each module in turn but would like to develop the CAI aspect of all modules at the same time.

SESSION IV LEARNING SYSTEMS

COMPUTER ASSISTED LEARNING AND TEACHING

Gordon Pask, System Research Limited

DISCUSSION

Rapporteur, Professor Harold Mitzel

COMPUTER ASSISTED LEARNING AND TEACHING

Gordon Pask

Director of Research, System Research Ltd.
Professor, Institute of Cybernetics, Brunel University

IN their recent report on computer based learning systems the NCET working group introduced the happy neologism "learning system analyst" to designate a person with an inter-disciplinary approach to the matters they discussed. I shall put on the hat of this new profession in tackling the more restricted topic of the present paper.

From this point of view, it is evident that teaching is a form of control and that Teaching systems are built to control a learning process. This idea is developed in Section 1. However, any controller is designed on the basis of a model for the controlled process. Hence, in Section 2, we take up several issues to do with learning and teaching models and relate these notions to the business of system design.

To limit the scope of the discussion, it is assumed that the reader is familiar with the salient concepts of programmed instruction and systematic training which, in many respects, are precursors of the ideas involved in the (chiefly) computer assisted (CAI)* systems treated in the paper. It is also assumed that the reader is conversant with the main CAI display and response facilities (teletypewriters, CR tubes, light pens, function boards, computer controlled slide projectors) and the currently available response modes (multiple choice, constructed, word matching against synonyms, open ended etc.). Although programming languages and programme organization are vital constituents of CAI (and though many questions of this nature are relevant to the present argument) these matters are not considered since they lie in the province of other authors.

Within this restricted field, the paper touches upon much of the research going on in Great Britain and the USA. No attempt has been made to review European and Russian developments, many of which are on a par with and some of which are in advance of the work that is mentioned.

1. TEACHING AS THE CONTROL OF LEARNING

1.1. Introduction

A computer assisted teaching system (CAI system) is intended to control the learning process in an individual (the usual case), in a team or in a community. Proper as it is, this use of the word "control" has often led to crass misconceptions because "control" is rather narrowly interpreted. The required connotation is "guidance". Control is not necessarily authoritarian. It may equally well be co-operative or catalytic. Moreover, tutorial control can be exercised even if the educational goal is underspecified (a point we take up in 1.5. For the moment consider the commonest case, where the educational goal *is* well defined).

Now the symbolic instrument of control is a strategy; when it is lodged in a computing machine I shall call this a teaching strategy. But the influence of a teaching strategy is always contingent upon its acceptance by the student and the *actual* control of learning is frequently bilateral. Students learn continually, even in the absence of educators or their artifacts. In particular they direct their attention, choose goals to achieve (problems to solve) and partition them into subgoals (subproblems). This activity is governed by one or more of a class of learning strategies, certain qualities of which constitute the student's learning set. Thus, any teaching strategy is in competition with learning strategies that already exist. It may be possible and expedient for the teaching system to suppress the student's learning strategy and to introduce its own strategy as a surrogate. In other circumstances the teaching strategy is co-operative,* insofar as parts of it replace defective or missing segments of the student's learning strategy. In other conditions again, the strategy followed by the coupled student-machine system is a compromise between the inbuilt teaching strategy and the strategy the student would have adopted if left on his own. To illustrate these points, let us consider the sorts of control exercised in a number of teaching systems.

1.2 Representative Systems

(1) *Direct Individual Control.* The computing machinery is equipped with a single teaching strategy. Excluding the trivial case, where the computer is used as a page turner** the execution of this strategy calls for more or less detailed performance information gleaned from the student to whom the machinery is coupled. Typical instances are CAI systems with history dependent branching programmes (decisions at a choice point may, perhaps, depend upon long sequences of past responses) and simple feedback controlled training systems such as Gaines's,[1-2] Kelly's,[3-4] Hudson's,[5] Sime's,[6] or my own.[7-10b] Here the level of task difficulty (for example,

* It is worth making a distinction between the strategic co-operation, noted above, and the co-operation which goes on in any of the systems cited in 1.2.(1), (2) or (3). Even with a fixed strategy any of these systems perform an operation which we class as "increasing the task difficulty" or conversely "decreasing the task difficulty". In reality, this is often a complicated operation based upon a model for the student's learning process (as in Section 2 of the paper) and "decreasing task difficulty" is reducible to the canonical form "simplifying the problems posed by the task" or (equivalently) "partially solving these problems on the student's behalf". Such an operation is clearly co-operative though *not* in the strategic sense. Since all of the systems in 1.2. (1), (2) and (3) perform this operation all of them are partially co-operative systems.

** Trivial only in the present context. Such arrangements may be quite useful but their value depends upon factors beyond the scope of this discussion; for example, the ease of recording responses, getting statistical data or updating administrative files.

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* Computer Assisted Instruction.

the mean amplitude of a forcing function input in a tracking task, the pace of operation in a perceptual motor skill, the withdrawal or delay of cueing information in an intellectual skill) is increased as the student's proficiency increases and vice versa. The overall result is to balance the student at an operating point (in terms of task loading) that is predetermined to favour learning.

(2) *Adaptive individual control.* Performance information is used directly as in (1) but, in addition, this information is evaluated and used to change one or more parameters of the teaching strategy. For example, the adaptive loop may change the operating point of (1) or it may change the weighting attached to several different variables which are adjusted to alter task difficulty or, as noted in (3), it may even change the form of the strategy. This category of systems is exemplified by Smallwood's teaching programme and by more sophisticated training systems for perceptual motor and simple intellectual skills. (Gaines, Sime, and Pask.[10-12])

(3) *Conversational Systems.* * The machine is provided with a *class* of strategies based upon a preliminary investigation of the learning strategies adopted by a population of students; this class is open ended; new strategies can be added as they are discovered. The machine is also furnished with information about the appropriateness of these strategies (for example, that Z_1 is effective if the student assembles the solutions to subproblems in the context of the problem as a whole, Z_2 is effective if the student solves problems like a puzzlist by stringing the subproblems', methods into a more or less linear sequence).

For his own part, the student also has a class of learning strategies from which he selects one at any moment. In a conversational system the student's and the machine's strategies are described and discussed (at a higher level of discourse than the problem and solution dialogue of straightforward instruction) and certain propensities of the student are specifically tested (for example, his ability to see problems as a whole, his ability to adopt an algorithmic approach or, at a more pedestrian level, the interference characteristics of his intermediate memory). Often the test data evaluates properties of which the student is either unaware or imperfectly aware. Other things being equal, the machine allows the student to employ whatever strategy he has selected but (a) the student may have doubts about how to learn, in which case the machine makes a suggestion or (b) the chosen strategy may be quite inappropriate insofar as (in view of the measurements just made) the student would be unable to handle the task in the way he prefers. If so, the machine overrides the student, tells him why it is doing so and enforces a substitute strategy. Naturally, this process is repeated throughout the conduct of teaching so that, on average, a compromise is achieved between the strategies preferred by the student and those preferred by the machine. It is also possible to envisage the evolution of hybrid strategies. This comment delineates an important area for research.

Several systems have a genuinely conversational calibre. Some of Stolurow's[13] systems do so (the conversation is phased into parts that determine the student's characteristics, parts involved in strategy selection, and so on). Kopstein and Seidel,[14-15b] at HumRRO are designing their system, IMPACT with the required properties (a pilot version has been put into operation); programmes like TASKTEACH[16] and PLATO[17] in its enquiry mode have many conversational features; Uttal has devised a system of this type. Conversational systems have been used for skill instruction in my own laboratory (Pask,[18] Lewis and Pask[19]) and we have completed a study of conversational interaction in simple problem solving which unequivocally demonstrate the efficiency of this mode of control.

In one way the distinction between the adaptive system (Type 2) and the conversational system (Type 3) is fairly tenuous. If (as in Type 2) the parameters of a strategy are altered by the control loop, then a family of strategies is generated. Thus both Type 2 and Type 3 systems are based on a *class* of strategies. However, Type 2 strategic control depends only upon the machine's interpretation of the student's behaviour. In a Type 3 system the student's *interpretation* of his own state is also taken into account (this is quite crucial) and the machine is required to "interpret the student's interpretation" as well as his behaviour. Indeed, the cycle of student-machine "interpretations of interpretations" has no theoretical limit and the total system is, in principle, akin to a system of interpersonal interaction. (Bateson,[20] Laing,[21] Brodey[22]).

(4) *Game like systems.* All of the systems so far considered are game like if they are properly instrumented; game like in the sense that the student plays with or participates in discourse with the machine. However, certain systems are game like in a different sense; the student is invited to participate in a game which (like a business or management game) simulates a situation he is required to learn about. Two categories of system are worth distinguishing (a) The game is a fairly veridicial representation of reality. Though it often constitutes a useful training device this fact is incidental to its primary function. Some examples of the category are aircraft simulators, the Leviathan simulation of Sidney and Berenice Rome[22-24] at SDC (a very large, computer controlled, system) the medical diagnosis game[25] at Harvard and the SIMPOL system used, in my own laboratory, to simulate the managerial and resource allocation aspects of a police unit.[26-27] (b) Games which are rigged up in order to teach someone (say an economics student) about the symbolic structure of his discipline (economics). Here, the paraphernalia of the game is specifically devised for instruction; economists are not generally required to play such games in real life (though, in the computer oriented environment of the future, they may be). Perhaps the best known system of this type is the Sumerian game[28] in which history students learn about the socio-economic structure of Mesopotamian civilization in 3500 BC (there are several less colourful examples).

(5) *Group systems.* The idea that students can be used to teach one another is by no means novel, and the concept has been refined in terms of group dynamics by Abercrombie[29] and by Ackoff.[30] Broadly, the adaptive and self organizing capabilities of the students are used as part and parcel of the teaching system. In many ways it is very convenient to mechanize the interaction between the students by providing

* Here, I am using the word "conversational" with its full logical meaning. Thus a quasi natural language computer terminal is not necessarily a vehicle for conversation just because it permits direct online communication with a human being. Conversation involves discourse at several levels; the higher levels accommodate statements that evaluate, arbitrate, criticise, command and select whatever is designated by the lower level discourse.

interfaces via which they communicate with one another or via which they gain access to data sources. In this context it becomes perfectly evident that the tutorial process must be catalyzed and guided (a) by assigning roles (such as A instructs B or C co-operates with D or E is the subject matter expert on X, F on Y); (b) by providing the channels of communication necessary to these roles; (c) by varying certain economic parameters of the system (in particular, the cost of communication and the gain obtainable as a result of successful performance).

Quite a lot of small group psychology, from Bavelas onward, is relevant to this theme; for example, Lee Christie[31] has for many years been alive to the potentialities of group learning systems (see Kelly for a useful review, slanted towards this point of view). More specifically, Osgood has used the PLATO system for group tuition; Glaser and Klauss[32] have examined reinforcement schedules for teams and Lewis and I have carried out a series of experiments on machine controlled group learning.[33-35]

The last system will be briefly described, since it illustrates the group teaching paradigm in a simple but realistic form. We were teaching inductive inference. For this purpose we used an iterated form of Bruner, Goodenow and Austin's[36] conjunctive concept attainment task (a) the group had to tackle a sequence of over 100 "concepts", i.e. any member had to handle a subsequence of evidence and to give a description, keyed into his console, of an unknown conceptual class; (b) the roles were (I) transmitter of information (concept exemplars), (II) receiver of the information (the man who sees the wood for the trees); (c) the communication channel conveying knowledge of (conceptual class) membership information was perturbed by varying amounts of "noise" (misinformation) so the students had to learn inference in noisy conditions; (d) the students sat at consoles in separate cubicles in which they received or transmitted concept exemplars and knowledge of membership information and via which they keyed their hypothesis and conclusions into external registers; (e) after each concept had been dealt with the controlling automaton (I) delivered knowledge of results, proficiency measures and updated a variable called "Bank Balance", (II) allowed the students to express their preferences for different roles, (III) weighted these preferences as a function of the standing "Bank Balance" and allowed the receiving students to purchase co-operative communication links, (IV) assigned roles and sequenced the next set of moves, (V) set the level of misinformation so that a certain level of success could be reached.

An initial study revealed that some groups learned better than others; indeed, a few failed to learn altogether. The successful groups could be characterized in several ways. For example, they engaged in an initial phase of objectively detectable co-operative activity; they traded off variety of behaviour (reduced by learning) for variety of communication and role structure; the entire group acted as a self-organizing system in the sense of von Foerster.[37-39] Later in the series we introduced teaching strategies that acted upon the economic and role selection parameters of the system so that the conditions conducive to success obtained in any group, i.e. the controller was given a set of *group* teaching strategies and used these to catalyze favourable aspects of the developing *group* organization. The controlled groups were significantly more successful than the uncontrolled. Similar results were obtained in training a trajectory interception team but, although the latter work was done in the early 1960s, the results are only available in report form.[40]

1.3. Areas Omitted

There are two major omissions from the list; both are important but neither is fully within the compass of this paper. (1) The computer is used as a tool (or laboratory) for teaching the student mathematics or programming. Notable instances are Feurtzig and Paperts LOGO[41] and James Thomas's[42] work with TELCOMP (both addressed to schoolchildren 10-12 years upwards). Here the computer only controls the student in the rather esoteric sense that any environment controls its inhabitants. Of course, the subject matter is irrelevant to the comment. The systems mentioned above are facilities (environments) that extend the student's programming experience. By way of contrast, Seidel and Kopstein's system at HumRRO is a computer controlled learning system that also (incidentally) teaches COBOL programming. (2) The computer is used to control community or school activities by differentially routing individuals through various educational tasks (for example, practical work, reading, programmed instruction). This is a promising field, so far chiefly represented by Flanagan's PLAN project.[43]

1.4. A Couple of Common Myths

Even with these exclusions the systems listed in 1.2 provide sufficient evidence to destroy the common myth that CAI is wedded in principle to the rather tedious paradigm of a question and answer routine. It is not.

Before going on, I would like to discredit another myth (mentioned in 1.1) which does a great deal to hamper development in CAI. The myth in question is that the educational goal of the control system must be fully and formally specified. Of course, the goal of the controller itself must be well defined: but that does not mean that we have to know the "right" answer to each question. There need not even be a "right" answer. It is still perfectly possible to design a heuristic device that encourages learning.

The following hoary and whimsical example demonstrates the point. Suppose you make utterances $x_1, x_2 \ldots$ (all of which are members of a set X) to a friend and that the friend replies with utterances, gestures or grimaces $y_1, y_2 \ldots$ (selected from a set Y). A very simple minded control scheme amounts to rewarding certain of the x, y relations with a nod of approval, i.e. you choose a mapping $\emptyset_o: X \rightarrow Y$ and reward all y such that $y = \emptyset_o(x)$. Here, the mapping $\emptyset_o$ is the crux of a fully specified educational goal. Equally well, however, you might choose to reward any consistent relationship, i.e. your friend could, unknown to you at the outset, select *any* $\emptyset$, not your $\emptyset_o$ and you would reward him provided his usage is regular thus encouraging him to learn *some* relation. Of course, you, as the controller, have a well-defined goal (mathematically it is of the form: maximize $-dH(X, Y)/dt$ where $H(X, Y)$ is the contingent entropy of the selections from X and Y but you do not have a fully specified education goal as you did in the first variant of the experiments.

The principle involved is neither restricted to trivial systems nor to simple minded reinforcement procedures. For example, it is easy to set up an adaptively controlled system in which the student is provided with more items to classify as he shows evidence of producing *any self consistent* and *informative* (efficient) scheme of classification (the student's reaction is interesting in its own right; people who *like* to innovate find life in this libertarian teaching system exhilarating; those who do *not*, find it thoroughly disturbing).[44] There is no reason why the same ideas should not be applied to much more complex teaching situations and a moment's contemplation indicates that similar notions are implicit in the operation of any open ended conversational system.

1.5. The Evaluation of Control Methods

The categories of control listed in 1.2 have psychological cogency; they correspond to recognizable situations or relations between the student and the machinery. They are also quite realistic. Given a skill or a body of subject matter to be taught, and given a description of the student population it is possible to come up with estimates of the cost of each sort of control in terms of hardware and software. Further, a good deal is known about the behaviour and relative efficiency of systems Type 1, 2, 3, and 5 (when a skill and a student are specified).*

Evaluation is possible because the control methods are specified relative to models for learning; hence the methods may be evaluated in respect to real systems with which the model in question is identifiable to form a theory of learning. The nature of these theories is taken up in Section 2. But we comment, at this juncture, that these theories are *educationally* relevant insofar as they treat subject matter organizations and modes of cognition that are characteristically in the human domain and with which all teachers are familiar. Hence they are not amongst the simplest sorts of learning theory which appeal to experimental phychologists because of their elegance and structural parsimony; the simplest theories are often (and perhaps rightly) discounted on the grounds that they have little relevance to education. The present batch of theories are proof against this criticism (and so are the system evaluations derived from them). However, both the theories and the evaluations can be attacked from a different quarter.

The fact is, the theories are most readily testable when the corresponding learning models are identified with laboratory situations. There are several reasons why this is so; the models themselves are workable with respect to small (though, as above, representative) chunks of mental activity. At an experimental level, the effect of individual differences (between subjects) becomes embarrassingly large if the experiment is unduly prolonged (by "pure" psychology standards the experiments are fairly lengthy; even so they do not often last more than a day or two). Finally, there is a purely practical reason why the control systems have been tried out in miniature. Most of the work in this field has been conducted in laboratories which (until recently at any rate)** have had special purpose on line control gear rather than on line equipment controlled by a general purpose computer (as a half-facetious, half-serious aside, workers having "big" CAI interfaces seem to have been preoccupied with getting them going rather than finding out what they do). Under these circumstances, the cost of experimentation is appreciable and it is necessary to choose experimental situations that are as small as *possible*.

Because of all this, it is perfectly possible to maintain that the theories and consequently the control methods attached to them have been tested in conditions that are educationally picayune. That is a caveat which must qualify all of the comments in the next few paragraphs and it may or may not be viewed as a damning one. My personal conviction (supported by the argument in Section 2) is that the educational relevance of the theory and the test situation are of primary importance and that the time scale of the experiment and the precise character of the problem solving activity do not matter too much.

The following notes are grossly generalized summaries of the main findings.

If a skill or body of knowledge is unstructured, i.e. if students are unable to say how they learn it after careful interrogation, apart from a statement to the effect that they engage in practice, then a fixed training routine (a feed forward procedure) appears to be as good as any other. Acquisition is just a matter of repetition. Type 5 control is useful in maintaining the student's motivation and may be used to check his perseverance.

Rather few skills are completely unstructured. Presumably, the skills (if any) acquired by simple conditioning are of this sort. In the later stages of learning (but *not* at the outset) many perceptual motor skills are unstructured. The same comment may apply to the later stages of learning computational skills (mental arithmetic) and possibly (though probably not) to the later stages of language acquisition. Rote learning, if it really took place, would be a matter of repetition but, unless precautions are taken to prevent him doing so, the student structures almost any list or catalogue, however meaningless it seems to be.

In contrast a skill (body of knowledge) may be structured in the sense that (I) it can be represented as an hierarchy of subskills *or* (II) a goal-subgoal hierarchy *or* (III) an hierarchy of TOTE units *or* (IV) an hierarchy of concepts *or* (V) if learning can be conceived as the elimination of a finite number of Error Factors. If the skill is structured (and the student can be persuaded to see it in this way) it becomes possible to talk about the existence of learning *strategies.*

Suppose that one such strategy has been selected on logical or psychological grounds as a good strategy. Now, a Type 1 Feedback control system designed relative to this good strategy is more effective than either (1) a fixed (feed-forward) routine based upon the *same* strategy or (2) Free learning. The advantage becomes marginal as (a) the acquisition of each component of the skill (body of knowledge) approximates "one shot" learning or (b) the set of *possible* strategies are uniformly "good".

Consider a *family* of learning strategies derived from a single good strategy and a Type 2 control system based upon this strategy family. In general, the Type 2 system is more

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* The evaluation of Type 4 control depends critically on the material. Sometimes a game like mode of instruction is mandatory. When a game is optional there is evidence to suggest that Type 4 control is a relatively effective method of instruction.

** The picture in this country is as follows: Kay and Sime have recently set up a computerised installation at Sheffield. Annett and Duncan at Hull, have an interface linked to an Eliott 903 which is just becoming operational. Cook, Hartley and Sleeman have a system with multiple hardware (KDF9, Modula R.I.) at Leeds. Gaines still relief chiefly upon special purpose equipment. So do I, though we are considering the economy of using a general purpose machine. It should be emphasised that the experimental requirements are fairly quirkish. A simple on line terminal is virtually useless for this purpose.

effective than the corresponding Type 1 system, if either (1) there is interference between the acquisition of one part of the skill (body of knowledge) and some other part of it or (2) the student needs to build up a learning set in order to secure competent performance ("interference" and "learning set" may be interpreted within any of the frameworks (I), (II), (III), (IV), (V)).

Suppose there is a class of learning strategies which may be adopted by different students (or the same student on different occasions). It may not be possible to single out a strategy as "good"; for example, because some student uses each strategy effectively, i.e. we could only say "that strategy is good for a student with certain characteristics". In this case a Type 3 conversational control system is more effective than either a Type 1 or a Type 2 system designed on the basis of an arbitrarily chosen good strategy and is very much more effective than free learning. The merit of Type 3 appears to be greatest when the influence of cognitive fixity (getting stuck with an inappropriate strategy or selection) is most obtrusive. As noted in 1.2 Type 5 control may be used to achieve Type 3 control, either in the context of a group of otherwise independent individuals or in the context of a team.

The majority of evaluations are expressed in terms of trials or time to reach a criterial performance with some check upon retention. A few are expressed in terms of uncertainty reduction. A more telling measure might be the time to reach a given level of understanding as indicated by the extent to which the knowledge in question is locked into a cognitive network. Tests for such a property have been devised but have not been extensively used.

1.6. Control Methods as Educational Facilities or Educational Subroutines

There is little difficulty in isolating skills such as list learning, relation learning, series completion or concept attainment for which one of the control methods listed in 1.2 is better than the rest, and to determine the cost of instrumenting it.

However, the majority of curricula—in mathematics, statistics, history, etc., call for the inculcation of several skills. This comment also applies outside the academic sphere; in the instruction of many complex tasks. Here, the picture is a good deal clearer since the subject matter is not so conventionally (perhaps arbitrarily) ordered.

In COMCEN operator training, for example, it is possible to justify the use of all five control procedures (listed in 1.2) at various stages in the process.[45] This is true, even if we confine our attention to the code teleprinting skill which is one ingredient of a COMCEN operator's repertoire.

At the outset, there is a strong element of problem solving. The student has to form concepts to do with different parts of the keyboard and the acquisition of one demonstrably interferes with the acquisition of another. A similar situation occurs at a later stage, when the student is mastering the many to one relationships entailed by upper-case and lower-case operation. With the "difficulty" variables chosen as cueing and pacing, a Type 1 feedback control (Section 1.2) is empirically superior to mere practice and, in certain circumstances (if the student's behaviour goes outside a limited range), the Type 2 (adaptive) control is still better. In our own system, COMOPTS 1, the demand for Type 1 and Type 2 control is met by providing an overall feedback control teaching system in which the student is normally situated and an adaptive system into which he is routed for remedial practice.

Up to 30 hours of conventional training (about 10 hours in the mechanized training system) there are several possible learning strategies. Since this is so, a conversational system (Type 3) is required (if only because we are unable to determine an appropriate teaching strategy on behavioural evidence alone). It is provided in a partially mechanized form, by a "programme" or "flowchart" in which the student substitutes values derived from the feedback trainer after each exercise block. Further substitutions are made to indicate the student's preferences and to point out aspects of the skill that are causing peculiar difficulty. Following through the substituted flowchart, the student is directed either to alter parameters of the feedback machine, to rehearse the skill on the adaptive machine or to engage in other activities (which will, in the final version of the system, involve working through segments of a programmed text).

After 30 hours of conventional training, the task is substantially homogeneous (from the student's point of view) and the acquisition of further competence depends chiefly upon practice. Here, an open loop training system would be as good as any other (given only a minimum monitoring of performance). The main problem is to keep the student motivated as he grinds away. For this purpose, COMOPTS 1 will make use of control methods Type 4 (simulation) and Type 5 (gaming), i.e. students will be periodically presented with realistic communication situations and periodically required to play partly competitive and partly co-operative games with one another via the teleprinter interface (augmented by a board that delivers commands and synchronizing signals). The frequency and the nature of these interventions are automatically scheduled as a function of performance which is measured during the communication act. These measurements provide sufficient information for monitoring purposes. At the moment, the monitoring is manual but it could be automated without difficulty. In a programme such as TASKTEACH (which is capable of teaching quasi intellectual skills, typically fault detection and maintenance), an instructor sets up the list which gives the system a structure akin to COMOPTS; within this framework the student is free to choose his own fate (conversational Type 3 control) or to invoke more restrictive procedures (resembling Type 1 and Type 2 control).

Similar comments apply to PLATO, Kopstein and Seidel's IMPACT and other large CAI systems. However, since these are generally used to instruct academic skills (statistics, computer programming and the like) the simple pattern is obscured. Statistics, for example, already has a conventional order imposed upon its instruction so that the plan for teaching the subject matter as a whole contains phases in *each* of which the control methods of 1.2 are called into operation, generally with different parameter settings to achieve specific subgoals. In the context of a large CAI system the control methods of 1.2 thus have the status of tutorial *subroutines.*

It should be emphasized that the distinction between a tutorial subroutine and a full CAI system is made on the grounds of organization rather than size. To see this, notice that the Stanford System (Suppes and his colleagues) consists in a series of isolated subroutines which are called into operation at the discretion of a teacher or supervisor. Thus the "drill and practice" mode, used for teaching children to carry out arithmetical operations, is a large but simply structured feedback (Type 1) subroutine; the "tutorial" system employed for logic instruction (and other purposes) is a mixed conversational and adaptive subroutine (a hybrid of Type 2 and Type 3). The Stanford system has, nevertheless, massive provisions for recording and evaluating data and the system itself is one of the largest and most liberally interfaced* in existence. Of course, if the external supervisor uses the data to select the subroutines or to adjust their parameters then the system (*including* the supervisor) *is* a full CAI system. Without the supervisor it is not.

1.7. Evaluation of the System as a Whole

It can be stated with some confidence that a full CAI system is no less effective than a system of programmed instruction or a system of classroom instruction. The more cautious commentators, seeking a general evaluation of the art, have gone no further than this and have still managed to justify CAI on economic grounds for higher education, special civilian and military training (where instructional costs are high in any case), and for many industrial and governmental purposes. When relatively inexpensive systems (such as Bitzer's) come into operation the cost of CAI will fall from about $2.4 per student hour to about $0.35 per student hour due, in no small measure, to large-scale production techniques and hardware innovation; this change will place CAI within the economic compass of the school system.

But all of these estimates, predicated on "CAI is no worse than . . .", may be unduly pessimistic. In view of the information available about the basic control methods (educational subroutines), it is not unreasonable to suppose that CAI may be "a great deal better than . . ." other techniques and, if so, any cost benefit argument in its favour should be more readily acceptable.

Unfortunately, the evaluation of a total CAI system is beset by a number of difficulties. Some of these have already been mentioned; for example, the problem of coping with individual differences. However, there are five obstacles which deserve special attention.

(1) Providing it has been competently designed, any CAI system whatever is bound to give a saving in time and effort. For example, we can claim that COMOPTS will train teleprinter students (up to 3 or 4 week level) in half the time taken by a conventional training routine. But we have a relatively vague idea about how much of this effect is due to the tutorial action of the system. Some of the benefit stems from an incidental rationalization of improvident training techniques; in specifying any CAI system an efficient planning procedure is forced upon the designer. In particular, the CAI system is far more flexible and individualized and the greatest organizational advantage is gained when it is possible to get rid of the class attendance concept (so that the system can be used optimally with respect to the pupils). The Army Operational Research Group[46] in a much earlier study, predicted a similar enhancement in training efficiency (for morse training) on these grounds alone; without reference to CAI as such.

Needless to say, the same comments apply with even greater force to CAI systems used in the academic sphere. The enhancement due to organizing instructions and avoiding time wastage is particularly great if, with Eide,[47] we count the students' time as one of the most costly educational resources (there is a very strong case for doing so at the national level).

(2) Any competent CAI system will work because of the Hawthorne effect. It is difficult to discount the influence of novelty in an experimental situation. Desirable though the improvement may be, it is not directly relevant to the tutorial influence of CAI.

(3) Whereas it is easy enough to find standard conditions for controlling small-scale experiments (free learning or a fixed training routine) it is not so easy to select a control condition for a full CAI system (glibly CAI performance is compared with the performance of "conventional teaching", but what *is* "conventional teaching"? It is fairly well defined for perceptual motor skills but not for academic skills).

(4) Individual differences are not only large (a point made already in 1.5) but specific to the motivational variables that appear in the fully-built CAI system.

(5) The final and fundamental difficulty is that no one really knows what to measure (as evidenced by the fact that vast amounts of latency and response data have been collected on tapes, though very little of it has been used for evaluation). Just as the functional evaluation of an educational subroutine calls for a learning theory (which, amongst other things, tells the experimenter what to measure) so the evaluation of an entire CAI system calls for an educational theory. At the moment no adequate theory exists, though several relevant developments are noted in Section 2.

Thus, at the moment, we are in the position of a programmer equipped with a collection of working and evaluated subroutines who is anxious to evaluate a programme (the full CAI system) constructed from these components. It would be naive to suppose that the evaluation of the whole (in the educational case) is the sum of the evaluations of the parts. In some instances, useful limits can be set up in terms of subroutine evaluation but a general appraisal of CAI seems to rest, as suggested above, upon an educational theory. We return to this point in Section 2.8.

1.8. Critical Statement

It is true that computers have often been used (under pressure to use the things somehow) in an unimaginative, narrow or downright stupid fashion. But this should not lead to a condemnation of the entire field: computer control of learning has great and diverse potentialities, some of which have already been realized.

The general development of computer control does, however, entail paying more attention to psychology and logic than it is currently fashionable to do.

To take just one aspect* of the psychological point, most of the varieties of control listed in 1.2 call for an adequate interface (which is certainly not a teletypewriter) and an adequate language. These questions are really in the province of other authors at this symposium; I only wish to make two points which illustrate a broad contention: (1) any conversational system must have an interface and a language which allows the student to state what he intends to do, not only as a plan for action but also as a plan for learning; (2) by the same token, the interface and language must allow the student to evaluate prescriptions and descriptions *either* to do with the task itself *or* with the process of learning it. One of the most useful evaluations is a subjective uncertainty

* For example, the student receives spoken messages in addition to visually displayed material.

* We return to it in the section on learning models.

measure, preferably obtained with a Shuford[48] type of scoring function as mechanized by Baker.[49]*

These facilities are mandatory adjuncts to quite simple studies of teaching and it is disheartening to find elaborate computerized systems which lack them altogether. Needless to say, the systems cited in this paper, especially Seidel and Kopstein's system, *do* have such facilities. So do many European and Russian systems which are excluded from the survey.

On the issue of logic, there is an understandable tendency to see things through the eyes of computation technology. Logic is parochially (and naively) identified with propositional and first order predicate calculus. But, insofar as a logic of teaching is a logic of conversation, this is an insufficient framework. It is at least necessary to synthesize a scheme from the framework as it stands and (a) a logic of relations (the higher order predicates); (b) a logic of commands (Rescher[50] and von Wright[51]); (c) a logic of parallel (rather than sequential) organizations, for example, using Holt's scheme;[52] (d) a context logic (in the sense of Kotely[53]); (e) a logic of distinctions and form (Spenser Brown[54]) and (f) a logic of games and metagames in the sense of Howard.[55] Some efforts have been made in this direction, notably by the social anthropologists who face much the same problem as "learning system analysts". It is plain silly to pretend the problem does not exist, to give up in despair or to bludgeon away with techniques that serve well enough for describing mechanical computation (as carried out by present-day computers) but are unfitted to adumbrate the dynamics of mentation.

2. MODELS FOR LEARNING AND TEACHING

2.1. Overview

Any controller is designed according to a model which can be interpreted and identified as a theory of the controlled process. In the case of teaching (the control of learning) this theory is a learning theory and it represents either the student alone or the student coupled to a specific teaching system. We emphasize that the underlying model is the *designer's* model *of* the process; it is *he*, the designer, who interprets it as a theory. Furthermore, it is *he* who carries out experiments to verify the theory and it is *he* who, if necessary, alters the model to fit the facts.

In contrast, models may also be used inside systems. Here the teaching device is provided with an internal model which it is built to interpret as a theory of the student with respect to the educational goal. It uses the model to determine its next move, it performs experiments to validate the model, and, if necessary, it modifies the model. In other words the system learns about the student and builds up an internal representation of the student state. The distinction between (designer's) models *of* the system and (system) models in the system is non trivial when the system acts in this fashion. All conversational systems and most adaptive systems do so. (It is of interest to note that the system might start from scratch and build up a student model *de novo*. In practice this process would take far too long and even if it could be instrumented would clearly constitute an uneconomic design.)

* Other techniques, such as a mechanised version of the Kelly grid, could be introduced with advantage.

2.2. The Scope of the Models

We have talked of learning theories and student models as though these things were neat packages. In fact, there are several separate representations which form part of any model and which are given varying amounts of emphasis.

(1) A representation of the subject matter to be instructed.

(2) A representation of the educational goal. In the simplest case this is a statement of the looked for terminal behaviour but frequently there are cognitive components in the specification.

(3) A representation of the initial state of the student when he enters the teaching system i.e. of his current level of competence, his attitudes and possibly his personality.

(4) A representation of the current state of the student (3) above providing a statement of the "initial conditions"). Generally, this part of the model is far more detailed and is mainly restricted to a representation of the student competence and his learning strategies (if attitudes, personality etc. appear in the model at all they are assumed to remain unchanged by learning).

(5) A representation of the teaching system including its teaching strategies.

All of these representations are present (perhaps in an embryonic form) within competent (designer's) model of the student and his instruction. Models *in* the system are set within the framework afforded by (1), (2) and (3) but (insofar as the internal model is changed as a function of experience, the internal model itself is restricted to components (4) and (5).

2.3. Some Types of Learning Theory

Confining our attention to components (3) and (4) of 2.2, there are several types of learning model available to the designer of a CAI system. (Many of these are only interpretable on the "subroutine" scale considered in Section 1.2).

In order to appreciate the state and potentialities of CAI it is necessary to review the major types of learning theory and to comment upon their ranges of application. As a prefatory remark the various theories are often complementary to one another; the differences are mainly philosophical. At a pragmatic level the recommended teaching strategies tend to be quite similar (as they should be! the theories are theories of the same system!). Nevertheless, one point of view may be very much more useful than the rest when it comes to modelling a particular situation.

(1) *Behaviouristic Models.* The operant conditioning approach of Skinner was largely responsible for "linear" small step programming (a teaching paradigm still at the roots of many CAI systems). More liberal concepts of behaviour shaping have led to the "Mathetics" type of programme[56] (which consists in large frames, eliciting many covert and overt reponses, each one resembling a well planned advertisement).* The S-R-operations (apart from basic conditioning and association) are chaining, discrimation and generalization and these operations are evoked in sequence in

* In terms of this paper, both Skinnerian and "Mathetical" techniques are "feedforward" techniques. The *student* received a reinforcing feedback but feedback signals are *not* employed to modify the sequence or type of instruction.

order to produce (by hypothesis) such a juxtaposition of associative connections that the criterion behaviour can be achieved.

The main attraction of this theory is its simplicity, atomicity and quasi physical calibre. Its main disadvantages are (a) that the structuring of the task (representations (1), (2) and (3) of 2.2) is *outside* the model and is catered for *informally* (the matter is left to the designer's discretion). (b) The representation of such entities as concepts, rules and plans ((4) and (5) of 2.2) is exceptionally cumbersome and may even be impossible.

(2) *Stochastic learning theories,* especially the stimulus sampling theory of Estes and his colleagues.[57-58] Stochastic models are admirable predictors of the statistical properties of simple behaviour, for example, of response probabilities (strictly, these are properties of an ensemble of students but they may be interpreted as properties of processes which are ubiquitous and thus represented in any student). Some typical and interesting applications to teaching are Dear and Atkinson's[59] model for concept learning and Matheson's[60] use of a stimulus sampling model in combination with the technique of dynamic programming to prescribe optimal teaching strategies for certain (more or less repetitions) tasks. The control and evaluation procedures in Smallwood's[61] CAI system are based, primarily, upon stochastic learning theory and this scheme, though not so highly developed as Matheson's, is applicable to a much wider range of subject matter. Hence the stochastic models have much to recommend them. Their disadvantages are those voiced in connection with the behavioural models and, in addition, the limited tutorial relevance of the statistical properties they predict so well.

(3) *Error Factor Theory.* Within this (more or less behaviouristic theory) learning to do something is regarded as the elimination of the influence of Error Factors which prevent it being done and which are responsible for classes of mistaken responses. Error Factor Theory[62] is particularly well suited to designing feedback and adaptive control systems for perceptual motor and problem solving skills. It has the great advantage of imaging the response process as potentially multidimensional and the vector of difficulty variables (Section 1.2) can be placed in direct correspondence with the set of Error Factors. The forms of learning predicted by Error Factor theory and simple reinforcement theory are somewhat different but the recommended training strategies are much the same (Error Factor theory yielding consonant but more detailed recommendations).

(4) *Functional Theories.* Enough is known about certain of the subsystems involved in learning to model them meaningfully as mechanisms (rather than "Black Boxes").* This is especially true of the functionally demarcated subsystems "Immediate" (short term) "Working" (Intermediate) and Long Term memory, of which the first two are fairly well investigated.

* In Ashby's sense; modelling the input output characteristics or transfer function of a system.

The characteristics and limitations of immediate memory are familiar from work in pure experimental psychology; clearly these limitations should be respected in the design of any CAI system (as in the design of any other man machine interface). The working memory system is less well documented but is especially germane to teaching since it is in this system that skills and bodies of knowledge are integrated into structures and it is here that interference and positive transfer of training take place.

There are various models for the system, but Atkinson and Shiffrin's[64] is well validated and is stated in a form applicable to CAI. The working *memory* is akin to a programme embodied in a working *storage* which serves as a general purpose computer that may be programmed in several ways. Each way is an information control procedure; for example, one procedure is a rehearsal buffer, another is a sort of push down list processor, another is a procedure for transfer to long term memory. Fiegenbaum's EPAM programme,[65-66] a computer simulation of working memory viewed as a discrimination and association network, is a further model of this type and is also well validated. Given a theory based on one of these models, it is possible to recommend very detailed teaching strategies. Several of these have been tested as part and parcel of the experimental effort connected with the modelling. It should be noted that the teaching strategies derived from functional theories are generally compatible with those derived from behavioural theories. But the functionally derived strategies are far more sophisticated.

(5) *Objective Informational Theories* (Wattanabe,[67] von Foerster,[73] Pask[68-72]). The word "information" is used in its technical sense (selective information, measures of information) and learning is viewed as a reduction in relevant uncertainty which is influenced by such variables as the student's information loading and the informational redundancy of the materials presented to him. "Objective" implies that the informations, uncertainties, etc., in question are those of an outside observer, not of the student. On the one hand such objectively measured uncertainties are clearly related to statistical indices such as response probabilities (regard stimuli as signs selected from an input alphabet and responses as output selections). Thus the informational theories of learning are related to the behavioural theories. On the other hand, the information measures, though obtained over sets of behavioural alternatives, may be held to estimate the student's uncertainty. Insofar as they do so a bridge is established between behavioural theories and subjective information theories and via these between behavioural theories and cognitive theories of learning.

(6) *Subjective Information Theories.* The information measures are computed from subjective estimates of degree of belief (or doubt) obtained by the methods of Shuford, Baker and others.* These workers have developed a learning

* Essentially in a game like situation where the student is assigned a score dependent upon his numerically *asserted* degree of belief in several alternatives. His assertion is constrained to secure "probability" numbers which sum to one over all of the alternatives. The scoring function employed is such that, over a sequence of trials, the student's mathematical expectation of score is maximised if, and only if, his *asserted* degree of belief equals his *real* degree of belief.

theory which is comparable with an objective theory and have used it to prescribe various teaching strategies.

(7) *Structural Theories.* The developmental psychologies of Piaget and Luria[74] are structural theories insofar as they postulate certain mental structures which dominate the psyche at different ages. At the level of individual learning (rather than development) there are several theories of a like kind; Gagne,[75-76] for example sees the acquisition of a skill as the assembly of an hierarchical structure of capabilities. Learning occurs when a pair or more of subordinate capabilities are wedded together by an instruction that combines them in some way; but the instruction will only be effective *if* the requisite subordinate capabilities *are* already established. For dealing with a body of knowledge (rather than a skill) the "capabilities" are replaced by "concepts" (given a behavioural emphasis a concept is a capability to classify and respond).

(8) *Organizational and Cybernetic Theories.* These are structural theories in which the basic units built into an hierarchical structure are goal directed, problem solving or control systems (either contained within the organisation or acting partly through the environment. The theory has a cognitive aspect; since "aiming for a goal" or "solving a problem" explicitly involves a state of knowing. Miller, Gallanter and Pribram[77] proposed a TOTE (test operate test exit) unit as the goal directed building block; essentially this is a piece of *programme* which corresponds to a contingent of IF, THEN, ELSE, statement. A plan or a concept is conceived as a nested structure of TOTE units.

I have pointed out that in order to build up or modify such an hierarchy (i.e. in order to talk about learning) it is necessary to invoke an independent *hierarchy* of control (or problem solving of problem solving). Because of this any Cybernetic learning model is *heterarchical.*[78-79]

(9) *Programmatic Cognitive Theories.* In general these turn out to be Cybernetic theories although the basic units are specified simply as information processing programmes, the execution of which may be expected to produce a state of knowing and the consciousness of a plan, hypothesis, concept or strategy.* All artificial intelligence models which purport to simulate human learning belong to this class. Since the models are very complex and varied, it is impossible to convey the gist of them in a few words but the subject has been reviewed in another paper.[80] Bennett and Hodges "Structural Communication" or "Systematics" type of programming is based on a cognitive model,[81-82] informally so at the moment, but a formal treatment is clearly possible. It is also quite clear that although systematics programmes can be administered by textual methods, they are really fitted to CAI administration and have the status of CAI systems.

(10) *Other Cognitive Theories.* Several perfectly respectable cognitive theories do not fit easily into the currently popular programmatic framework. Two good examples are Festinger's[83] cognitive dissonance theory and Kelly's personal construct theory.[84] Both of them have potential value in connection with certain aspects of learning and teaching (notice for instance the close relation between the "cognitive fixity" of 1.2 and "cognitive dissonance").

* Unless the entity is specifically tagged as a reflexive or autonomous unit.

(11) *Statistical Cognitive Theories.* Guildford[85] and Bunderson's[86] factor analytic studies of learning showed that different mental processes (aptitudes) are important at different stages in learning the same task. Clearly, these "processes" have a statistical calibre akin to the response "processes" in a stochastic model apart from the fact that they are cognitive rather than behavioural entities. A body of hypotheses frames in terms of there variables can be usefully interpreted as a theory (such a construct is used in the IMPACT model).

(12) *Theories of representation and learning type,* notably Bruner's[87] theory of ikonic, mnemonic and automatic representation and the linguistic theories of Vygotsky,[88] Luria and their pupils.

2.4. Models and Theories of Learning

The learning theories of 2.3 are concerned with the components or representations (2) and (4) of Section 2.2 (namely of the student's initial state and his current state). Given a specific task or body of knowledge it is fairly easy to adjoin a representation of the subject matter (component (1) of 2.2) and of the educational goal (component (2) of Section 2.2) to yield a *descriptive* and predictive (or explanatory) theory of *learning the task in question.* Clearly, the representations employed for this purpose must be *compatible* with the type of theory chosen and it is almost platitudinous to remark that the choice of a learning theory will depend upon the subject matter and the educational goal that an investigator has in mind. For example, the behavioural theories are simple and thus (in one sense) preferable. But it is difficult if not impossible to set up a subject matter representation which is compatible with such a theory if the subject matter entails plans, concepts and the like, in anything more than a naive fashion.* In general, it is necessary to reach a compromise between theoretical simplicity and realism of subject matter representation and the structural and Cybernetic theories are peculiarly useful in this respect.

Although the models of Section 2.3 are chiefly descriptive (and predictive) models, they can all be used in a *prescriptive* fashion** to yield recommendations for teaching; either a set of teaching strategies or a teaching system. Thus, we enquire what operations would be necessary to achieve the educational goal (with respect to a given body of subject matter and a given student model) and specify a teaching model capable of performing these operations. The requirement may, of course, be more or less refined; for example, we might demand a set of operations to achieve the goal as fast as possible or set of operations that lead to a generalized rather than a specialized competence. But, in any case, the teaching model constitutes component (5) of Section 2.2 and, when

* This is a personal bias. For instance, I *do* believe it is naive to regard a concept as no more than a class of stimuli that evoke some common response.

** The distinction between the descriptive and prescriptive use of models was originally drawn by Kopstein. It has been employed extensively by Stolurow and myself. Stolurow also consider models that have little predictive power. Thus, my usage is somewhat different. All of the models cited in this paper, for example, have predictive or explanatory power.

coupled to the student model in the context of the task, it provides a learning and teaching model of which representations (1), (2), (3), (4) and (5) of 2.2 are constituent parts.

The learning and teaching model may be a purely symbolic, mathematical affair. More often, however, it is convenient to embody the model in a special purpose artifact or a computer simulation, when the student part and the teacher part are explicitly distinguished as separate subsystems. It should be noted that the mode of interaction between the student part and the teacher part of the model depends upon the type of learning theory that was originally selected. For example, if the base theory is behavioural, then the "language" whereby the student part and the teacher part communicate is able to accommodate stimulus signs, response signs and signs for knowledge of results or reinforcements; if it is structural, then certain expressions designate descriptions and commands or instructions; if it is a subjective informational theory, then the student part produces evaluations (of degrees of belief) and if it is Cybernetic or cognitive then the language must be an altogether richer approximation to natural language.

The learning model can sometimes be validated directly and used to prescribe a teaching procedure. However, it is also possible to employ the entire learning and teaching model as the experimental tool in a very efficient fashion.* To do so, the joint model is set in motion (or "run") to generate predictions; as a result of which interaction or "discourse" takes place between the parts. The predictions are of the form "The students learning process will be like X if the teaching strategy is Y". Initial values of the "student" parameters are assumed and the parameter values in the teacher part of the model are adjusted in order to secure the requisite tutorial functions. This is a period of *abstract experimentation* or simulation during which the teacher component is refined to yield a final prescription for a teaching system. At this stage, the *joint* model is interpreted as a *theory of teaching*; the student part is identified with a real life student; the teacher part with a CAI system (or a CAI subroutine) the *interaction* between the two with the student teacher discourse and the subject matter and the educational goal with their correlates in reality. The real teaching machine is now used to instruct members of a group of students and data gleaned from this *real experimentation* is used to modify the student model before the entire cycle of operations is repeated.

2.5. Models in the Teaching System

This completes the story so far as simple feedback systems (Type 1, Section 1.2) are concerned. For example, Matheson's dynamic programming model for a teacher leads to a set of well defined teaching strategies that are optimal provided that the learning process is adequately described by a stimulus sampling model. These strategies have been successfully embodied in real teaching machinery.

On the other hand, the prescription for a teaching model may be a "learning model" (a model that learns about the student, a model *inside* the system in the sense of Section 2.1). This may occur for either of two reasons: (1) the characteristics of the student are unpredictably variable (either from individual to individual or from time to time) or (2) the student must be allowed a free choice (say of learning strategy) if his learning is to be optimized.

If the teaching model is, itself, a learning model then the abstract experimentation phase, mooted in 2.4 assumes the status of an on line process and the resulting CAI system becomes a learning system. All adaptive and conversational CAI systems are of this sort.

Since these CAI systems unequivocally do something that cannot be done by a bit of promgrammed instruction, they deserve further attention and will be briefly discussed in Section 2.6 (at the level of CAI subroutines) and in Section 2.7 (at the level of full CAI systems).

2.6. Case Histories of Learning and Teaching Systems

To illustrate these concepts, I shall briefly describe and comment upon a series of learning and teaching models for which I have been responsible in one way or another. All the systems in this series are addressed to "rule application" which is a skill required in the performance of many intellectual and perceptual motor tasks. (The student is given a rule or set of rules relating stimulus configurations to response alternatives; the rules may be simple or complex. At any trial, the student receives a stimulus configuration together with information that directly or indirectly indicates the appropriate rule. He is required to produce a legal response as soon as possible. All in all, "rule application" is a tractably simple paradigm for "problem solving".)

The first learning and teaching model (EUCRATES) was fabricated in the late 1950's before general purpose computers were readily available; hence, it was embodied in a special purpose hybrid computer. It is, incidentally, by far the most *complex* (though the least conceptually sophisticated) model in the series and even today, its computer simulation would be a sizeable undertaking. The next case is a simple minded informational-cum Cybernetic learning model which (like EUCRATES) was used to design adaptive teaching systems with a *single* teaching strategy. The model is computer simulated since the work in question was started about 8 years ago. The last case is a recent and moderately sophisticated Cybernetic learning model (again, computer simulated) used to design conversational teaching systems based on several learning strategies. These teaching systems have been tested on real life subjects (Pask and Lewis,[89-90] Pask,[91] Pask and Scott[92]).

(1) The EUCRATES system (Bailey, McKinnon, Wood and Pask[93-94]) has two functions (a) it is a learning and teaching model embodied in a special purpose hybrid computer and (b) it can be used directly as a teaching system. The main object of building it was to provide a facility for designing, evaluating, and testing simple adaptive teaching machines.

EUCRATES consists of a console for student interaction a learning machine and a teaching machine, both with variable parameters. The teaching machine is either coupled to the learner, when the entire system acts as a joint learning teaching model ((a) above) or via the console to a real life student; the teaching application ((b) above).

The learning model is based upon a behaviouristic or Error Factor theory insofar as the rule or rules are never stated symbolically to the learner and insofar as the rule becomes internally represented as a set of stimulus response associations embedded in the association storage matrix of a conditional

* Since many of the learning models are easily validated in on line controlled experiments (notably Atkinsons and my own) the distinction between the learning teaching procedure and ordinary experimentation is blurred.

reinforcement probability device. However, the behaviouristic paradigm is liberalized in the following ways (a) the EUCRATES learner has a primitive attention directing mechanism, impelling it to focus upon submatrices of the storage matrix. (b) It can generate stimuli internally, even if no stimulus is presented. (c) It has curiosity (or a drive to learn about something); hence it does generate its own stimuli if none are provided. (d) It has a simple minded anticipation or expectation mechanism. (e) Given a stimulus (internal or external) a column of the storage matrix is selected; its entries are presented as a biasing vector to a set of response processes which *compete* to produce a response; the competitive activity is inhibited by *cueing* signals (from the teacher) indicating that a certain subset of responses are not correct (i.e. signals eliminating the influence of Error Factors).

The EUCRATES teacher contains a representation of the rule or rules and comparators for providing knowledge of results or reinforcement signals. Apart from that it approximates the stochastic inverse of the learner. It consists of a variable probability stimulus generator (stimuli eliciting correct responses being selected with the lowest relative frequency). The output of this device picks out columns in an associative storage matrix. The resulting vector biases a cueing process analogous to the response process in the learner. Just as the learner generates a response with a latency and form dependent upon the currently ongoing activity, so the teacher generates a set of variably delayed cueing signals that differentially inhibit the learners response process. The entries in the learners associative storage matrix (and certain other stored values) depend upon contingent reinforcement from the teacher. The corresponding entries in the teacher are built up as a function of the learner's success and, in aggregate constitute a developing model for the learner. Further, the teacher has the overall goal of withdrawing (delaying) cue information so that none is delivered and presenting the stimuli equi-probably in such a way that the learner is performing at the required level of proficiency (rectitude and latency) when these conditions prevail. Hence the teacher is an adaptive teacher.

Typically, the learner is set up with sensibly chosen parameter values (change of associative linkage as a function of reinforcement, decay of associative entries, degree of inhibition). The system is run as a learning and teaching model and the teacher parameters are adjusted to approximate optimal convergence (abstract experimentation). The parametrically adjusted teacher is next used as an adaptive machine to teach a real life student (real experiment) as a result of which the learner parameters may be further adjusted and the cycle repeated.

(2) In a Cybernetic model (Pask, Lewis, Mallen *et al*[94–96]) the student is conceived as an interpreter rather than the reactive mechanism imaged by the behaviouristic theory. He interprets stimuli as posing problems within a *given* task *description,* he sets about solving them and he experiences uncertainty about how to solve them.

At a *macroscopic* (molar) level, the novice is overloaded by a sequence of real life configurations in the sense that the uncertainty engendered by the problems they pose exceeds a threshold. Further, it is hypothesized (in the student model) that learning is most efficient if the student's uncertainty is held within limits (if he is maximally loaded but not overloaded). In order to learn at all, the student is furnished with a description of the skill within which problems can be decomposed into their constituent subproblems and he is able to focus his attention upon any class of subproblems. Hence the student is able to control his maximum uncertainty (determined by the complexity of the subproblems that occupy his attention). By hypothesis, he adopts a learning (attention directing) strategy in which the *maximum* uncertainty is controlled as a function of *actual* uncertainty in order to satisfy the limits mentioned a moment ago. Concisely, the student acts as a self-organizing system in the sense of Von Foerster. This general view of human learning is supported by experimental data.

At the microscopic (molecular) level, the same learning process is described by a computer simulated model which represents the construction, reproduction, and generalization of an hierarchy of TOTE units in an intermediate (working) memory system which is subject to interference. The process is controlled by an executive which assigns effort to the various levels of internal and external problem solving activity. Many of the more detailed predictions from this model are also confirmed by empirical data.

Used prescriptively, the microscopic and the macroscopic models lead to the same recommendations. The teaching system should have a single strategy; the learning strategy already mentioned. It should act in a partially co-operative fashion (a) by sampling the students competence or level of relevant uncertainty; (b) by "partially solving the problems that are presented", to a degree determined by the current competence level (equivalently the teaching system co-operates "by selecting subproblems of a difficulty dependent upon the student proficiency). The parameters involved in (a) and (b) are chosen to satisfy the limits mooted in connection with the student model.

Insofar as these limits can be determined for all students (by experiment), the teaching system is a simple feedback device (Type 1 of Section 1.2). If the limits are variable, as they are for some tasks, then the system must determine the limits appropriate to an individual by an adaptive process (it is a system of Type 2 in Section 1.2).

The learning and teaching model is a computer simulation of the (microscopic) student model interacting with the (adaptive) teaching model. Sensible parameter values are assigned to the student part and the model is run (abstract experimentation) to determine parameters for the teaching part. A physical system isomorphic with the teaching part of the model is now used to instruct a real life student (real experiment) and the results from a group of experiments determine what (if any) parameters in the student model need adjusting before the cycle is repeated (in fact, one repetition is usually sufficient to yield the specification of an efficient teaching system).

(3) The final model in the series[97–98] has greater cognitive realism and is based upon a *class* of learning strategies, rather than a *single* strategy.

Experiments were carried out in a special mechanized system that allowed the student to output his learning strategy* as an objectively measurable stretch of attention directing behaviour. Given a task description compatible with *many* learning strategies, real students, in fact, employ three or four different ones. However, in free learning conditions, students are liable to adopt and stick to an inappropriate

* Together with his degree of doubt about where to direct his attention and his doubt about how to solve the problems.

strategy; inappropriate in the sense that its execution is hampered by constraints of the sort that are imaged in the microscopic student model. All but one of the learning strategies are *logically* defensible but *effective* learning takes place when the chosen strategy is matched to the data processing characteristics of the individual who chooses it.

The student part of the learning and teaching model is a computer simulation that extends the "microscopic" model (cited above) to accommodate several learning strategies; indeed, the model has (a currently rather primitive) process for generating strategies. Used prescriptively, this model determines a conversational teaching system which gives the student model a maximum freedom of choice provided (a) that a learning strategy *is* chosen and (b) that this *could* be a "matched" strategy. Briefly, it engages the student in discourse, commits him to objectives, offers him advice about his own internal state (of which the real student is commonly unaware) and guides him through a programme that is a compromise between the strategy the student would have selected alone and the strategy he ought to accept on logical grounds.

Conversational teaching systems (isomorphic with the teaching part of the learning and teaching model) have been realized and used to instruct real life students. They have the effect of enhancing the performance of *any* student to the level achieved by those few students who attain excellence in the free learning situation. It is of some philosophical interest to observe that a conversational teaching system is in a very real sense an extension of the student's own faculties.

2.7. Case Histories–Some Fully Specified Systems of CAI

All currently instrumented CAI systems consist in tutorial subroutines that are glued together by the subject matter structure and the educational goal (by components (1) and (2) in the discussion of 2.2; the names for it vary. sometimes the subject matter structure is called a "concept ordering", sometimes a "job analysis" and so on. We shall comment on the status of the subject matter structure in Section 2.8. For the moment, in order to describe a few CAI systems, let us assume that it exists.

(1) The TASKTEACH system (Ridgeway and Towne[16]) is a CAI procedure for teaching "serial action" taks such as problem solving. For any particular task certain lists and other information structures are set up by the teacher (task programmer). As a result the system makes available (a) an overall map or plan of the task which is open to the students' inspection;* (b) a "smorgarsbord" (the author's term) of educational facilities and "supports" to which the student is allowed conditional access. In the case of fault detection training, for example, these will include explanatory routines, test equipment, signal and state simulations. Clearly, the subject matter structure is embodied in (a) and (b).

(2) The TASKTEACH programme is conversational insofar as it allows the student to choose his own learning strategy (within the limits set by the overall map) and insofar as it provides him with evaluation data when he uses the educational facilities. It is a great advance upon straightforward programmes which present an orderly sequence of frames. All the same, it leaves most of the decisions up to the student and there is no explicit sense in which it secures a compromise between the student's desires and its own rules. From a scrutiny of the single available paper, the learning and teaching model behind this CAI system is partly behavioural, partly cognitive and partly structural, the design is not committed to one particular theory.

(3) The PLATO system (Bitzer and his colleagues at the University of Illinois). This is an impressive CAI system which (like TASKTEACH) permits a great deal of student control. However, it does so within a much more liberal format (PLATO has been used to teach nearly everything; network manipulation, circuit theory, nursing, and history, to cite only a few subjects). The student interface (student logic) is flexibly programmed and the student is free to get away from the stream of instruction into a free learning or enquiry mode in which he can access a variety of information sources.

However, at a higher level of organization PLATO is uncommitted to any particular learning theory. If PLATO is regarded as a teaching and experimental facility, this fact allows for a healthy eclecticism (since it is *easy* to impose *any* structure). If PLATO is regarded as a complete CAI system, then the lack of specificity is a defect.

(4) Smallwood's System. The subject matter is structured as an ordering of modules which refer to conceptual structures and the programme is concerned with determining a path through this network. For this purpose it uses a learning model of a behavioural and stochastic type and a teaching model based on dynamic programming. The system is a feedback system insofar as behavioural indices are fed back to influence module selecting decisions and it is adaptive insofar as the decision structure is altered as a function of the students' performance.

(5) The SOCRATES System.* This system (or class of systems) is due to Stolurow and is designed on the basis of an "ideographic" technique.[13] The tutorial process is broken down into a pre-tutorial phase, a tutorial phase and an administrative phase. As in the other systems, the subject matter is pre-structured and the educational goal is specified at the outset. It is, however, clear that Stolurow intends to base his subject matter structuring upon a preliminary investigation of the learning strategies adopted by members of a population of students (essentially the preliminary study technique of 2.6(3)) and he has carried out experiments of this kind (notably in the field of syllogistic reasoning). The pre-tutorial phase of the CAI operation uses various tests, including specific and non-specific aptitude tests, to determine the student's initial competence. A teaching strategy is selected that depends upon their outcome and a structural (2.3(4)) learning theory. During the tutorial phase this strategy is executed and monitored by feedback information from the student and, if necessary, it is changed. The administrative phase involves the moment to moment housekeeping required in such a system.

Thus, as I understand it, this system consists in a preliminary test (pre-tutorial phase) as a result of which some feedback, adaptive or conversational subroutine is tentatively selected. The operation of the subroutine is overlooked by a model that is not at the moment dogmatically specified; clearly, however, it is either a Cybernetic or a cognitive model and it might well be an artificial intelligence programme.

* The designers make the extremely important point that this, and certain other TASKTEACH facilities, encourage the student to learn how to plan his own learning.

* SOCRATES was set up at the University of Illinois. I am using this as a generic term for all of Stolurow's work, including his later work at Harvard.

Performance information is collected and may either be used to modify the set of available subroutines or to divert an individual student to a different subroutine.

(6) The IMPACT system (Seidel and Kopstein) resembles the SOCRATES system in its overall design. However, there are certain very important differences (in fact, IMPACT was independently devised and its relation to SOCRATES is largely due to the fact that both are big CAI systems, inspired by comparable objectives and ideas).

(a) The operational core of the IMPACT system is an instructional decision model (IDM) which asserts what should be done when a student, his state of knowing, and the current state of instruction are given. In a limited context the IDM is the control rule in a conversational subroutine. However, it may be more broadly interpreted as the instructional sequence selector (the higher level control of SOCRATES). Thus, the IDM is the IMPACT *Teaching* Model.

(b) The short-term educational *goal* of the system is to establish coherent and maximum information interchange between the student and the system itself (this goal is satisfied if and only if the *discourse* satisfied certain criteria; notice the marked departure from the behaviouristic paradigm and the obvious necessity for a rich interaction language).*

(c) The long-term educational goal is to achieve a state in which (as indicated by properties of the discourse) there is symmetry between the state of knowing in the system and the student.

(d) The IDM aims to satisfy both goals. It does so on the basis of a subject matter *structuring* and a student *image*.

(e) The subject matter structuring resembles that used in the other systems (since IMPACT teaches COBOL programming, the "map" part is fairly tractable). It should be noted, however, that the IMPACT designers are the only people who have made a really serious attempt to deal with the subject matter structure, in particular to condense it, in terms of general systems theory. This part of the model is incomplete but some very promising progress has been made.

(f) The student *image* is a direct, system representation of the student embedded in the IMPACT learning model. Part of it is a pre-tutorial (initial condition or component 3) representation and part of it is updated (component 4 of Section 2.2). Most of the properties used to specify the student image are fairly conventional (aptitude test data, latencies, mistakes, etc., taken with respect to specific exercises) but IMPACT is notable for its pioneering use of Shuford's subjective probability or *confidence* estimates which will form an increasingly important data source as the system is developed.

(g) The rest of the IMPACT learning model is of the Bunderson and Guildford type (the statistical cognitive model of 2.3(12)).

(h) The statistical data of (g) are related to the subject matter structuring and the input to the IDM (Teaching Model) by Structural and Cybernetic Models (in the sense of Section 2.3) and by records of the students' preferred learning strategies. Some of these strategies are built into the system as a result of preliminary experiments but some are learned (by the system) as the system operates. The communication between the student and the system is rich enough to allow the student to access new strategies of his own invention and to add these to the strategy list).*

* These are evaluated. There is a clear sense in which IMPACT can reach a *comprise* with the student.

* Satisfied by rather sophisticated interface equipment and an elaborate set of rules for comment, command, description etc.

2.8. Conclusion, Research Fields, Task Descriptions and Subject Matter Structures

It is possible to specify competent tutorial subroutines for various tasks and further research in this area is needed and may be expected to provide an immediate payoff. If enough of it is done, we should soon have a framework in which the appropriate subroutine can be recommended for *any* aspect of education.

Unfortunately, we can have far less confidence in the specification of a full CAI system. Several essays have been made in the direction of a general paradigm (as in 2.7) but all of them are marred by one outstanding deficiency. The subject matter structure and, to a lesser extent, the educational goal statement are arbitrary in the sense that there is no theory for saying what structure *should* be adopted. The matter is important because the subroutines in any of the CAI systems so far devised are held together and integrated by this structure. However, the problem can easily be overstated and it is worth giving some thought to the nature of the blemish and to just how "arbitrary" the subject matter structure really is.

Miniature tasks involving a single tutorial subroutine also have a subject matter structure; At this level it is classed as a "task description" which the student is asked to accept.** The description of the task and the educational goal is "small" enough for the student to assimilate at one intellectual gulp. Because that is so he might *reject* it instead of *accepting* it (i.e. "I didn't see things that way" or "for all your blandishments, I *won't* see things that way"). Because the student *might* reject the task description if it was altogether inappropriate, the task description is *not* tagged as objectionably arbitrary and, in general, it goes unquestioned.

Although the subject matter structure of a full CAI system has exactly the same form as a task description, it is much larger. It cannot be assimilated all at once and consequently it cannot, in principle, be rejected by the student (at the most, the student can reject the task structuring up to the next *subgoal*; essentially the task structuring imposed by the operation of a *single* tutorial subroutine). Hence, any structure that *is* imposed is open to the criticism that it was arbitrarily chosen (by convention, at the whim of a designer, etc.).

In a way this is true. But I would like to emphasize that the subject matter structure (an ordering and specification of concepts to be attained) need be no more arbitrary than many similar constructs in the behavioural and social sciences that are commonly accepted without question. The fact is, the teaching system designer could set about *discovering* the *natural* subject matter structure in much the same way that a linguist sets about *discovering* a *natural* language or the social

** We have already emphasized that the operation of a subroutine, a single control system, is game like. The game like or normative character of the tutorial interaction is, for example, stressed in Section 2.6(2) and 2.6(3) but is suppressed in the behaviourally oriented system of Section 2.6(1).

anthropologist sets about discovering the kinship system of a strange tribe. In the case of a subject matter structure the task is eased because the culture is far from alien (the native informants are students and teachers) and the symbols and ikons have a clear meaning. On the other hand, the basic units are concepts rather than phonemes or words and the emphasis is upon pragmatic and semantic (rather than syntactic) relations between them.

I do not propose this as the most economic or efficient method for determining a subject matter structure. But it is important to recognize that it is always a *possible* method. For, if the teaching system designer *did* adopt it, then his structure would be no more "arbitrary" than, say, a language.

Further, with this assurance, it is possible to develop a *theory* of subject matter structures of exactly the same sort as a *theory* of language. This, I believe, is the crucial next development on the learning model side of teaching technology. The probable basis for the theory is a cognitive (artificial intelligence) learning model or a general systems model as in IMPACT.* It is interesting to notice that the linguists and the anthropologists are currently using models of exactly this sort to deal with the open ends and dilemmas of their own field.

* However, in either case, the cautionary comments of Section 2.7 must be kept firmly in mind.

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DISCUSSION

The session began with Professor Gordon Pask in the guise of a 'learning system analyst' contributing a comprehensive overview of the theoretical bases of the learning process. Taking the point of view that teaching is a form of control and that teaching systems are built to control the learning process, he reviewed representative teaching-learning systems and discussed distinctions between the various types. Continuing on the thesis that any controller must be designed on the basis of a model for the controlled process, he took up several issues to do with learning and teaching models and related these notions to the business of computer based system design. His paper touched on much of the research going on in Great Britain and in the U.S.A., and in his introduction Professor Pask introduced illustrative material taken from his own recently completed experiments.

Professor Pask was at pains to lay the myth that CAI was wedded in principle to the tedious paradigm of a question and answer routine; and that the educational goal of the control system must be fully and formally specified. Other points he made included discussion of control methods as educational facilities or as educational sub-routines; the problems of evaluating CAI systems as a whole; and the need to pay due attention to psychology and logic in designing computer based systems. In talking about learning models he stressed that these incorporated several separate representations, such as that of the subject matter to be instructed, the educational goal, the teaching system and its strategies, etc., and contrasted their descriptive (predictive) uses with their prescriptive uses. Finally he illustrated his analysis by case-histories of some fully-specified CAI systems.

Professor Mitzel then raised four questions for general discussion by the group. (1) Psychologists have traditionally ignored individual difference variables (except mental ability) when studying human learning. How important will this set of variables turn out to be in building future CAI systems? (2) How important is it for future CAI systems to have a query capability for the student in order to approximate more closely live tutorial interaction? (3) In the evaluation of learning of different CAI systems, what is the impact of using norm-referenced achievement tests versus criterion-referenced achievement tests? (4) What degree of learner control of the general or typical CAI program is optimum in order to maximize both speed of acquisition and retention of information? These questions were followed by a brief discussion of conversational control systems.

An intervention followed in which **Professor J. Jones** of Louvain University presented additional information on the automated teaching program which he had described the previous day. He described the teaching strategy and feedback mechanisms of the system which is designed for the teaching of physics to undergraduates at Professor Jones's home institution.

Dr. Rothkopf asked about the possible application of a kind of Heisenberg Uncertainty Principle in attempting to diagnose a student's particular learning situation. **Professor Jones** agreed that there was a variability introduced by the act of diagnosis. **Professor Pask** said that interrogation of the students does undoubtedly modify the student's choice of a learning strategy. It does, he said, define the choice set of learning plans and, in his experience, learners invest in a plan and achieve a kind of "cognitive fixidity." In the subsequent discussion, **Professor Pask** held that a conversational control system (in which the student participates in the learning strategy) is simpler and less expensive than a fully adaptive and automatic control system. **Mr. Duke** asked if there wasn't a danger of overemphasizing the decision role of the machine. Shouldn't, he queried, the teacher be furnished with information about the student and then the teacher make some of the adaptations in the instructional strategy? **Mr. Hill** raised a question about the adequacy of the information processing powers of the teacher and indicated that he doubted whether these powers were sufficient to allow a person to act in place of the machine. **Professor Duncan Hansen** related his experience at Florida State University in dealing with students on a CAI physics course. He pointed out that human beings are "least effort" machines and that they will typically find the path through the material which involves the least amount of time and of effort on their part.

Dr. Eraut questioned what one was trying to optimize. There was danger of optimizing on the content and using the student strategy for this end; surely the main educational objective should be to help the student to choose the most appropriate strategy. Results of evaluations would also be markedly affected by the performance level selected as acceptable. A further point he made and on which several speakers commented was that since courses did not exist into which CAI could be fitted, how was a context to be formed to create information on which policy-makers could make decisions about implementation. Until better theoretical insights were available one could only work by trial and error to establish a base-line and improve from there – however such was the bankruptcy of the evaluation procedures of classical psychometry that one did not know when a case became optimal and when to stop developing.

The corollary was that management decisions had to be made on hunch today, but that neglect of this information would prove crippling to the development of computer based learning.

The difficulty was whether the results from psychological experiments using non-meaning learning will apply to meaningful human learning which we hope to implement with the aid of CAI.

SESSION V ECONOMIC PROBLEMS

INDUSTRY, GOVERNMENT AND EDUCATION: WHITHER OR WITHER CAI?

Robert J. Seidel and Felix F. Kopstein
Human Resources Research Organization

DISCUSSION

Rapporteur, B. R. Gaines.

INDUSTRY, GOVERNMENT AND EDUCATION: WHITHER OR WITHER CAI?

by

Robert J. Seidel and Felix F. Kopstein

Human Resources Research Organisation[1]

INTRODUCTION

This paper will deal with the broad picture of resource allocation for research and development and implementation of computer-administered (or computer-assisted) instruction, CAI. Specific cost projections within an operational setting have been discussed previously (Kopstein and Seidel, 1968) and therefore will be touched upon only briefly. Resource allocation will refer to funds, people, facilities, and the delegation of appropriate authority to formulate appropriate policy. And the fact that all these resources will be considered, viz., government, industry, and education, means that inevitably politics and economics will be intertwined in the subsequent discussion.

The features of the presentation will be a brief description and justification for CAI as a technology. The need for incorporating a systems approach to educational innovation will follow to set the proper framework for the magnitude and complexity of the required research and development effort. An analogue to a corporate level of investment into research and development, 3% - 5% of income, is proposed to effect the orderly transition of CAI from breadboard, through prototype to an operational system.

Problems which arise in the course of considering appropriate resource allocation stem in part from the fact that none of the so-called entities, government, industry, or education are monolithic. Government involvement will be both central and local. Industry in CAI includes hardware manufacturers, book companies, etc. Education includes central and regional administrators, teachers, research and development personnel as well as the ultimate user, the student. Problems of program management and co-ordination are thereby made difficult. (The problem of educational value is also considered *en passant.)*

Finally, a partnership model will be proposed to evolve operational CAI. The vehicle of a national R&D center with regional satellites is suggested to provide both proper training and to permit flexibility of research approaches to accomplish the goal of operational CAI. The context within which these points are discussed is, anything worth doing is worth doing right.

Thus, we will ask if research and development into CAI is worth expenditure of money, time and effort. As you might predict, our answer will be affirmative. Granted this is so, what expenditures are necessary to do it right? Finally, how should the resources be properly allocated among industry, government and the educational community to bring CAI to fruition? Fruition in this case refers to the actual production of multiple copies of operational CAI systems usable in schools and universities throughout a nation.

CAI is a Necessary Technology

Various prominent individuals and agencies in the United States have indicated the need and desirability of exploiting the educational opportunities inherent in individualised instruction. The Committee on Economic Development has represented the broadest cross-section of U.S. society in its appraisal (businessmen, educators, psychologists and community leaders). In essence, they present the case well for a failure of our current educational system to take advantage of modern technology and to deal effectively with the increasing requirements of our complex society. The Committee has pointed out that 'individualized instruction geared to the individual interests, abilities and learning rate is one of the cherished goals of American education. It is an aspiration which we wholeheartedly share, yet the schools are making very slow headway in this direction through present means ...' Psychologists have been engaged in the study of individual differences for years. Teachers have long been complaining of the inability – administratively – of coping with students as individuals and have been thereby forced to teach, for the most part, to the mean of a class.

Our view is that CAI is the leading, operationally defined edge of a model of individualized instruction. It represents the *potential* (with all due respect to Oettinger and Marks' objection) for a quantum leap in adapting instruction to the momentary needs and capabilities of the individual student. It provides the basis for an iteratively improving instructional environment. A word should be added here about the distinction between technique and technology. The criteria for evaluation of each differ. A technique may be properly compared to another technique with the same system model. Teaching reading by the phonics method versus 'look and say' is an example of such a comparison. Indeed studies have been conducted attempting to hold all other components of the momentary education system constant save the difference in technique.

In evaluating a new technology, however, such relatively clear and simplistic comparisons are insufficient. It may well

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[1] The research reported in this paper was performed at HumRRO Division No. 1 (System Operations) 300 N. Washington Street, Alexandria, Virginia, under Department of the Army contract with the George Washington University; the contents of this paper do not necessarily reflect official opinions or policies of the Department of the Army.

happen as in the case with CAI and individualized instruction in general, that the system in question must be redefined. It is silly to mold a computerized, individualized teaching environment around a 6 hour day. It is also improper to consider the economics of the new technology in terms which neglect the new opportunities opened up and hitherto impossible. To quote Harley (p.56, 1967) 'When economies result [from using the new technology] they are derived from the reduced cost of providing additional services – from the improvement in the quality of teaching and the level of learning; from the ability to shrink time and space, and from the sharing of limited resources.

CAI is thereby a technology, not a new experimental classroom technique. Indeed, the magnitude of societal effect possible with CAI without any hesitation may be made comparable to that of the industrial revolution. The potential for basic improvements in educational systems exists but it must be brought to the proper climax. The economic exploitation, frustration, disruption of employment, suicide, etc., which the industrial revolution had led to, could have been avoided with proper planning. With the advent of the computer, automation has changed man's role already to that of innovator rather than routine performer. On a purely rational basis, therefore, CAI is worth doing wherever individual differences make a difference in the field of instruction

CAI Research and Development is Complex

Having answered – all too briefly – our first question affirmatively, i.e. CAI *is* indeed worth doing; the second and more thorny question must be addressed: What do we mean when we say, 'It should be done right'? We will first present in Figure No. 1 the Eight Steps which comprise a total systems approach.

The Eight Steps of the Systems Cycle

1. State the real NEED you are trying to satisfy.
2. Define the educational OBJECTIVES which will contribute to satisfying the real need.
3. Define those real world limiting CONSTRAINTS which any proposed system must satisfy.
4. Generate many different ALTERNATIVE systems.
5. SELECT the best alternative(s) by careful analysis.
6. IMPLEMENT the selected alternative(s) for testing.
7. Perform a thorough EVALUATION of the experimental system.
8. Based on experimental and real world results. FEEDBACK the required MODIFICATIONS and continue this cycle until the objectives have been attained.

Figure 1

This framework (with slightly different words if you like, or 7 versus 8 steps) must be followed from research through development and implementation in order to result in operationally valid and useful CAI systems. We should add that this approach is also necessary when attempting improvements in a traditional instructional model. We shall return and enlarge upon this approach later when proposing a model for accomplishing proper CAI development. Its importance is amplified tenfold with an innovation as encompassing as CAI can be. Note then the framework does not preclude CAI as drill and practice, simulation, or use of a strictly calculational aid for problem solving. These can all be useful parts of an overall CAI R&D project. However, as I have previously asserted, the instructional system consists of N components. If only 1 or 2 components are clearly identified, measured and controlled, their contribution to instructional output relative to that of all the N-1 or 2 other uncontrolled components becomes extremely difficult if not impossible to assess (Seidel and Kopstein, 1968).

'Doing it right' thus means having a careful system research and development effort integrating the facets of computer hardware and software with content development and studies of alternative instructional strategies. This means in turn a multi-disciplinary effort. If CAI is to fulfil the promise of delineating the relative importance of the various characteristics pertinent to appropriate decision making in instruction, it must have the opportunity to model the instructional situation, to vary parameters and to apply these to meaningful human learning.

The Magnitude of Required Effort for CAI R&D is Large

Let us ask the question at this point what experience has shown us to date have been the requirements of any large-scale CAI centers for annual budget requirements. From informal discussions with knowledgeable persons regarding their CAI projects' fiscal problems, it appears both internationally (Mr. Kirchberger of France) as well as in the United States that an operating budget of approximately \$250,000 to \$300,000 a year is necessary merely to maintain facilities in operations. The reason for this becomes quite clear if one considers simply the rental price of an IBM 1500 system as an example. The hardware alone averages \$100-110K per year. Taking the \$250K total, this leaves \$150K per year for staffing, administration, and support facilities. The result is that, given approximately \$38K cost per professional man year, one can have only a minimal CAI program (4 professionals) concentrating on operational activities.

How much then should a total systems approach toward the development of CAI require to produce an operational, useful example of individualised instructional models? We cannot answer this in absolute terms, but on the basis of our experience with Project IMPACT's multi-disciplinary staff involving 18 professionals and 7 others in supporting roles, a personnel budget of at least twice these amounts seems necessary. Our installation is unique in that it is funded, so far, by a single arm of the government. Of course, one of the problems for most of the CAI projects is that they are funded from multiple sources with different demands; and in order to satisfy the requirements of the various funding agencies, the research and development is fragmented in many different directions. Until recently the awareness of funding at a 'critical mass' level did not seem to exist. Recently it seems that the Office of Education in the United States has taken steps to support fewer projects in CAI but at a higher level of funding. At least this seems to be a move in the right direction. The problem, however, to maintain this critical level is to permit not simply existence of an operating environment, but rather to facilitate large-scale, integrated centers to study and arrive at both the adequate descriptions of learning processes and the necessary prescriptions for instructional development.

The most recently published figure from the Bureau of Research in the U.S. Office of Education (*Educational Technology*, April, 1969) indicates that they are providing an average of roughly $287,000 per project over ten CAI projects. If other governmental agencies could support these *same* projects, without changing their goals, with a comparable amount of money, then it would seem to be possible to proceed beyond the breadboard stage of CAI development. One point of clarification is worth noting at this moment with respect to encouraging flexibility and diversity in approaches. This promotion of varying approaches to solving the strategy development and overall construction of useful CAI should not be in any way misunderstood as promoting the support of multiple small-scale efforts. Furthermore, if a project is required, once funded, continually to submit and resubmit a multiplicity of proposals, a large amount of time and effort will go into non-productive work. What is required is that a rational basis for selection of project proposals should be used at the outset, and then a reasonable amount of funding be provided over at least a five-year period. Without advocating that all the eggs be put in one basket, we are saying that the highest rate of progress is likely to result from a distribution of available funds to fewer baskets at sufficient levels to permit large-scale integrated efforts. On the other hand, funding a diversity of projects at very small levels of funding will most likely result in none of the efforts ever getting to the point of providing a full-fledged operationally, implementable CAI system for education.

An Analogue to the Corporate 3%-5% Investment is Advocated

Next, what expenditure should be invested in a CAI total systems effort? We can start by taking a cue from a corporate model and note that a number of sources (recently Duckworth of the United Kingdom, 1967, as well as representatives of corporations in the United States) have indicated a 3% – 5% level of corporate income is appropriate for these purposes. In a recent talk at the American Educational Research Association, the branch head of special projects in the Office of Computing Activities of our National Science Foundation estimated that last year the entire educational enterprise in the United States cost somewhere around $50 billion (Melmed, 1969). He gives a figure for expenditures on educational research which approximates $100 million, or in other words a .2% investment. Even with a large error factor, it nevertheless appears 'that the investment in educational research is only a fraction of 1% of the educational enterprise.' In contrast to this, R&D investment in the electrical communications industry last year stood at approximately 3.4%. Secondly, he alleges that IBM invested $300 million, or roughly 5%, in R&D of its reported $6 billion gross income for the last year.

If we accept the 3% – 5% figure as necessary to sustain viable R&D in education, the annual dollar investment given the $50 billion total year expenditure should be between $1.5 and $2.5 billion. Before you wilt under the apparent enormity of this amount, consider it relative to innovative programs with which we are more familiar. The United States has just put a man on the moon. Our understanding is that we have spent $24 billion and 10 years of research and development to go from the breadboard stage through the prototype to the ultimate system for the lunar landing and retrieval. Accepting the 3% –5% figure, a comparable time period for innovative developments in education would amount to an investment between $15 and $25 billion dollars. The question we ask you to consider is, is education any less valuable than a lunar landing or space travel in general? Our personal reaction is that both efforts are extremely valuable. Forgive us if we seem to go off on events within the United States, but these are figures and programs with which we are much more familiar. You can readily apply the percentage estimates to your own country considering your own expenditures, gross national product, etc.

In any event, let us carry the analogy one step further. The dollar cost of investment in education, in particular in CAI, further pales by comparison to the costs of other single technological developments. For example, the United States government's contribution so far to the controversial supersonic transport program is roughly $1 billion. The cost of the deep-dive nuclear research sub is roughly $99 million. Many more such examples could be cited. Note that these are specific system efforts. We have previously documented that an implementable computer-administered instructional system, following from breadboard through operational development stages, could be accomplished for something in the order of $5 million in a careful time-phased schedule (Seidel, 1969). We would submit that this is certainly not off by more than a factor of 2, and further that the value of such a development, as we have tried to indicate, can be monumental in reshaping the whole field of education. You recognize, of course, that this must include adequate interdisciplinary staffing and evaluation and testing of all the components of experimental hardware, computer software, instructional strategy and various selected subject matter. However, we submit again that the expenditure is but a minute fraction of the cost for other technological developments. Surely the goals are at least equally desirable. Let us submit further that given the 3% –5% investment in all of education, enough money should be available for such innovative efforts as CAI to permit, as Oettinger has proposed (1969), a great deal of flexibility and diversity in approaches. It thus should be possible to solve the educational technological problems of using the computer properly in the entire field of instructional and educational improvement.

Problem of Interpreting the Value of Education

To return and answer some of the rejoinders which have surely been developing as you have been listening to what we have been proposing as a reasonable level of dollar investment, let us consider the fact that the goal of a space program such as putting a man on the moon and retrieving him is quite specific. The parameters for guidance, for control of the entire system required to perform this feat, although large, are finite, measurable, quantifiable. A major problem for education is to identify all those factors which are pertinent to estimating requirements for specified achievement characteristics, and also for interpreting the value of that educational achievement. Another paramount problem that educational technology faces as opposed to a neat and closed engineering technology such as the example of the space program is that the return on investment on education may not be visible for roughly an entire generation. The attainment of objectives in the space program, on the other hand, was relatively immediate, dramatic, quite tangible, and rapid. Our only rejoinder to that is that in educational technology, one must extrapolate from immediate criterial effects of measured educational proficiency to ultimate criteria of general societal significance. Of necessity this means at the outset that we have clearly identified the parameters, our educational inputs and our educational outputs.

We must not permit our experience with the ambiguities and vagaries of the traditional educational instructional system to force a premature and inappropriate evaluation of computerized instruction. True, there have been difficulties in measuring a 'good' teacher, certainly in traditional instruction one of the most significant educational inputs (Froomkin, 1969). But, as noted previously (Kopstein and Seidel, 1968; Seidel, 1969a; Seidel, 1969b) in computer-administered instruction, we can objectively document the dimensions of that system. Cost effectiveness *can eventually* be measured. The instructional agent's value (instead of the human teacher's) *can* be measured against its output (student achievement). The costs of the entire CAI system, input, transformation and output, *can* be evaluated and justified or not, upon tangible and objective bases.

What then are the implications for consideration of cost effectiveness studies in CAI? Granted that we may extrapolate to later generation returns, it certainly seems we must consider *direct* outputs of the instructional system if our evaluation is to have any substance at all. Standardized achievement units must be the criteria (see Randall and Blaschke 1968). Harley (1967) in an insightful appraisal makes the point even stronger. '... we have been concerned with the cost per student taught (our input) and not the cost per student learned (our output) yet we know that what is taught and what is learned is not synonymous.' We have ignored therefore the vital '... cost of our scrap (non-operable units) – students who cannot function in today's society ...' and therefore our cost statements have fallen far short of the true costs of our education system (page 52).

A host of other problems beyond the scope of the present paper relate to establishing other measurable values of education. For instance, Suppes (1968) has recently called for 'clearly stated normative principles' (page 12) for dealing with the contradictions in modern philosophy of education. While not a direct concern of economics and CAI, certainly resolving the existing antonomies of educational philosophy (e.g. maximum freedom of choice etc, versus development of a sense of discipline, content versus method, social adjustment versus maximum achievement) is essential for a meaningful evaluation of *any* educational innovation.

This is particularly critical (perhaps propaedeutic) for CAI which depends upon acceptance to a large degree of the model of individualized instruction. We do not wish to dwell on this except to point out that it is an extremely important problem to be resolved.

Problems Exist in Establishing a Potential Partnership Model
The next item is equally important to establishing that CAI is valuable, and to establishing the necessary dollar figures for R&D investment. That is, what kind of a workable framework can exist, within which this research, development and operational environment is appropriate? Can industry, government and the educational profession be combined to bring the effort to fruition? What policies must be incorporated thereby to bring this about? How can resources, money, facilities, personnel and time be most appropriately allocated?

Are Goals Compatible?
Before delineating the proposed prototype for the three-way partnership, let us examine potential problems that may arise from the combination of industry, government and educational professions in this manner. One can ask if the model of research, development and operational utility for industry is compatible either with the educational profession or that of the government. Interestingly enough, we already have at least one failure in an attempt to bring these three entities together. In the United States there had been a Project ARISTOTLE intended to be a catalyst and continuing stimulant for educational innovation through these three arms, and it has been dropped for lack of support. Perhaps the answer lies in incompatible models. Industry in the United States exists to manufacture and sell at a profit. Its investment of 3% – 5% in research rests clearly in the belief that the return will occur in a relatively short period, perhaps two to three years. This premise becomes muddied when we attempt to apply this industrial template to education. Recall the generation lag for evaluation purposes in educational products that I spoke of earlier.

Considering the educational model, the goals of education have never been defined in terms of profit and loss statements. Selling a product has never been part of the system. In fact a frequent criticism in recent years has been that the intellectual aspects of education were being subverted for more specific and practical occupational training. It almost seems that the traditional roles of industry and the educational profession are so antagonistic or at least not overlapping that throwing them together without creating a new compatible model for R&D purposes in CAI is to create an anomaly doomed to failure at conception. Moreover, government and education are interested in welfare of the populace, education being – in this sense – a subset of the governmental function. Industry is concerned with product development and sales. But need these be different? (Galbraith has previously said in *The Affluent Society* that the private sector could not handle this type of effort on its own, but why not a partnership?)

'Government, Industry and Education' are not Monolithic Entities

For another thing, the so-called education 'industry' in CAI is not monolithic and not coordinated. It involves hardware manufacturers, book companies and computer software houses at the very least. The companies are *relatively* independent with their own profit and loss statements, corporate policies, etc., and they all must be brought together in order to construct a meaningful CAI system. The educational community and the government are also made up of components with differing capabilities. 'Educational community' consists of at least administrators, middle management in the person of assistant headmasters (or assistant principals) and the teachers on the one hand. On the other hand is the ultimate user, the student. Government is represented by central and local spheres. For funding we require federal and for active participation in implementing CAI, we require local involvement.

There may well be many objections to a proposed cooperative set of overlapping functional relationships among industry, government and the educational community. Not the least of these is an abhorrence at attempting to apply the corporate model of R&D to education, but we raise the question, why not? It has produced inventiveness, increased profits, and viable, new products in the market place. Why not ask the same of education R&D?

Will the corporate model apply? If education is to be considered like industry, it is peculiar in that the financial resources are clearly not within the system per se but must be provided by outside sources – the local, regional and central governments. Recently (*Educational Technology*, May 1969) this has been called into question by those who would not like to apply the corporate model; but the alternatives are not being readily accepted (they imply clear, behavioral definitions of educational objectives, etc.) by the educational community.

This difficulty is epitomised in a statement by a noted special assistant on education in the former U.S. presidential administration – 'Perhaps the most traditional . . . , and the one (local community) most resistant to outside change has been the educational community.' (Kearns, 1969). The purpose of the Elementary and Secondary Education Act of 1965, Title III program, is to provide federal grants directly to local schools '... for the very purpose of stimulating innovation and change in local education patterns.' The prevailing mood, however, has been deap-seated suspicion in the United States that federal aid means federal control. Consequently, a very serious question is to be answered. Even given sufficient funding resources, how can a workable cooperative model be developed to ensure (a) valid R&D involving the educational community, and (b) proper implementation in local systems? *Part of the solution must of necessity involve commitment of dollar and personnel resources toward large-scale R&D efforts in CAI and toward massive training and retraining in the educational community.*

Let us turn the question around and ask it again. Is education becoming an industry? Should it be? The problem would seem to be one of retaining the goals of intellectual expansion, freedom and innovation while adopting where feasible a model of improvement in education drawing upon the techniques of industrial development. What also seems to be required at the very least are policy guidelines from the central government to force a necessary workable structure. This would, providing the policy is appropriate to the task, aid not only industry, but the educational profession and the educational user, the student.

A Proposed Partnership: Allocate the Unique Resources amongst the Steps of a Systems Approach

It should be clear from the foregoing discussion that we are faced with an enormity of (a) financial investment, (b) the requirement that this effort serve the public welfare, vis-a-vis the educational consumer, as opposed to a private corporate entity and its stockholders, and (c) that the return on investment may in fact take much longer in accurately calculating than what industry's profit and loss statements demand. All of this indicates that the central government then is the only one that can adequately and properly provide the funding the policy guidelines for this type of partnership. Secondly, the techniques of industrial research and development (that is, product development) are appropriate to contribute to an evolving CAI system. Various industries have the facilities and the tools for development and production (certainly for the necessary hardware and software components in CAI). The educational community is a unique partner in the sense that the local school system and its personnel are going to be the focal point of the development but they do not have the financial resources nor do they have more than a portion of the total personnel required to accomplish this innovation properly. Their partnership contribution consists in developing instructional content through providing subject-matter experts as part of an interdisciplinary team, and by providing the demonstration and test facility within which the innovative experimentation and development can take place.

Finally, in addition to the partnership structure, the developing CAI effort must include, as I have indicated earlier, a functional approach which embodies systems design and total systems development using the 8 steps. Now, how does this apply to CAI? The discussion of the steps is worth repeating in slightly different form if we are going to demonstrate a workable model for this partnership.

To create a proper operational CAI system, it must pass from the breadboard stage, through the prototype, to an operational, cost/effective phase. 'Breadboard' is a term originated by electronic circuit designers. During very early stages of developing an electric circuit the paper design (conception) is translated into a set of components provisionally connected (by alligator clips and a few wires) and tacked onto a wooden board. The purpose is to verify that the design scheme will have the general characteristics expected of it. By extension 'breadboard' refers to any first and provisional realization of a system design.

Applied to CAI, documents like the CED report have stated the NEED (see pp. 3 & 4) in education for exploiting individualized and personalized instruction. We have defined our OBJECTIVES in terms of producing student output at a given level of achievement. As part of the design note that this process is to be an iterative one in attaining that goal. In the breadboard iteration, only the most crucial design criteria are applied. Secondary objectives, i.e., desirable features or 'nice-to-have' characteristics, are kept from confusing the basic design problem. For example, with reference to CAI, at the breadbroad stage it is inappropriate to consider timesharing the computer with batch-processing operations. Similarly, during the breadboard stage of design, operating CONSTRAINTS are minimized. In terms of CAI, it may be essential to develop inexpensive student terminals, but first terminals with adequate characteristics must be designed. Further limitations stem from available computers and compatible CAI equipment and languages. Current CAI systems are divided among those which have not progressed past the breadboard stage and those which have tried (unsuccessfully) to by-pass this stage. ALTERNATIVE instructional decision-making strategies and mixes of hardware and software subsystems with selected subject matter must be considered. Following systematic evaluation and study of the alternatives, SELECTION of an initial system is made and IMPLEMENTED for a test run. EVALUATION is made based upon student output. FEEDBACK to improve (modify) iteratively the CAI system, viz., meeting objectives, is made.

This process continues throughout the iterative development in order to refine the system. Once the breadboard phase has been completed it is possible to proceed to a prototype system design, the circumstances under which the system must perfoim. In this phase one first establishes precisely what the system is to do and major constraints such as permissible costs or delivery time are also taken into consideration. Various available means (e.g. magnetic or optical information storage) are weighed against optimization criteria. Optimization means a best compromise among contradictory objectives and imposed constraints. (e.g. lightweight, portable student terminals with character-video-audio display capability for no more than $500 per unit) in terms of some ordered set of criteria (price more important than display capability which is more important than portability). Finally, the design plan that has emerged is implemented and a first prototype is synthesized. A prototype CAI system may have operational usefulness, but is likely to include design flaws and oversights that ought not to be multiplied in many duplicated installations. A prototype is merely an untried and unadjusted assemblage.

A tested system emerges over a number of subsequent repetitive development cycles. In the case of a CAI system only a small number of students would be exposed to its instruction initially. Their interactions with the system must be minutely monitored and appropriate adjustments made. Massive data need to be collected from which it can be determined whether the prototype is actually performing as envisioned. Where actual and expected performance disagree (e.g. , mean delay of system response to student exceeds stipulated value of 1 second) revisions must be made in the system design so as to bring them into line. A tested system exists only after actually observed system performance coincides with expected performance. Only then is it economically justifiable to use the prototype design as a template for multiple reproductions.

To place this approach within the partnership framework, the initiation of policy and guidelines (statement of NEED) would come from a central government agency. (It is conceivable that in a somewhat different form specific needs might arise from statements within the educational community.)

These would be transformed into specific system OBJECTIVES jointly by team members representing all these arms of the partnership. An interdisciplinary research and development effort (comprising the remaining steps except EVALUATION and FEEDBACK) would be conducted with the lead role most probably taken by a non-profit (rather than a profit-oriented) R&D corporation (see next section for reasoning).

Local government and educational system personnel and facilities would provide administrative aid. Industry would fabricate the necessary hardware and software, and members of the three-way team would then attempt to IMPLEMENT the provisional system. At this stage, the work primarily would be accomplished by industry and educational community with administrative aid provided by local government.

Considering the possibility of this joint venture as indicated, one more link must be added. To provide the necessary objective EVALUATION and FEEDBACK in a coordinated manner, an independent fourth party is required. The form of the feedback information would be appropriate to the particular partner of the three-way team in order to make appropriate modifications to those aspects of the systems development process uniquely under its jurisdiction. For example, if modifications were required regarding statements of need, this could be provided to the policy and guideline process for the government. As the modifications were necessary in fabrication of equipment and software, it would be given in unique form to industry, etc. While this may be difficult to conceive of within a given country, it may not be far off from what is currently proposed by the OECD group (Organization for Economic Cooperation and Development), an international body to establish policy and make apolitical, dispassionate and objective evaluations of CAI studies. In the U.S. fragmented examples are beginning to crop up.

A Vehicle for CAI Research, Development and Implementation

The last item we wish to suggest is a definite means by which the proposed partnership could proceed efficiently. Within a country and in particular the U.S., there are two such vehicles: We propose first the establishment of a national center for research and development on innovation in educational systems.

This is a necessary institution to establish, in fact, and has been proposed previously for the Navy Department in our country but was not funded by the Department of Defense. The Center's prime function would be to coordinate the application of diverse scientific and technological principles in the solution of educational problems and, generally, to evolve educational technology to higher and higher levels. At any rate, this centre would have closely tied regional satellites which would carry out the translation of the results of the research and development into operational reality within local school systems.

The fourth party, EVALUATIVE entity, which I described earlier fits here. It would be this entity which would bring together the industry, central government funds, and local governmental and educational systems for reorienting personnel into a demonstration program.

At the national center a training emphasis would be given to pre- and post-doctoral levels in order to develop increased national competence in instruction theory. The areas to be included might be illustrated by Computer Sciences, Behavioral Sciences, Applied Mathematics, in general what we might call educational-technological research, technical writing programs, etc. On the regional level, the regional centers would train for tasks relating to the implementation of CAI, that is orienting communities, training local officials, local administrators of programs, etc. It is important to make clear that the national R&D Center will not be the sole technical, or active research, installation. Research and development would be carried on at local installations to permit flexibility in approaches and there would be technical feedback or input in both directions to upgrade the R&D status in general. A plan for coordinated activities amongst the regional and the national centers would be essential, else fragmentation and lost efforts (such as seems to be the case currently with the USOE-sponsored regional laboratories) would result.

To accomplish testing and implementation there already exists a potential prototype of a fourth party in the U.S. It is a non-profit corporation (the Institute for Politics and Planning) which has the role of bringing together government, industry, and educational systems. This takes the form, for example, of establishing advanced learning centers in conjunction with the government, in this case not only the central government as the funding source but the local governmental groups as well as the local educational system participating as members of a testing and evaluation team. (We might add that the way this program is established currently the profit-minded industry operates on a fixed-fee basis and gets paid if and only if students succeed in reaching established achievement criteria.)

This effort is somewhat premature with respect to CAI because it assumes that we can already accomplish CAI implementation on a large scale. Nevertheless, a non-profit corporation may well be the focal point for making a partnership viable regarding all the activity phases, research, development and implementation. In the non-profit corporate model goals tend to be more directly oriented toward the welfare of society than those of the profit-maker who must put survival first. Alternatively, it may be possible to adjust the goals of the profit corporation. If the return on investment cycle were extended (to five or more years) through the provision of some type of government 'insurance', profit-making industry could play a role equivalent to the non-profit entity. The 'insurance' debt could be retired at the end of some agreed period either out of the corporation's assets (if no marketable product was delivered) or as a percentage of the profits derived from an implemented product. This at least represents one mechanism to consider.

In any event, the partnership model would have to encompass all the facets of research, development and implementation. Too frequently, an innovation is developed and implementation is given short-shrift in the form of simply a written recommendation. To quote Mr. S. Clark Beise (Chairman, Executive Committee, Bank of America N.T. & S.A.) in the report on innovation in education from the Committee for Economic Development. 'One of the major problems inhibiting change in our present educational programs and processes is the lack of communication between educators, teachers, administrators, school boards and the public.' He goes on to note that the statement in the report by the CED develops a program that should be accomplished for research in innovation but does not carry the recommendation through sufficiently 'to the point of being able to demonstrate their value to those who must be convinced that changes should be made. *In order to disseminate information on recommended changes effectively, there should be established a system of demonstration schools, reasonably available geographically, to show what can be done in general practice to implement and integrate the recommended improvements within practical costs, into a rounded program.*' (Italics ours). We take what Mr. Beise says as to be reflected in the needs of CAI efforts internationally.

We trust also that this discussion has demonstrated that 'CAI is worth doing', and that the approach proposed herein has suggested a reasonable framework for 'doing it right', We are certain that alternative proposals can and will be made to deal with the complex problems of resource allocation for CAI research, development and implementation. The rought sketch given in this paper can be viewed as no more than an opening wedge. However, we are equally certain that some such approach must be put forward and developed as a workable model if CAI is to live and fulfil its vast potential; otherwise this promising technology will die on the vine.

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DISCUSSION

Dr. Seidel opened the session by amplifying the material in his paper and giving some indication of the nature, objectives and costs of his own project. At HumRRO he has an operating budget of some $250,000 and a team of some 18 specialists. He noted that a CAI system has to develop through the stages of breadboard, and prototype before becoming a production system and estimated that to produce a prototype would require some $5M over 5 years. It is essential that this funding is fully committed in advance both as a hedge against inflation and as a guarantee that funds will be available.

At present, he felt that industry, in the sense of profit-making industry could not take the leading role in CAI developments because open-ended systems were required.

Dr. Seidel illustrated multi-point his model of CAI R & D given in Fig. 1 of his paper

He emphasised very strongly the iterative, cyclic nature of this R & D model and the necessity for strong and definite feedbacks.

Dr. Adams critised some of the points made in the position paper. "Bob says that CAI research costs an awful lot of money so let's go out and spend it. $100M is quoted–lot of money–should be able to *slaughter* problems." He pointed out a contradiction in that it is implicit in the reasoning behind educational innovation that the present establishment has done a bad job, yet it is the present establishment who have to provide the research funds. He doubted that any major projects could be fully funded in advance or have a blank cheque. He suggested, taking a cynical view, that it was unwise to try and pioneer in any project, since the more the project claimed to be doing, the more political management it required and the more people had to be squared. It was better to choose an application which you were certain would survive, and concentrate on systems which were crudely useful from the beginning.

Dr. Rothkopf noted that there were two technologies involved in a CAI research enterprise: computers and pedagogy. When allocating resources to computers it is essential also to allocate them to pedagogy, if only to protect ourselves against present pedagogy. Clear ideas have not come out of current projects in the way everyone seems to assume. To balance all the $1M projects there should be a $50M project systematically evaluating the $1M projects. This could well be modelled on the Rothamstead Agricultural Station and its systematic exploration of agriculture. We need a long-term program of research into education. However, no-one will listen–they want their blue-painted boxes in the corner!

Mr. Hill stated that institutions do not solve problems–what solves problems is taking action. People spend money on what they want and not what they should have. They require a pay-off and cannot see the value of long-term research.

Mr. Broderick stated, "I am one of the few people here who work for a Local Education Authority, I am, therefore, probably more especially aware of the problems that will be involved in implementing computer-aided learning in the field in the United Kingdom. The biggest problem, as always, will be money and I shall assume the unaccustomed and uncomfortable mantle of a Chief Education Officer."

It is necessary for a Chief Education Officer to make out a case for the use of CAI to a lay Council. This case must be a good one, if he requires £50,000 extra it will be necessary for him to ask the Council to sanction an extra 1d rate and rates are highly-charged political issues. The Chief Education Officer, however, must make out his case, not on the grounds of politics and prestige, but on the grounds of social and educational benefits. What are the possible grounds he could use?

(a) "Individualized instruction": this is true, but if individual student terminals are to be supplied, this could be a very expensive exercise.

(b) Computer-managed instruction: he stands a better chance justifying this if he can use computer equipment currently owned by the Local Education Authority.

(c) "Enrichment of education and extending the experiences of the Student": here I am really referring to use of CAI in a gaming mode. This can appear to be one of the most valuable applications educationally, but the idea of enriching education may well be a difficult one to sell.

(d) "Deprived areas": chronic staff shortages, be the causes either sociologically or otherwise, would probably make a strong case with the Committee, there are already many schools that have serious difficulties in obtaining Mathematics and Physics teachers.

(e) Fewer teachers will be required: this is blatantly untrue and at last Education Committees are looking to their Chief Education Officers to justify such claims by actually reducing the number of staff employed.

(f) For use in remedial work: quite a strong case can probably be made out for this application, for remedial teaching is an area where it is difficult to get educational staff and which can cause minor chaos in school organization.

(g) "Raising the base level of education": a strong case can be made here if the current base level could be defined.

In view of the points above, I recommend that research workers in the field considering the school area of application for CAI should bear in mind the climate in which their products are likely to be implemented.

Miss P. M. Ash noted that, "Comments have been made that the educational system has failed." What measures have been applied which lead to such a conclusion? How, in fact, can success or failure in education be measured? Certain developments here suggest success:

1. Selection for different types of secondary schools at age of 11+ yrs. has been called in question largely due to the efforts of teachers in Secondary Modern schools who have shown that they, as well as the Grammar schools, have pupils capable of succeeding in external examinations. Surely this is an example of effective teaching?
2. There are increasing numbers of students continuing their education in establishments of Further Education and Higher Education.
3. In addition, adults follow courses of their own choice in adult education centres.

As far as the role of the computer is concerned we should ask: What are we trying to do in education? What are the resources? How best can we use them?

If the computer is a resource—and I believe that it is—we should see that its use relates to trends in education. Our horizons should not be limited to considering CAI only. There are, for example, trends towards more independent and group work, to the use of learning modules—CMI would therefore be valuable in providing a means of assessment and diagnosis. Investigation in this field should be linked with current curriculum development projects.

We should also examine the tool use of the computer and simulations. These offer a powerful potential for curriculum innovation, since they are likely to encourage us to review approaches to learning and to extend the learner's experience beyond conventional bounds.

Mr. G.M. Hodgson noted that, "The economic arguments put forward so far in this symposium seem to ignore the global pressures which are emerging for large-scale action in automation aid for education." Phillip Coombs, Director of the Institute for Educational Planning (a UNESCO body) in his recent book "The World Educational Crisis" (Oxford University Press, New York 1968) points out that current educational systems will demand a most alarming proportion of national income. Only if some major programme of cost-reduction based on automation aid is mounted urgently will economic breakdown be avoided.

I do not agree that the present educational system is a failure. In this I agree with Miss Ash. But I do believe that all the trends implicit in long range social and technological forecasting make the present system obsolescent. If these points are to be entertained, then the thought must also be entertained that considerable national and international resources should be channelled into avoiding the anticipated crisis. Parochial economic justification becomes secondary.

Dr. Seidel replied to Miss Ash noting that if she were serious then we have been pursuing ambiguous goals up to now. We are in an educational crisis in that we are lagging behind by a generation. The problems we see are those of 20 years ago, not today. We are trying to apply educational techniques which we should have used 20 years ago.

Mr. F. Duerden gave an industrial viewpoint of the economic problems of CAI development—

It seems to me that what is sauce for the student should also be sauce for the master—in other words the principles found effective within the CAI system should be effective in a system for learning about CAI. Professor Pask showed yesterday that control was not necessarily authoritarian but could be co-operative or catalytic; also that there was advantage in the student's choosing his own learning path to a declared objective. I believe that the best managers and "controllers" are primarily enablers, at least in an activity with any degree of intellectual content. The problem inherent in Dr. Seidel's Systems cycle lies in getting past point one. If you can state the need, and have chosen the people with motivation and capacity, then control should be pretty minimal (from an authoritarian point of view). The difficulty, which I think is beginning to be realized about organization for controlling systems containing people, is that you have a pretty primitive controller (the management system) operating on a network of very complex devices (the human brains). Awaiting the outcome of "catalytic control" may be nerve-racking, but it is the only means to real progress.

In considering the strategic area, Dr. Seidel looks at the possibilities of government/industry partnership. Although I believe that we in the U.K. can profit from the considerable work done on CAI in the U.S.A., this may not be equally true when considering the strategy of partnership, because the two countries start from opposite sides of what may be the optimum amount of government intervention. It is worthy of mention that Industry is more co-ordinated in the U.K. than page 14 of Dr. Seidel's paper suggests, because of the existence of the Industrial Council for Educational and Training Technology.

Industry is in a simpler position with regard to defining its needs, which are less complex than those of Education, but can be stated in such a way as to bring out the general benefit to the community. Industry enters into the model of this educational process (a) as a user of human resources and (b) as a developer and supplier of technological equipment and systems. The benefits it can hope to derive from (a), in what I think if the order of priority, are:

(i) improved competence and motivation of existing staff;
(ii) reduced wastage of trained people, i.e. rapid retraining to counter redundancy and technical obsolescence;
(iii) earlier competence for new staff.

Under the (b) heading the industrial concern is likely to be for effective investment. As Dr. Seidel has noted, Industry's record of development spending stands up to comparison; but there is a problem of time scale. A million pounds spent on development now requires a resultant 13 million in sales in 3 years' time, but 26 million if the sales do not appear for 10 years—assuming in each case that 10% of the value of sales is available for repayment of costs of development and also that the funds cost 10% p.a. for as long as they remain unrepaid. It is interesting to notice that a development program costing £1M total spread over 10 years requires sales of £26M if spread over 10 years also—this is true whatever the shape of the build-up of development spend and of sales provided they have the same shape. A smaller sales volume will suffice to recoup, if the sales build up more rapidly than did the development. If development cost build-up is linear over a 10-year period, only about 10% of the sales is required to pay for the first 3 years' work.

An important requirement emerges, if the total programme is to place the minimum drain on resources, for very sound judgment in the earlier (possibly study) phases before the heavy expenditure has been committed. The greatest importance must however be attached to the need for a rapid market build-up at the end of the development period, and to attain this we need a well-considered public relations activity (as referred to in the NCET Study Team's report), demonstration facilities, and better organization of the whole educational market which currently combines the worst features of the systematic vagaries of central funding, with the randomness and high costs of individualized selling. If adequate and early attention is given to the market problem, I do not think that Industry will be lacking in doing its part in the development programme.

Dr. L.C. Jesty reported work on "Electronic Aided Instruction" at Chelsea College (University of London), "The choice of this title is deliberate as, although we are using a computer, it is a component in the system and the operation is not dominated by it. In addition to its technical accuracy therefore, the word 'Electronic also gives the correct emphasis to the direction of our efforts."

The investigation began with a preliminary survey of the work already underway or planned in the U.K. in this field of Instructional Technology, (a) to ensure that we did not indulge in unnecessary duplication and (b) to direct our own efforts most effectively. The present programme is sponsored by the Electronics Dept. of the College, under Prof. Houldin, and is being carried out in collaboration with the Centre for Science Education, under Prof. Keohane.

The primary objective is to investigate the possibility of setting up standards for a two-way communication channel between a Central Programme (Lesson) Distribution Centre and suitable student terminals which will give worthwhile help in dealing with the educational explosion which has already arrived. We consider this objective must be achieved inexpensively. It is not so much a question of "what can we provide" as "what can we afford". If the channel standards envisaged could cater for the education of 90% of the pupils for 90% of the time it would be ample justification of the project but a much smaller proportion would still make it worthwhile.

There are many parallels to be found between the present state of educational technology and television in the early '30's. At that time television "Systems" were prolific; equipment was inadequate; programmes were non-existent and so was finance. The establishment of sensible standards and the inauguration of the Television Service in 1936 immediately put the pressures in the right places.

We are at present assembling equipment, and the first exploratory experiments will be carried out using simulation wherever necessary. A parallel engineering investigation will evaluate the possibility of providing the electronic and other equipment to replace the simulators, and if necessary, modify the standards. As soon as the simulation equipment is operational we shall attempt to deal with as wide a variety of programme (lesson) material as those qualified to do so can provide. We shall welcome suggestions and material at the phase of the work.

It is hoped that the two-way channel envisaged will eventually be capable of dealing with all forms of teaching technology ranging from a simple one-way closed circuit television channel conveying the same lesson simultaneously to a large group of pupils, through all the intermediate stages of branching programmes with student response and evaluation, to the fully-conversational computer based learning situation giving individual tutorial instruction. The same student terminals will be used throughout. The only difference between these limits will then be the cost per student-hour in operating the system. The proportion of the central distribution equipment allocated to each student will increase with the complexity of the lesson strategy and with the degree of individual tuition involved. If our objective can be achieved—and this we have to determine—then the use of the channel can be regulated entirely on the basis of the finances available to the operating authority.

Mr. J. Duke enquired about the possibility of educational technology at the level of CAI which did not necessarily involve a computer.

Prof. Pask replied, "Yes, there are at least two relevant activities that do not *necessarily* involve a computer, though in each case a computer might be employed if it turned out to afford a less expensive or more convenient tool than special-purpose equipment." These two activities are:

1. *Research and Development*—Especially research into educational subroutines (in the sense of my paper). A great deal of my own work, and that of others, has been done using special-purpose equipment.

Quite elaborate man machine interfaces may be required for studies of control strategies (in an educational subroutine) since, over and above the task in hand, the student must receive:

1. various (mechanized) instructions, and
2. evaluations and he must respond with (mechanized) statements and selections.

Whereas it would be easy to instrument the required facilities with one of the elaborate CAI interfaces (C.R. Tube, projector and so on) this expedient is only mandatory if string manipulation is required. Otherwise, it is probably no more expensive to build an interface for each experiment.

So far as computation and recording is concerned, some special-purpose equipment is needed in the absence of a computer but the experimenter, working from a flow chart, can do most of the deep computation, parametric adjustment and so on providing he is given summary performance data and provided the serious business of recording is off-loaded onto a mechanical system. Apart from giving the initial instructions the experimenter does not, of course, interact directly with the student. Clearly the experimenter and some of his equipment should be replaced by a small computing machine and in that case it would be sensible to computerize the data recording as well (at present we process the tapes after the experiment and only do summary computations during the experiment). To do so, would call for the commitment of one small machine to each student (say a PDP 8 with 4K additional storage) or its equivalent.

2. *Operating Systems*—The real merit of research in CAI is that it provides (for programming, it *must* provide) a clear statement of how instruction should proceed. It is a matter of economy, convenience, and the need for personal contact that determines whether (1) the procedure should be carried out by a real life teacher or (2) by a CAI system. Nor are (1) and (2) exclusive. In many systems a good solution can be achieved by mixing human and machine administration. A couple of "hybrid" systems have been developed in my own laboratory, namely COMOPTS (for COMCEN operator training) and SIMPOL (which is being fitted with a TUTOR supervisor) for managerial training of detective inspectors. Both of these systems use the human teacher in two different ways: (a) as someone who instruments a *procedure* assisted by summary data and interface computing apparatus and (b) as a private instructor who is called upon from time to time by the *procedure* and who, in that role, interacts directly with the student. Obviously, function (a) can be computerized at will and it may or may not be economic to take up this option. In general, function (b) must remain in human hands.

Dr. Karl Zinn stated that it was not definite that the computer would have an ultimate role in any educational application where it is currently used for research. There are motivational techniques of equal sophistication to CAI where often the goal is to get people to interact with other people. He illustrated this with the example of Layman Allen's academic games, not using computers. Originally these were to be designed for CAI, but in analyzing them it became clear how to implement them without a computer. Finally, a computer was used only to generate tables which were put in booklets.

Dr. Derek Sleeman noted that the computer was a tool for use in a deep and thorough analysis of the educational system. The tool could be misused and if rubbish was put in then rubbish came out. He felt that it made sense to use a small computer system as a CAI testbed, going over to large systems for implementation.

The remaining discussion covered some of the internal problems of the IBM 1500 system, the importance of students as programmers in software development, and the relative costs of computer hardware and the manpower necessary to drive it.

SESSION VI

PLANNING AND MANAGEMENT PROBLEMS

PLANNING & MANAGING THE R & D PROGRAMME

P. McLaren,
Programmes Analysis Unit, Ministry of Technology/UKAEA

DISCUSSION

Rapporteur, Dr. Karl Zinn

PLANNING & MANAGING THE R&D PROGRAMME

P. McLaren
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Introduction

By the time this paper is considered at the Seminar on Computer Based Learning Systems there will have been considerable discussion on whether, or not, there is a need for such systems in the United Kingdom, whether such systems can work in the United Kingdom and on whether the United Kingdom should mount any kind of National Programme of Research and Development into their use. Since so many of you, I know, are to a greater, or less, extent, supporters of such systems, I will assume that you have, by this time, agreed that there should be a National Programme. My task, therefore, is to try and set out some kind of proposals on how such a programme should be planned and managed. In attempting to carry this out I shall draw both from the experience I gained as member of the study team which NCET set up to examine the use of computers in education and as a member of the Mintech/ UKAEA Programmes Analysis Unit, which was set up some two and a half years ago to evaluate R&D proposals which required the support of the Ministry of Technology. I would emphasise, however, that the views expressed in this paper are not necessarily shared by my colleagues on the study team or in Programmes Analysis Unit.

The American Scene

As you all know, the study team started off its consideration of what should be done by way of using computers in education by making a visit to the United States of America. This served to provide the Team with first hand experience of the new technologies in use in the United States of America and a report of our visit has been written up. I expect most of you will have seen it by now. As well as looking at the various technological and educational aspects of this small sector of the American scene, I found it of great interest to try and find out how the various projects were managed and how the results of the various studies were brought together. It was also of interest to me to try and determine how they were funded and to find out how this affected the overall plan. My objective in doing these things was not only because of my personal interest in the administration of research and development but because it would be valuable to draw on USA experience if a similar programme materialised in the United Kingdom.

I do not propose (and indeed I would not be capable of doing so) to provide you with a historical account of how the various studies on computer based learning systems grew up in the United States of America. All I can do is to give you my highly personalized view of what I saw in the Autumn of 1968.

Some American Projects

During the four and a half weeks which the team spent in the United States of America visits were made to over 40 projects. The overall impression I gained was of visiting over 40 *different* projects. Some of these were small, while others were very large, both in terms of objective and cost. Some looked as if they would be successful, others looked as though they were staggering on to their end. There seemed little correlation between the two factors of size/cost and probability of success. This, however, is not a phenomenon unknown in this country nor is it confined to the field of educational technology. All of these projects rejoiced in the title of research projects but to my mind really formed parts of the banded spectrum of pre-production work labelled R&D.

This spectrum of work was divided into three main parts. Firstly, a large amount of it was, by and large, of a 'basic research' character. By this I mean that a topic and a method of attack is determined by a particular individual to satisfy his own tastes and intellectual curiosity, rather than because a 'need' has been identified or that the work will lead to a discovery which will be of any practical use. Much of the work we saw was indeed valid 'basic research' in that it was carrying out semi-empirical experimentation in order to identify some real-life problems. It is often neither desirable, nor indeed possible, to 'plan' such research, except perhaps to put some upper limit to expenditure before reviewing the next stage. The decision on whether this is done, or not, seems to rest with the particular funding agency and practices clearly differed.

Secondly, a considerable sector of the work being carried out was not of this 'marginal basic research' but was more 'applied research'. It covered research in fields of recognised potential technological importance (I would define the imparting of knowledge as a form of technology). This type of research demands a more planned approach in that there is, or should be, some clearly defined technical objective to aim at. For example, in some of the projects we visited the objective appeared to be to find yet another technique of using the computer without, however, much thought being given to either need or desirability. Despite the fairly clear objectives of this type of work there was little evidence which I saw of any attempt being made to direct the research towards that objective or to resist temptations to be side tracked. Indeed this work was just as unplanned and uncontrolled as the basic research work.

The third major area of work going on was very much in the applied research and development field. Since this work was largely under industrial control, there was evidence of a planned, and perhaps too tightly controlled approach.

The Research Approach

It is, I think, of interest to try and find out why the relatively unplanned tackling of a project of this kind has developed and to try and determine the advantages and disadvantages of such a method. There is no doubt that a great deal of the work we saw was started up mainly in Universities because of the interest and curiosity of some individuals. Seldom did a request for aid come from practising teachers or educationalists. Depending on who the individual was, his interest would be for example, in learning theory, in human behaviour, on using a computer or perhaps even in selling a computer. Again, depending on his interest, he obtained funds from one (or more) of a number of different funding agencies. To judge from their titles these funding agencies covered a wide range of interests and it was only by some stretching of the imagination and some fairly close questioning that it was possible to determine why a particular agency was funding a particular piece of research. Included among the more easily identified sources of money were the United States Department of Defense, the Office of Naval Research, the Office of Education, Office of Economic Opportunity, National Science Foundation. It was difficult, for example, to reconcile the interest shown by ONR in school education with the funding by OE of the U.S. Navy project at Annapolis. Others, more difficult to identify, although their interests were clearer, were the local and State School Boards and internal University projects. Another source of funds, both for internal and for extramural activity, were the large industrial companies such as IBM, RCA, etc. Undoubtedly, support was also obtainable from organisations such as the Ford Foundation. This technique of funding seems to be quite common in the United States of America. There are no doubt historical reasons for it and that it continues is probably due to the active part played by various pressure groups. It is most refreshing even if somewhat confusing, to find that these 'Establishment' type organisations refuse to be ham-strung by their own red tape and are not constrained by 'terms-of-reference'. I wonder what effect this has, however, on the 'not invented here' complex when it becomes desirable to use the results. Would the Office of Education be prepared to support an 'applied project', based on the results of 'basic research' which had been funded by the Department of Defense? I think I know what the answer would be in this country.

It is not surprising, therefore, to be faced with a bewildering assortment of projects, the proposals for which had had to be framed to take account, not only of the personal interests of its initiator, but couched to make the maximum effect on the particular source of funds chosen.

After the funds have been granted the personal interest of the protagonist seemed to take control again, and so the aims of the project, in most cases, tend to deviate from the objectives given in the proposal. The effect on the observer, such as I was, was rather devastating. I would be told by the sponsoring body that Dr. X at Y University was engaged on a particular study but on visiting Dr. X at Y I would find a completely different study going on. Some of the apparently successful practitioners of this type of R&D seem to have made more a study of where to receive their funding than they had of trying to identify the solution to their problem.

free publication can be produced. Many of these are valid but perhaps because of the 'publications explosion' many of the people we saw were not aware of what others were doing in a related field. In fact, one of the first questions Team Members were asked on practically every visit was 'can you tell us what you saw in . . .?' There are other explanations for this lack of knowledge of parallel work which I don't necessarily subscribe to but which cannot be entirely ignored. Is there a fear that someone might have shown that your own programme wasn't necessary? Or is it that in order to continue to get funds the hypotheses are somehow presented as facts? Or is it that people don't publish enough of the right information? Whatever the reason there was what to my mind was an appalling lack of information about similar work, not only at the other end of the country, but often in the same, or neighbouring, State and even in one case on the same campus, indeed within the same department of the same campus.

Is it any wonder then that the overall picture appears to be such a hotch-potch and that there seemed so little to show for 4/5 years' effort at an annual expenditure of many millions of dollars per year?

Applied Research

As I have said the relatively unplanned basic research type approach can be justified for some of the work we saw carried out in the United States of America. Many of the projects we visited had, however, gone beyond this stage and were more concerned with trying to solve the problems of using the results of the basic work. We found, therefore, projects which were attempting to produce CAI/CMI techniques, which could be used to teach some specific skill or topic. We saw many projects where such techniques were being used in a teaching situation. Many of these had progressed beyond the ad-hoc experimental phase and it was reasonable to assume that someone had identified a reason for doing them. It is, to my mind, much easier to spot the disadvantages of current United States practice in this area than to pinpoint any advantages.

One major disadvantage is that if there has been no clear-cut objective to aim at it seems to me very difficult, if not impossible, to assess how close, or how far off, you are to the target. How then can the success, or otherwise, of the project be determined? To be told as we were on many an occasion that CAI was 'better' than classroom teaching required the question to be asked (and we often did) 'How do you know?' Unfortunately, this question was nearly always unanswered. Perhaps the objective wasn't to show CAI was better than . . . If so, what is the objective? Again, we were baffled. However, in the U.S.A. context our Team was of no significance, and rightly so! However, there was just an inkling that some of the funding agencies, particularly those providing direct Federal support, were beginning to ask the same questions. Unless some better answers can be produced than we got then there seems to be real danger of a drastic cut in funds for this whole project. Let me say here that I do not think it always to be necessary to show that the 'new' approach is 'better' than the old one. There are many

There is no doubt that an approach such as this can be attractive in that it enables a wide spectrum of problems to be examined by a large number of people of widely different interests and abilities. It is, however, expensive both in real money terms and in manpower and can only begin to be justified when truly basic research is being carried out.

On the question of communication between projects all the arguments relevant to the benefits and advantages of cases where the 'new' system does what the old one cannot do. Or a completely new vista can be opened up for students. If, however, protagonists of the 'new' system claim it to be 'better' then they are responsible for making this comparison and surely must attempt to justify their claims. Equally, however, I cannot accept that just because a method is 'new' then it must be 'better'.

In many of these 'applied research projects' we sensed that the people working on them felt they should still be doing 'basic research' and were using the rather 'airy-fairy' type of approach which seems to go with this type of work. It seemed that some of the funding agencies, particularly those under close Governmental control, were tightening up on their 'basic research' budgets and the only way these projects could continue was for them to be aimed at solving particular problems. No doubt there had been some very skilful re-writing of proposals to suit the needs of the funding body but this seemed to have been done so quickly that insufficient time had been given for the workers in the field to readjust either their objectives or their methods of working. In some cases it was clearly wrong to expect the basic researcher to continue with the new type of programme. It was not clear to me whether it was only the project staff who were paying only lip service to their objectives, or whether, in fact, the fault lay much more with the funding agency, who were being forced to at least appear to be solving problems.

Another of the signs that there is no co-ordination in the present system is the use of so many different high level languages. Referring to my personal notes of my visit to the United States of America, I came across references to between fifteen and twenty. This, I may add, was not an exhaustive list. I have no doubt that each and every author could demonstrate at least to his own satisfaction how impossible it was for him to use an existing language. Surely, however, one of the axioms of scientific work is that results should be verifiable by any other worker in the field. How can this be done at present? Allied to, or perhaps one of the reasons for, this state of affairs is the multiplicity of computers and computer systems. This, of course, impinges on the field of commerce and no doubt again can be justified. But I wonder what effect all this has on progress towards solving the problems of education, which CAI is supposed to deal with. Or is it? Has anyone attempted to identify what problems in education the computer is supposed to solve? We found very few teachers taking the initiative in the setting up of projects. Is it that they haven't yet realised they have problems? Or is it they feel there are other ways of solving them? Again I think this points to the need of at least trying to identify an objective.

Development

This phase of the project involves designing the system and carrying out prototype operations. Again, this is not a clearly defined sector of the operation but is analogous to the band at the opposite end of a continuous spectrum from basic research. Here we found a number of projects were going on. Many of them involved the use or development of specific items of hardware or software. Most of these were being carried out by, or were funded by, industrial companies particularly by computer companies. In these, as might be expected, there was evidence of fairly clearly defined aims and objectives. Sometimes these were couched in terms to allay the suspicions of the educationalist, but often they were perhaps more honestly directed towards the shareholder. In this latter case the crudest but most honest form was to aim to increase the sales of X's products.

Here again, but perhaps more understandably, there was little, or no, attempt at co-ordination of projects although in some cases an attempt had been made to carry out a wide ranging series of experiments using the same basic system. The example which immediately comes to mind is the number of projects using the IBM 1500 System. We were told, by some of the IBM people, however, that the results were less useful to them than they had hoped. What we were not clear about was whether these experiments had been initiated to assist IBM identify a market or to assist educationalists to try out new approaches to education.

The Overall Position

I have been, perhaps, unduly critical of what I saw in the United States of America? If so, I apologise to our guests from there. It might be that I expected too much and that having been told of the vast amounts spent over the past 4-5 years on computer based learning systems I was expecting that problems where these systems could be used had been identified, and that planned experiments would have been undertaken to compare the worth of different systems according to some sort of criteria and that there would be some attempt to identify what still needed to be done. Unfortunately, I found very little of these had been done. Instead I found a bewildering amount of research-type projects, some good, some not so good, but all of them showing an altogether awe inspiring command of technology, particularly the technology of using existing computers in an on-line mode. This was very impressive but as has been said by someone else about a town famous for its part in another great techno-logical achievement, 'everyone knows how, but no-one asks why?'

The Over Planned Approach

Having examined the relatively unplanned approach to R&D exemplified by the computer based learning projects in the United States of America, we must now look at an almost diametrically opposed system of carrying out such a programme. In this method an attempt is made to define clearly the aims and objectives of each small sector of the project as well as of the whole project. Estimates are made of the resources in manpower and money likely to be required and of the timescale which has to be met.

During the course of the project strict adherence to the timetable would be required and deviation from the planned programme would require careful explanation.

The advantages of such a scheme are that the sponsors can be very sure of how and when resources are used. They can integrate this project with others to enable optimum use of those resources which are difficult to come by. This type of scheme brings joy to the accountant's heart. It ensures that those scientists whom he believes to be a useless and feckless crew engaged on spending money for their own amusement are brought under control. The scientists and technologists, however, being honest and tolerant men, can very easily point out why such a system of control would not work. They would claim that when new ground is being explored objectives cannot be clear, that precise programmes are dangerous because the most valuable discoveries are unexpected ones and that genius must not be cramped by budgeting.

Both parties to this kind of argument could produce examples of how right their approach is. They will continue to do so and money and resources will continue to be wasted in many projects dealt with in both ways until there is more realisation that there are differences between basic research, applied research and development. The differences are not clear cut but because they are different activities the method of managing them and controlling them must be different.

I would reject completely any proposal to conduct all R&D on a completely planned basis just as vigorously as I would reject any proposal to conduct it on the completely unplanned system which seems to be the delight of the basic and pseudo-basic research workers.

The United Kingdom Scene

There is one characteristic of the United Kingdom attitude to science and technology about which I think we can be absolutely certain. It is that neither money nor resources will be available to match the efforts of the United States of America. Having said this I think we must then ask whether in this particular field (e.g. computer based learning) we want, or indeed need, to match them. Can we learn anything from the work done there and elsewhere to provide us with a starting point? (The more fundamental question of do we need, or want to do anything at all has, I presume, been answered earlier in the week.) We have, in our earlier discussion this week, and the study team in their report to NCET (i), tried to identify the areas of activity which needed to be covered by a national programme in the United Kingdom. We must now consider how this affects the planning and management of the programme.

CAI

In the strictly CAI field we feel there is a need to apply some of the known concepts of learning theory and the known techniques of computer programming to the task of preparing teaching programmes of different kinds and in different subjects. The team recognised that a great deal still needed to be discovered about the mental processes which enable us to 'learn' but felt (perhaps rather unkindly) that as the education process had gone on more or less successfully for several hundreds of years without all these problems having been solved, perhaps progress could continue without waiting for their solution now. A partial analogy can be drawn with agriculture. It will, undoubtedly, be possible to grow 'better' crops once we have understood all about the sciences of botany, plant nutrition ecology etc. but farmers do not, and cannot, wait until all the problems of these sciences have been solved before using empirical or pragmatic means to improve their products. It seems to me, therefore, that while it is of vital importance to improve our knowledge of how people learn, how people think, how to devise esoteric computer programming techniques and so on, the main thing we should be trying to do in the United Kingdom at this time is to harvest the fruits of the research already done.

CMI

When we consider the possible requirements for R&D into CMI then the story is very much the same. We have to decide what parts of the education administration system as it is now, and as we think it will be in the future, require the use of computers. Will this be in organising the subjects, the courses and the examinations of individual students? Will it be to assist in estimating future requirements in the way of schools, universities, teachers and so on? Will it be in dealing with the provision of information from libraries and data banks for students, teachers or administrators? Very few of these topics require basic research but all of them require considerable effort on finding out how to interpret the results already available from research projects and of how to apply these results to the foreseeable needs of this country.

United Kingdom Requirements

You will see, therefore, that while acknowledging the need for basic research into many aspects of the education process, we feel, and I consider rightly so, that the main effort from the national point of view must be directed towards finding out whether, or not, the research already done could help with our future educational problems. . while investigating these problems, we come across applications which would help to solve some of our current problems, this would be of considerable value. In all of this we recognised the likelihood of identifying the need for new basic research. We recognised that the results of current basic research might make it necessary to change course but we were, I think, completely united in believing that if a United Kingdom national programme was to be mounted now it could not rest on proposals for more basic research. The United Kingdom has often been accused of being good at basic research but neglectful of the applications. In this case let us be sure that we can apply what is already known albeit by applying the results of someone else's basic research.

Having said this I must point out that very strong arguments can be produced for not mounting even a modest United Kingdom national programme now. This possibility exercised the minds of the study team for a considerable time before we rejected it. I do not propose to repeat these arguments here as they are set out in Chapter VIII of the study team report to NCET.[1]

In summary, therefore, I believe that a potential need exists in the United Kingdom for a learning system involving the use of computers. The immediate objective of a national programme must be to see whether these needs can be satisfied by applying currently available knowledge. If not, then the programme should help to determine what areas of knowledge still need to be explored. Let me repeat that in basic research the scientist does not know what he is going to find, he only knows the direction in which he is looking. In applied research he knows what he wants and is trying to discover how near he can get to it. If he cannot get close enough to justify development he might at least have helped to put up signposts for the basic researcher.

The United Kingdom Programme & Its Management

I have until now considered some of the more philosophical aspects of planning an R&D programme such as one on computer based learning systems. In doing so I have used my admittedly limited experience of the United States programme in this field to highlight the problems of applying the 'basic research' type of approach and to argue that the United Kingdom need is for 'applied research' and that this involves some form of overall planning.

We must now examine how the United Kingdom programme is likely to be financed as this will have a very direct influence on how it has to be planned and managed. Here again there are major differences from the United States of America. There are few, if any, industrial companies in the United Kingdom comparable with IBM or RCA, who are prepared, or able, to finance even the in-house expenditure of these companies on computer based learning systems, apart from their contributions directly to identifiable experiments run by schools and universities or indirectly through non-earmarked contributions to universities and colleges. In the same way there are fewer sources of revenue from among the charitable foundations in this country while local education authorities are not noted for their contributions to educational research. Indeed, the Department of Education & Science spends very little of its total budget on this kind of research and development.

It seems clear then that if a national R&D programme is to start the government will have to be persuaded to foot the bill. Whether this is done by a direct contribution for this purpose, or via a number of different department votes and ledger headings, will not, I think, circumvent the need to persuade the Treasury to agree to the expenditure. This is the kind of expenditure which the government should in fact support, at least in principle. It is work on an area of activity where the public sector will be the main consumer; it has an end objective which is essentially a social benefit and it is of such a size, in its requirement for resources, that no industrial organisation would, or could, finance it. However, in practice government support will only be forthcoming if a case can be made which shows why this project should be given approval, rather than other projects which would use the same resources. In other words, because of limitations on money and men it is necessary to estimate the benefits likely to accrue to the nation from R&D expenditure. These benefits can, of course, be in intangibles such as improvements in environment and 'better' education as well as in purely economic terms. It must be recognised, however, that until we know better how to deal with and compare social benefits, the economic ones are more easily thought about and compared.

While such an approach to making a research proposal is anathema to the 'pure' scientist, we must, these days, be prepared to face the facts of life. Many people will argue that only by allowing a hundred plants to bloom will we ever have a garden. It is as well to remember that many plants, if not pruned and kept under control, will give you an unmanageable and unproductive mess, the only remedy for which is to ruthlessly cut them down.

In my view any work done in the United Kingdom in the field of computer based learning systems must have as its overall objective the identification of where and how computers can be used in the education system of the United Kingdom. This will involve, for example, experiments in writing teaching programmes, in methods of presentation, in assembling and analysing information about individual performances and so on. In the early stages there will be very little basic research work required and very little development and design of equipment needed. The various sub-objectives can, and should, be modified as the work proceeds, but the aim of reaching the overall objective should be preserved. This will involve adopting a moving plan rather than a fixed one.

While the above must constitute the major part of the programme, there will still be room for, and indeed a need for, basic research. The planning of this cannot be too rigid. There must be flexibility to allow for examination of new ideas. I do not believe, however, that all of this basic work should form part of the United Kingdom national programme. A large part of it is of a type that should be conducted under the normal cloak of basic research and should be going on with, or without, a national programme such as we are considering here. It should have to compete for funds with other basic research projects and be judged on the same basis as they are, however that may be. If, however, one of these basic research projects looks as though it has potential value to the main project then the main project must be flexible enough to adopt it for its use in reaching the overall objective. It will then cease to be managed as a basic research activity but will become an integral part of the project.

As will be clear from reading the report of the study team and the recommendations of the NCET steering committee, as well as listening to the discussions here this week, there are many ways in which a detailed programme could be put together in order to aim at the same overall objectives. I do not intend to repeat here the details of these alternatives. It is sufficient to point out that there is agreement on the areas which will need to be covered by the R&D work and the order in which it should be done. There are some differences of opinion between individuals on 'exactly' how things should be done, on what precise kind of hardware should be used, and on where different projects should be sited. It is to be hoped that one of the results of this Seminar will be to initiate even more detailed proposals for certain sectors of the work. None of these differences, however, prevents us carrying out the strategic planning of the project at this time. In my opinion we must do this in stages. I do not think that we can, with our present state of knowledge, carry out any form of cost-benefit and/or cost effectiveness study to give us an estimate of the upper bounds of expenditure. We do not know for example the contribution made to our Gross National Product by changes in the education system. Derek Medford, in Chapter VI of the Study Team's Report[1] has put forward a possible mathematical model for this situation, but I am confident that he would not claim this to be anything more than a first attempt, albeit a very good one, at trying at least to identify what the important parameters are. This is a field of activity which I am convinced must be given urgent attention. One essential part of the programme must be the identification of those aspects of the education process which contribute most to national progress and which will most readily lead to the achievement of the nation's will. Another factor which prevents the carrying out of cost benefit/cost effectiveness studies is the difficulty of obtaining agreement from experts on the aims and objectives of education. Speaking for the technical economists in the study team, we would have welcomed, and indeed we pleaded for, some guidance on these. Not surprisingly we were disappointed. We found ourselves unable to identify a 'learning systems model' (or even a teaching one!). This accounts, in part, for my lack of enthusiasm for basing the national programme on the results of basic research into learning theory or behavioural patterns etc. Let me repeat, these things are important and if someone can see how currently available knowledge can be used, then by all means let us use it, but it must be knowledge which is reasonably acceptable as truth.

We return then to the problem of reconciling these uncertainties into a coherent proposal. The first question asked by the Treasury in these matters is usually 'how much?' Although we cannot be precise at this stage, there does seem to be fairly broad agreement that over the first three to five years a total expenditure of about £2M would be necessary to achieve anything worthwhile. I would emphasise that this sum includes the various overheads etc., which universities in particular feel unashamed in ignoring. It also excludes any benefits likely to arise from using the computer to save other expenditure. Such savings have a knack of never materialising. Assuming this sum comes within the upper limit of expenditure which could be countenanced, we must try to identify some form of organisation to ensure that the money is well spent.

The Board of Management

Assuming, as I think we must do at this time, that finance will be by the Treasury through a large number of individual department budgets, there will, of necessity, be a group of people representing all these departmental interests. It would be nice to think that they would also all be representing the interests of achieving the aims of the project. These people, part-timers, would constitute a board of management. They are not likely to be in a position of taking any direct executive action within the project, as they would have neither the time nor presumably the inclination to take the necessary day-to-day interest which executive control involves.

The Directorate

Serving this Board would be a small full-time directorate. This would consist of three or four people, whose essential qualities would be the ability to oversee a number of projects and to withstand the pressures from the more voluble sectional interests involved. These people would, in other words, be good project managers. They would not need to be experts, either in computing or educational psychology or teaching or in any of the subjects being considered for CAI techniques. They will have the responsibility of firstly framing the detailed proposals and of ensuring that the overall aims and objectives are adhered to within the overall allocation of resources. They must not hesitate to modify the detailed plans within these limits, or to propose additions and deletions to them. In fact an ability to say 'stop' to a project director might be an essential feature of the job specification. The appointment of this Directorate is to my mind the key to the whole project. Only when these people have got together and have discussed among themselves the ideas for individual projects put forward not only by those currently involved in this work, but also by those whose imagination has been kindled – perhaps at this Seminar it will be possible to sort out in detail a programme which looks like achieving the overall objective. There will be much argument and discussion; much give and take before the project begins to take shape. Only then can firm proposals be assembled.

Projects

It seems clear to me that in order to obtain the maximum value from the national programme, as outlined, it will be necessary to carry out work at a number of geographically separate centres. One important requirement of the organisation for the project is that these different centres can, and do, communicate with each other and that there should be the opportunity to cross check results obtained at the different centres. This will require early agreement on methods to be used and to some extent on the hardware and software to be employed. It would not necessarily be either sensible, or indeed possible, to start off by insisting that only one type of computing system should be used but it would be sensible to try to ensure that only one, or at most two, competing languages should be used. It will also be essential to ensure the maximum amount of compatibility between the systems in use.

It has been said that 'the total cost of unnecessary computer language differences may well be of the order of hundreds of millions of dollars annually'. Although we have not, as yet, reached that state in the United Kingdom, we are fast approaching it. It might be that one of the by-products of this Study might be to prevent this situation arising. This will require both good judgment and firmness from the project management to achieve this without stultifying the ingenuity of the workers.

The Project Directors

As I see it then, the national programme will be built up from a number of centres, each of which will have a reasonably clearly defined role, both for itself and for its part in the overall programme. Each centre will have a project director, who will be responsible for ensuring that the centre works towards these objectives. At each centre will be multi-discipline teams of computer specialists, subject specialists, teachers, psychologists and systems specialists.

The key role at each centre will be played by the project director, who will be required to keep the correct balance between the conflicting demands of the various specialist groups. Each project director will have, of course, considerable freedom of action within his own centre and within his own budget. They will report to, and be responsible to, the board of management through the full-time directorate, who have to ensure that each centre is working towards the overall objectives set for the project.

It is not possible to be specific about the organisation of each centre. This will depend on the programme for that centre, but in all cases it will be desirable for some form of service contract to be used to ensure that the staff's day-to-day loyalties are towards the project rather than to their parent organisation. This will be particularly important in the case of part-time staff or staff on loan or attachment. It is not suggested that such staff should cut off all ties with their parent organisation. This would neither be practicable nor desirable. Indeed, the maintenance of their particular expertise over a period of two, three or four years will depend on their maintaining contact at the correct working level.

Conclusion

There are many facets of the planning and management of a national R&D programme on computer based learning systems which I have not discussed in this paper. This does not mean that they are unimportant; many are of vital importance, for example, how important will it be to have the 'right names' associated with board of management? Should we have a Lord Robens, or a Lord Beeching there? Or is it more important to have the right people there and in the directorate and the projects? How important is the timing of this? I know some of you have, what I consider to be, very strong views on this, which I hope you will express. I do not claim to have been either exhaustive, or indeed profound. I feel that there is a need for an R&D programme (with emphasis about left of centre), that such a programme can, and should, be mounted now but that the maximum benefit can, and will, only be obtained from it if it is planned and managed as a 'mission-orientated applied research' programme. It is with this in mind that my proposals have taken shape.

Reference

1. Computer based learning systems: a programme for research and development, National Council for Educational Technology, London 1969.

DISCUSSION

Mr. McLaren in introducing his paper said that the views he expressed were his own and must not be attributed to all or any of the members of the NCET study team, or to the Programmes Analysis Unit.

'The different proposals put forward for the scope and content of an R&D programme do not affect greatly my point of view on how such a programme should be managed. I will admit that a lot of consideration should be given to the proposals that effort should be devoted to investigating how people learn, think, and respond.

This week we've heard a lot about learning theories, but I'm not convinced that they're very different from the ones that we had twenty-odd years ago, and I do not think it helps us very much along the way to doing the job which the Study Team was asked to do – and that was to examine the feasibility of carrying out a large-scale R&D national programme in the U.K. on computer-based learning systems. The conclusion I came to after my American visit, after reading a lot of reports, and talking to a large number of people, is that if you want to say at this stage to me, 'Should we have a computer-aided instruction system in the United Kingdom at the moment?', all the things I have heard, all the people I have spoken to, all the things I have seen, would not convince me that we should – because I do not think we know nearly enough about it. However, I do not think concentrating entirely on a programme of looking entirely at the psychological and behavioural aspects, even carried on for twenty years, would bring us one whit nearer the answer at that time. But from what has already been done, I think we have reached a stage where a good case can be made for trying CAI to see what happens. The unfortunate thing is that such an experiment requires a certain minimum expenditure if it's going to be viable at all.

Unfortunately, that expenditure is very large compared to the usual expenditure on educational R&D in this country, so we have very carefully to examine not only whether we should do anything, but indeed how we do it. We constantly get told in this country that we are very good at doing research and not very good at applying the results of it. We also have a tendency to modify this a little to the stage of saying that, not only are we very good at research, but perhaps nobody else is very good at research, and therefore if any new ideas come forward before we would even think of applying them, we must re-do all the research ourselves.

What we have to do in this case is to learn the lessons from what has already been done and adapt the ideas, inventions and systems that have been developed – particularly in the United States – to our particular needs in this country and see whether they work. Now as well as learning lessons on the purely technical side of how to use the computer and how to apply it, there are some equally important lessons to be learned on how to run a system, or a programme. This is mainly what my paper is about.

In writing my paper I did'nt want to upset some of the people in the U.S.A. who had been very kind and helpful to us. I was somewhat relieved when I read the papers that had come from the United States because I concluded that, perhaps more so than would have happened in this country, the authors were prepared to put in print a criticism of themselves.

They very openly admitted that they have made mistakes in the past few years; and that is always the first stage in trying to make sure to do better next time. I think we should all learn from this.

I hope I've said enough in my paper to demonstrate that I don't believe that any great progress will be made through a large number of small-scale experimental set-ups. I think there has to be an attempt made to identify nationally what our objectives should be and to operate on a viable scale an experimental programme which will try to meet these objectives.

This isn't a problem just for computer-aided instruction. Last week I was attending a conference of production engineers who were talking about introducing computer-aided design and numerical controlled machine tools. There was an amazing similarity between the problems that are being faced there especially the decisions that have to be made on what needs to be done now, and the problems that have cropped up here this week.

There was great emphasis put on the need in engineering to set up integrated teams of design engineers, production engineers, maintenance engineers, and of people with a concern for human beings. I think this is something the education system should perhaps take note of. Even hard-headed industrialists who in the past would never give any consideration to a person as a person, are now beginning to believe that one of the major problems in the industrial field is how to get people to cooperate.

This is a thing which educationalists need to watch very carefully in the future so that they go off in the opposite direction when industry is beginning at long last to realize the importance of human problems and values.

The planning and management of a complex project in CAI depends largely on the concept of integrated teams. I think it's inevitable that in each team a leader will appear. He may be appointed, he may just appear. This leader may be a computer scientist, a psychologist, a systems analyst, or a humble school teacher. I don't think it matters all that much. What does matter is that that one individual must not exert too great an influence over the rest of the team.

Further in overall control of a programme such as that proposed there must be a group of people, whom I've designated as the directorate, whose job it is to manage the programme and coordinate the individual projects. They should not concern themselves with being expert computer technicians or psychologists; they may work in any one of the disciplines involved, or indeed be expert in none of them. The important thing is that they should be good managers. They should keep their eye on the objective, they should allocate the resources in the best possible way in order to make sure that that objective is reached in a minimum of time with a minimum of expenditure. They must also – and this is probably the most difficult task of all – do this constantly bearing in mind that in fields all round about them work will be progressing whether funded from this programme or from some other programme, and that people in different places will be producing new ideas, some of which it may be profitable to incorporate into the overall programme.

It is at this point that I think the main difference must be mentioned between the Study Team's proposal and the NCET's final recommendation. At first sight they are very similar; they are about the same amount of money, they are about the same general topics, they are spread over about the same period of time. There is however one important difference. A Treasury official looking at the NCET programme might say, 'There are six different projects proposed which total £2 million; as a matter of principle, let us cut out a random selection of projects that will save us £500,000'. Now I believe that if this were done the programme could not achieve anything.

However in the Study Team's programme there is more flexibility, and if the Treasury came along and said you would only get one and a half million instead of two million, I still think you could possibly get by, because there is, while not duplication of effort, sufficient flexibility built in still to cover a really wide field in different places. Now this doesn't mean that the budget has been artificially inflated to £2 million. I still think that two million is probably the minimum.

However at this stage I don't think the detail of what is going to be done exactly is important. I think the important thing is to be able to convince the powers that be – and this will require all the persuasion that can be mustered – that this is worth doing. Let's face it – there is very little evidence that CAI will work in the context of the United Kingdom. There is very little evidence that it has worked anywhere. I believe that there are certain areas where it could work, where it could make a very valuable contribution to education. But I don't think we know nearly enough about it yet. We have to convey this act of faith to the people with the money, and at least convince them that if they give us the money, it will be used wisely. I think the first step is to persuade the Treasury that they should agree in principle and that then strenuous efforts be made to put together a very small group of people, probably the people who would constitute the directorate finally, to sort out from among the half-dozen or so proposals we have today a coherent programme. This isn't going to be easy, because one of the great difficulties is in trying to distinguish between what has been done, what is being done, and what people hope will be done.

The job of the directorate is going to be to probe very carefully, to persuade people to modify their own ideas to fit into an overall plan, and then to get this off the ground. I reckon this may involve a year's work before any detailed proposals can be formulated at all.

One of the great dangers is that whoever has this task will be forced into a position of making a detailed proposal before they're ready for it, for there is a conflicting interest. This is that there are a number of people who are already enthusiastic and a number of people whose enthusiasm is beginning to wane, largely because they feel, and rightly so, that they haven't had the support that their enthusiasm deserves. Delay can be very serious. A large project takes off because of individual enthusiasms, and it's a great pity if they've got to be held in check.

This is the great dilemma for the sponsor of a programme. I'm not sure how you deal with it, because you obviously can't spend money until you've got it and there is a danger that momentum will be lost. The philosophy I take is that we should be at the stage now of trying to identify *why* we want to do CAI in this country, and then direct our energies towards it. I hope the planning goes on, I hope a programme gets started. I have no personal axe to grind in this, but I would hate to see the programme founder because it was split up into too many little segments and sectors which couldn't be demonstrated to be productive.

Mr. Hubbard, chairing this session, remarked, 'I think there's a point to be learned from the history of some other developments – particularly the development of atomic power. The thesis I want to illustrate is that it doesn't really very much matter, if you have your major and ultimate objective clear, which route you take towards it, provided that you take a route which at the time you make the decision appears to be immediately practical, and you go for it as hard as you can.

In about 1947 the British Atomic Energy Authority experts took the view that the practical system for a reactor was a gas-cooled reactor. The American Atomic Energy Commission took the view that the practical system was a water reactor. They belted ahead for twenty years and at the end of that time they both had effective working economic systems, and it would take today an extremely able economist to make a fraction of a penny difference between the operating costs. Now one might have said that one of them must be making a wrong decision, but in fact this sort of decision – whether course A or course B will take you to your objective – can be made provided you can see the first few steps ahead. I don't think either party totally followed the course they'd planned for themselves, but it enabled them to start. So I suspect that the important thing is, having got your money, having seen what you can do that is useful, you go ahead and do it.

I'm very impressed with Peter McLaren's paragraph in which he says that applied research and developmental work can point the way for the pure research worker. I think this is the way you really have to attack this sort of rather intractable problem – not by trying to see clearly where you're going, seeing clearly what pure research you want done and getting that done first, but doing what is immediately available to you so that you can immediately get a usable, worthwhile result. This is terribly important from the point of view of getting continued support.'

Dr. Karl Zinn, as rapporteur, continued the discussion. 'I do not wish my remarks to be viewed as a formal response on the topic of management. I am at best a specialist on programming languages for instructional use of computers and perhaps on instruction strategies. When I finally agreed to be rapporteur I decided to begin my presentation by listing the persons I had asked to fill this spot, indicating what each has accomplished in his position with govern-

ment, non-profit corporations or universities, what his present problems are now, and in some cases why he could not be here today. However, rather than take time for anecdotes and generalities, I shall instead move to specifics of managing the R&D programme, at least providing a framework for comments and recommendations from other participants here today.
I wish to encourage especially my colleagues from the other side of the Atlantic to continue their participation. Bob Seidel has already expressed his opinion about managing the R&D programme in his presentation and the associated discussion this morning, and he might now speak in the context of this afternoon's topic. You already know of his role in a sizeable project for the U.S. Armed Services. Harold Mitzel has been unusually successful in funding education research and development at his institution. Duncan Hansen is running a large laboratory, and initially had to struggle to obtain grants and contracts by which to feed his 32-mouthed monster once the institution made a commitment to purchase the instructional system.
Ed Adams has already expressed an important perspective for the subject, and his experience as a researcher in industry is quite relevant.

Incidentally, I tend to agree with the critical remarks made by Peter McLaren and the ones in the longer reports of the Study Team's visit to the U.S. I am quite impressed with the thoroughness and the thoughtfulness of NCET deliberations; and embarrassed that such a set of documents and critical view do not exist in the U.S.
I would like first to provide an outline or framework for discussion of goals, and then move on to specific recom mendations.

Mission-oriented research and development. If a large programme is established with a specific mission and co-ordinated planning it will take up most of the funds which might be available for research and development in the area. Care must be taken not to exclude from the overall national programme those basic research projects which could not by their nature fit a specific mission. One can say that funding an applied programme will not compete with sponsorship of research as has been done in the past. However, new research will have to be championed by the Directorate of any specific programme, since those holding the purse strings will repeatedly refer proposals, for basic research along with others, to the Directorate for handling, or at least for review.

Programme goals. have listed three kinds of goals expressed or implied in the NCET writings. Perhaps some of you would prefer to call these [illegible] the means to achieve some more substantive goals, or phases in a sequence of development and implementation. Whatever the label, I invite comment on the relative importance of: 1) development of tools; 2) demonstration of technology; 3) diffusion and change.

1) I have heard much talk about developing computer-based tools for computer learning and teaching, tools for which the potential uses have been identified in research already completed. These tools would include curriculum and the personnel to apply it, as well as the system, devices and

past successes have been of such a trivial nature (in light of computer capabilities) that they provide inadequate basis for determining future directions of applied research.
programming techniques associated with computer use. A crucial question which I find implicit in the NCET working materials concerns the transition from initial probes where progress was easy (e.g., drill in arithmetic or language vocabulary) to a coordinated effort to remove the obstructions to achieving significantly greater rewards. Most of the
A second question I have about development of tools concerns a split into: a) tools for information processing (used by students as well as instructors), and b) tools for systematic instructing (used by the instructor-author-manager to apply pre-defined learning strategies to individual students). The latter set of tools (systematic instruction) should be derived in association with other efforts in education, training and performance. Other systems of similar purpose and character may successfully achieve the same objectives without using a computer; computer-related projects should learn from these non-computer techniques and devices, as well as anticipate the possibility of being replaced by them.

Tools for information processing in education and training ("a" above) should be constructed in anticipation of the use of such tools by the trainee or student later on, and the study of information processing as a direct component of the process of learning and teaching.

2) Demonstration programmes have been talked about by NCET, but it has not been clear to me for whom the demonstration is to be made. The intended audience should be a considerable factor in determining the programme characteristics. In the end is it the potential sponsors, users, or the supporting citizen who is to be reached? What attitude and information should the intended audience acquire? Is it too soon for any kind of demonstration?

3) Diffusion and the actual process of bringing about change in instructional process effectively to incorporate computers and similar technological devices has been implicit in considerations of demonstration. Are some uses sufficiently tested to merit introducing them in some big way into practice throughout the country? Should computer uses be developed in a way which anticipates and tries to work around possible obstructions to adoption by local education authorities?

Of these the second two aspects are the most difficult problems faced in programme planning: who are the demonstrations for and how do we diffuse the results? Perhaps one of the more powerful ways to get things into the schools in this country is to get a demonstration working somewhere and let people see it. The schools have a rather complex structure and it is not possible to identify one person in each system throughout the country who must be reached; whether it is the director of instruction or the headmaster or someone else depends very much on the conditions and interactions in the particular area. Demonstration is an essential step in diffusion.'

Miss P.M. Ash said that education has changed over the last twenty to thirty years largely because we have come to recognize the child as an individual. Production engineers are probably changing their attitudes because of the influence of education.

Innovation in education is often two-way: first, it can begin in the classroom with an imaginative and creative teacher, and then spread to the rest of the school and outwards to other teachers; and second, ideas (after originating in the classroom) may be taken further, developed and refined by various agencies. These may be teachers' centres, lecturers in Colleges of Education or Universities, curriculum development projects, study groups, in-service courses, or other agencies.

I have great confidence in the teacher and I believe, given the opportunity, teachers will find new areas of exploration and exploitation for the computer.
Teachers and lecturers should be involved in any project from the beginning, for it is they who, perhaps more than many of us, are in daily contact with children and young people learning. In addition, local education authorities should be involved for it will be they who will have to take on responsibility for implementation. If teachers, lecturers, and representatives of local education authorities are not involved from the beginning, projects to use computers in education will founder.

Mr. Karl Zinn returned to his main theme: I would like to put the remainder of my framework before you as a guide to consolidating specific recommendations for managing the programme.

Board of Management. What role does it play? What kinds of persons (and positions) best serve? What would be a desirable relationship with the Directorate; what is likely?

Directorate. Success of a national programme (contrasted with other means to encourage information exchange among independent projects) will follow from the selection of good people for the Directorate, the assignment of authority, and then prompt action.

Projects. Careful selection of projects must be followed by effective monitoring. How many projects can be supported by the monies available? Can evaluation be conducted in terms of the achievement of specific objectives and the checking off of milestones marking a desirable route to those objectives? What is to be the extent of 'communication' among the projects: exchange of information and ideas; external testing of procedures and materials; sharing of common facilities? What are to be the priorities and management practices within each project?

Public Relations. Eventual provisions for realization of beneficial changes in the schools should be anticipated from the start in an effective relation with the press and general public.

Mr. A.M Hodgson commented that a view had been put forward that the management of the proposed two million pound scheme is simple and straightforward as long as there is clear accountability to individuals and not to committees. I would like to suggest that things may not be quite so simple. Any mission-oriented programme must be clearly guided by objectives. An objective requires some clear value system and some clear criteria for assessing accomplishment of objectives. I submit that in such a complex educational mission, agreement on both these scores is vastly more complex than in an industrial mission.

Secondly, it seems to me that individual accountability is difficult to realize in practice in this type of work, partly because of the extreme complexity of the problems and partly because of the interdisciplinary nature of their solutions.

Mr. E.N. Adams: The project management plan may be weak in spite of thoughtful considerations at the higher conceptual level of overall programme planning. Three aspects of each project, whatever its goals may be, need to be weighed: software development; system operation; and application.

In experimental projects, system operation tends to be at the mercy of the (system) software development people. One thing which must be decided at the beginning is who the machine is being run for. The system scientists will always be working on something that is new and interesting and will be ready next year; and the applications people will never produce without a machine that is operating today and nearly every day.

Another likely conflict is between development of curriculum materials and development of instruction methods. The argument of method development people is to wait on curriculum development until the methods are demonstrated to be effective and economical; on the other hand, without a first draft to use there is no place to begin the iterative process of developing effective and economical methods.

In practice it is very hard to make a computer system work well. And when a shared system doesn't work it is especially obvious. The manager of an operating system must have complete authority; it can not be run by a directorate. The question is who has power over what is at the heart of these problems of pursuing research, development and service with the same system. I suggest appointing a single good manager for the operating system and a directorate responsible for the applications work done with it. All those in managerial positions might participate in negotiations about the properties of the system, but the actual running of the system can not be done by a committee.

I doubt that the level of resources available will permit effective maintenance and use of more than one system, even if all the systems development work had been completed today.

Mr. R. Seidel: One should bring in as team members, from the beginning, those people who will be responsible for implementing the materials being developed. They need training or, if you prefer, a reorientation toward the kind of change intended. And they should participate from the beginning of the sequence of research, development, testing and evaluation. Although there may not be much of a role for them in the beginning, toward the end, in the testing and evaluation phases, their support becomes essential to the success of the project.

Mr. P. McLaren: The existence of a national programme should help motivate significant basic research, and the Directorate should review proposals and encourage funding from other sources for worthy projects. Experience with the applied programme will help isolate basic research projects.

Anyone wishing to do work has at least two avenues to obtaining support: the national programme, if funded, and the usual research councils.

Mr. K. Zinn (after the Symposium): Much time was spent discussing the hardware requirements for various activities. Could four or five projects use the same facility, especially considering communications costs and unreliability? Is a larger system required for a research project, or for a 'systems' approach to instruction which requires large data files for student records to be maintained on line? What is the value of maintaining separate efforts to explore alternative system concepts? How long would it take to get a new system running? Will the manufacturer, on new systems, have solved many of the problems which an instructional system designer now struggles with on old equipment?

To what extent can CAI uses be shared with others, e.g., computer literacy for persons outside science and engineering? Can data processing uses be shared with CAI, by time sharing, or by scheduling in long periods the sharing of a particular hardware system.

Toward the end of the session McLaren reminded the participants of the important difference between what one would like and what one is willing to accept to work with. The hardware questions being discussed really are questions for the Directorate, to be decided during the first 6 to 18 months using the advice of many persons, including those present at the Seminar.

SESSION VII

REAPPRAISAL OF PROBLEMS AND PRIORITIES

INTRODUCTION

J. Duke

CONCLUDING STATEMENT

J. Annett

DISCUSSION

Rapporteur, J. Annett

INTRODUCTION

J. Duke

Introduction

Listening to the discussions this week my understanding of the directions in which developments of computer based learning should take place has alternated between periods of blinding lucidity and black despair -- it is like trying to catch the soap in the bath, now you have it, now you don't.

It seems to me there are four broad goals to which research effort might be applied:

- to use CBL as a vehicle for psychological investigations into the learning process,
- to explore CBL to help solve real-life educational problems,
- to exploit the technical gadgetry to the full,
- to derive economic benefits in teaching.

I would like us to explore this morning the balance of effort that should be applied to each of these activities.

We have considered the subject from a number of points of view. I have been gratified at the way the papers and the discussions have interlocked, vindicating my rather arbitrary choice of session titles. John Annett will in a moment be recalling some of the questions we attempted to answer and some of the significant pointers we threw up. I would like us to examine the interdependencies of these aspects and consider what should be our scheme of priorities. My personal view is that we all too often think only in terms of CAI with the computer being a sort of buffer between the student and the teacher rather than the computer being a component in a tripartite student/teacher/machine system.

In deciding on the best course of action I would like to gauge your reaction to the idea of a concerted programme. I do not intend to invite you to draft a detailed set of projects, but would like your views in principle to a plan on the lines put forward by the National Council. I would like some indication of willingness to collaborate in such a scheme and under what safeguards and conditions. I would like further to explore opportunities for collaborative action on an international scale – the example of the joint project of Professor Le Corre and Professor Jones is particularly interesting in this respect. OECD is already an active agency in this field. Possibilities include:

- secondment of staff to projects overseas
- sabbatical tours to projects here
- international information networks
- international forums for discussion

I think we are bound to apply as much system to our own affairs as that we are advocating should be applied to the schoolroom and I commend Dr. Seidel's 7 point approach.

CONCLUDING STATEMENT

J. Annett

Statement

One acknowledged purpose of this meeting to set out the case for a substantial investment in CAI research. If we are to convince the Government, and ultimately the public at large, that this activity is worthwhile, we must first ask ourselves why we, as individuals and as a group, are convinced. Short term (e.g. 5 year) economic justification of CAI does not seem possible and there are many ways in which the sum we contemplate spending on research could be immediately applied to the benefit of education. If we are completely honest with ourselves, most of us believe in the potential of CAI because education has to do with the transmission, collection, storage and retrieval of information and that computers constitute the foremost and the most powerful tools serving information processing. Whether we look ahead 5, 10 or 50 years, the involvement of computers in education must be seen as the inevitable marrying of the tools to the needs. For this reason, I am not too disturbed by the possibility that support for research may not be immediately forthcoming. In the long term CAI, perhaps in some forms as yet not envisaged, will inevitably come about.

This week we have been examining various aspects of CAI research as they may affect the outline plan for a coordinated research effort in the U.K. I shall try to summarize what have seemed to me some of the major points.

Hardware and Engineering Problems

During the period in which the research programme is likely to be operative, we expect rapid technical developments in the speed, capacity and cost of control processing units. On this count questions of cost and efficiency are likely to look very different in five years time. We have something of a dilemma in the choice between starting cheaply with a class of redundant obsolescent machines such as the KDF9 or taking the best advantage of the newest CPUs. Possibly a compromise will be effected by using an 'available' machine in the very first instance but without tying the whole project to obsolescent hardware.

It has been suggested that CAI may provide some inputs to CPU development. The older machines were designed with payroll and general 'number crunching' in mind and the possibility of more suitable CPUs should be explored. However, this aspect of hardware is not a serious obstacle and much can be done with existing machines. More important are the student machine interfaces, the terminals. No one is satisfied with existing teletypes. CRT/light pen systems are still relatively expensive although the plasma tube offer some hope in the field of visual displays. Certainly research is needed in the design of more appropriate terminal hardware and a plea that the ergonomic requirements of terminals should be studied was met with general approval.

Software Problems

By and large appropriate computer software is available or can be developed for CAI use. This is not to say that what has been done could not be done much better and that new educational requirements will not bring new problems. One serious question is in the interchangeability of languages between systems. Discussions on common, or at least translatable, languages must be pursued.

The "educational software" problems are not entirely distant from general control software problems. The lowest common denominator of CAI was referred to, rather scornfully, as "stuffing a textbook into a computer." It is clear that putting a textbook into a computer is no solution to the educational software problem. There is a general recognition that CAI implies some kind of model of the learning process on which effective teaching strategies can be based. There has been some discussion as to whether adequate psychological models of learning exist.

Currently experimental psychologists working in this area distinguish between theories of learning and theories of instruction. Skinner's "learning" theory is strictly a theory of instruction in the sense that it is prescriptive, it tells you what kinds of teaching operations are necessary to achieve specified changes in behaviour. The aim is to refine and adapt models of the instructional process and this can and should be done in the context of CAI.

The days of competing theories, a decade or two ago, when "the learning process" was said to be of this kind or that, have passed. It now seems likely that there are various types of learning process. The question thus arises, can any type of learning be identified with a given subject matter? A number of ill-defined categories are in common use. We talk, loosely, of different subject matters (e.g. physics), different objectives (e.g. knowledge), analysis and different "mental" processes (e.g. problem solving and skills). These cut across semantic boundaries and lead to confusion. A given subject matter (say, physics) can include a whole range of educational objectives and the psychological processes involved could be of many different types. It does not, therefore, make too much sense to ask whether physics is suitable for a certain kind of instruction (say CAI). The educational and psychological characteristics of a given subject matter will constitute a unique mix of objectives and processes and will have this feature in common with other subject matters. It is implied that a variety of teaching strategies are likely to be involved in any given subject area.

The group seems almost unanimous in the view that learning psychology is essential not just in preparing the way but in implementing CAI and that no amount of computing expertise will compensate for psychological naïveté.

The NCET Plan

I have some anxieties about the implication of the NCET's plan as set out in the feasibility study report.

First, a bad precedent was set by the working party in not combining their analytical skills with suitable expert psychological knowledge. It is to be hoped that any R & D programme will not repeat the same weakness. Educational and psychological expertise are of the essence in getting the most out of CAI.

Second, the proposed central type of organization for the project could lead to unimaginative and scientifically unproductive work. The project directors' concern with the general selling objective of the project may lead to the temptation to produce short answers to pressing practical problems. The burden of justifying CAI in the short term could be counter productive in terms of worthwhile scientific objectives.

Third, I am worried by the "takeover" attitude which colours the NCET report. I cannot accept the bland assurance that the existence of a £2m central project will not inhibit "free lance" research. It is quite possible that research councils would be inclined to discourage small projects on the general grounds that a great deal of money was already being spent in this area. In this conference, we have seen both the stultifying effect of large projects and the ingenuity of some independent researchers working on small budgets. We could get the worst of both worlds in trying to attain the best.

Finally, the NCET does not define CAI or refer to the necessary relation between computer work and other efforts in educational technology, the psychology of learning, curriculum development and so on. There is a danger of intellectual isolationism in the structure of the project which must be avoided at all costs.

In the ensuing discussion, **Mr. Flood Page** agreed that psychological research was important but pointed out that various research plans might work equally well. He suggested that, as in dentistry a "point of entry" was needed and that one point of entry was the automatic scoring of examinations by computer. He agreed with other speakers that we should soon have to think seriously about standardisation of computer languages.

Professor Pask elaborated on the role of CAI in social development. Society is apt to run into catastrophes and the only way to avoid these is to pay attention to the thinking processes of man. CAI should give us not only quantity but quality in education and social awareness. CAI is not a trivial improvement in method, like a brighter slide projector. A non-trivial system should interact with the student to discover his learning plan and should measure the student's relevant abilities such as short term memory. The system must then interpolate itself between the student's learning plan and his measured competence. Ways of doing this must be specified before a big CAI system can be built. Some of the present CAI systems are not adequate in the social context. For these reasons an essential part of CAI research should consist of experimenting with miniature systems to discover the basic design data for large CAI systems.

Dr. Sleeman felt that more work should be done on adaptive teaching systems and in the general area of artificial intelligence. The Leeds project is pursuing this line in some of its work, for example, The Medical Diagnosis System. Pilot work of this kind should be done in preference to stuffing machines with instructional materials. If this was all large scale CAI meant, we would get nowhere in 3 or 5 years.

Mr. Hill liked the miniature system idea but suggested that one does not need much more than a pencil and paper to do it. The reasons for large scale demonstrations should not be confused with scientific requirements. There is a need for a pedestrian demonstration of what CAI is all about. What is needed is a programme which concentrates on a small number of systems and topics but which give rein to the intellectual capabilities of CAI.

Mr. D'Arcy interjected that much would depend on the calibre of the project director. The NCET plan requires a man of high calibre.

Mr. McLaren held that the pragmatic approach must not be overstressed. He had in mind a parallel system in which CAI development and learning research ran in parallel and psychology would be important in this context. However multiple projects are wasteful and one must bear economic realities in mind.

Mr. Hodgson thought the directorate is going to have an impossible job if all the various aims are to be reconciled within the budget. Educational research is not the same thing as educational reform. Do we want analytic research or innovative research? Educational reform requires a large scale demonstration and entrepreneurial innovation requires financial backing.

Professor Le Corre underlined the great deal of time required to develop course material. The cost and difficulty should not be underestimated. Co-operation between countries, like that between France and Belgium in developing the physics course might help to economise in course development. It is also possible to begin with a good recognised text book.

Mr. D'Arcy referred to the supposed failure of the educational system as a failure of the social system. CAI will not solve social problems. Care would have to be taken in introducing CAI so that it does not flounder.

Dividing up the cake is going to reduce the effect of CAI. There is no reason to suppose we can do better than the Americans, but one way of doing better lies in the effective organization and funding of projects. We have to choose educational rather than social problems, which can be solved, problems such as ancillary mathematics at University level. In the schools CAI could be used in 'modern' maths which is an attempt to teach genuine problem solving. Good materials in this area are already being produced.

Dr. Eraut spoke of the need to integrate CAI and other educational technology. A lot of people could work on various educational "subroutines" which could slot into non computerised courses.

Professor Cook dissented from the view that the programme should concentrate solely on University maths when the same strategies might be used in sciences and medicine. He also underlined the need for serious work on student terminals.

Mr. Hill thought it right to concentrate on secondary or University subjects and **Mr. Duke** said we should build on what has already been developed. **Mr. Hill** thought we could do better by doing co-ordinated research. **Dr. Bate** felt that the training of computer specialists had a lot to recommend it, especially as the topic was likely to appeal to Government and the computer industry. **Professor Cook** whilst agreeing that the U.S. had a great deal of experience, pointed out that in Europe and the U.K. we might have had more time to think and the project should take some account of this thinking.

Mr. Duerdin explained that ICETT had not felt able to support the NCET proposal as a package. The "programme for action" should be quietly dropped but the proposals in chapter IX of the feasibility study should be pursued provided the whole programme is not based on the use of KDF 9's. The Culham case might be an exception to get something moving rapidly. Industry can help a great deal as a user of the "products" of training and as a competitor for the resources of education. Industrial experience in forming and mounting viable long term projects could be valuable. Industry should co-operate in hardware design and work on student terminals is urgent if the price is to be brought down so that the use of CAI may be widespread. A kind of market research is needed in putting the "product" (CAI) to the needs of the market and industry has a great need in industrial retraining.

Miss Ash suggested we could learn from American experience in using CAI for parts of courses or whole courses. It is preferable to consider whole courses but to use CAI only in those parts for which it is best suited.

Mr. Crippin referred to developments in Scotland where many teachers were being trained in computer work, although not CAI as such. By familiarisation teachers may be taken along with the protagonists of CAI. Teachers are very active and much of the work in curriculum development comes direct from them. Whatever the short term potential of CAI, we cannot, in teaching, afford to ignore computing systems which involve processes similar to human thought but are in some ways much more powerful.

Mr. Duke regretfully had to break into the discussion at this point. "It remains for me now but to bring this Seminar to a close. To me in many ways it has shown many of the characteristics of an ideal learning situation. The *environment* has been pleasant, relaxed and rich in experiences, and I am not only referring to the plumbing, the *logistics* have been unobtrusive and fortifying, the curriculum material has been fascinating. We have experienced a wide variety of teaching techniques from brilliant didactic exposition to group heuristics, opportunities for satisfaction of individual needs and curiosities have abounded, motivation has remained remarkably high and transfer great.

This Seminar has also exhibited many of the characteristics of a system. The NEED for exchanging ideas was evident; the OBJECTIVES to outline the main problems and priorities. The CONSTRAINTS have been minimal and I must congratulate both those who have let their hair down, and to those who have managed to keep their's on. Many ALTERNATIVE suggestions have been explored; the SELECTION of bons mots is now in the capable hands of our rapporteurs. In not too long a space of time I hope we will IMPLEMENT a report of these proceedings. The EVALUATION of the success of this Seminar is I feel already favourable and I sense many valuable feedback paths and communications nets have been set up to keep us all in touch with each others thinking.

For my own part my own horizons on computer based learning have been considerably broadened (and if nothing else I have learnt a lot about organizing conferences). Thank you all for being such excellent participants; thanks, also, to Leeds University, our hosts; to the Leeds CAI Unit for putting on their demonstrations; to NCET and the US Office of Naval Research for their sponsorship; and to Dr. Jeremy Bray, Joint Parliamentary Secretary, Ministry of Technology, for his kind and encouraging remarks at our Conference dinner. I hope we all meet again before long."

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13. ABSTRACT

This report includes position papers presented at a four-day Seminar convened by The National Council for Educational Technology (UK) at the University of Leeds, and summaries of the discussions.

Proposals put forward by N.C.E.T. for a national research and development effort were considered. Contributors from the USA and several European countries outlined the problems of research and development in their experience, and British workers reported on their own activities and plans for future work.