COMPUTER ASSISTED LEARNING: ITS EDUCATIONAL POTENTIAL

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The aim of this chapter is to suggest ways we might assimilate our thinking about computer assisted learning into our thinking about educational processes and options more generally. What we have to suggest is based upon our experience of the National Programme but our interest in what follows is in the potential contribution of the computer to education rather than in its current level of accomplishment. This is less, then, an evaluation of the performance of the National Programme than an attempt to say what has been learned about computer assisted learning through the medium of the Programme. As we wrtie, the story of NDPCAL is still unfolding. The final UNCAL evaluation report is in preparation.[1]

INTRODUCTION

Those with long memories, who recall the revolutionary promise of educational television in the fifties, of teaching machines and programmed instruction in the sixties, may well be sceptical about the future of the computer in the classroom. Another 'machine', more 'programming', the technological error in yet another form. 'Plus ca change' is the sceptic's weary response; we have been here before. And it doesn't help that much if the talk of the early innovators, being designed to persuade sponsors to disburse large sums of money for support, was inflated in educational terms, and imprudent in political terms. Teachers do not take kindly to the notion of their imminent dispensability, and it was not just classical scholars who were offended when one of the first books published in this country on the subject (Fine, 1962) claimed that the pioneering American electronic teacher P.L.A.T.O. was "almost as intelligent as its namesake, the Plato of old". Such claims did more than merely camouflage the gap between promise and performace, they misconstrued the nature of the promise itself. Like most innovations, computer assisted learning suffered heavily at the hands of its friends. And so, just as programmed instruction, in both book and machine form, has settled largely for a place in technician training, and television for distant learning within the Open University framework and for

* This chapter reflects the work of the whole UNCAL (independent educational evaluation) team; the authors and David Tawney, Robert Stake, Gajendra Verma and Rob Walker. The reader should allow for some disparity of view within the group.

supplementing conventional classroom fare, might we not expect the computer in due course to assume an equally modest role in the teaching/learning environment?

It is important to state that, after closely observing the explorations in computer assisted learning promoted by the National Programme for the past four years, we do not incline to this view. Computers are here to stay in education, and will play an increasing role in the experience of learning. There are many reasons for taking this view, but we shall summarise just a few. The computer is as versatile a tool as the teaching machine was restricted. Its potential in education is virtually unknowable at this primitive stage but its ubiquity and importance in society at large ensures its continued technological development, which ensures in turn that its educational possibilities will continue to be explored. It is not tied to a particular view of how students learn, or how teachers should teach, so that its survival does not depend upon the stability of pedagogical theory. Finally, it is already clear that the machinery required to support computer assisted learning, the hardware itself, is rapidly becoming cheap and small without loss of capacity as the manufacturers move into the phase of mass production and miniaturisation.

The reader may wonder whether to deduce from this that we expect the computer to improve education. Here prophecy becomes hazardous, and not just because the reader's view of educational excellence may differ from ours. The computer is versatile; it may be used to teach facts, concepts, skills, imagination, to subjugate the learner or to emancipate him; it has a place in the pedagogies of instruction, discovery, and enquiry. The spread and diversity of applications is already wide, and each has its advocates and adversaries. Of course some applications will flourish and others will fade. But the mix of economic, administrative, professional and popular considerations which shape educational practice is too complex to support predictions of the forms of computer assisted learning that will be favoured. Our task is to state as clearly as possible what the options represent in terms of educational values, theories, justifications and issues. The reader will make his own judgements of merit.

The Stereotype of CAL

It is important to realise the extent to which the National Programme represents a departure from a monolithic tradition of computer based curriculum development, a tradition, largely American, which has given rise to a stereotyped view of what computer assisted learning means. The stereotype conceives CAL as computerised programmed instruction which is used as a replacement for conventional teaching. The evaluation issue seems relatively straightforward; is CAI (computer assisted instruction - the American term associated with this view) more or less effective than what it replaces?

It is not difficult to understand why the stereotype is so strong, or why the evaluation issue associated with it is equally persistent. The predominant emphasis in the first decade of the new learning technology (1960-1970) was on this type of utilisation, with the computer restricted to a tutorial or exerciser role. And the near exclusive emphasis of evaluation studies has been on comparative experiments designed to determine whether or not computerised provision was a better way of teaching the same things.

None of us can be sure about what kinds of computer based learning will characterise the next decade, but it is worth noting influential reactions to this tradition. The Carnegie Commission on Higher Education, in its latest report (1975) concludes that "CAI has been overemphasised. In the areas of learning where it is applicable, other technologies dominate along the relevant dimensions ... The primary clear target of opportunity for the computer in Higher Education is in 'enrichment activities'. For almost all kinds of material, problem solving, games and simulation can provide the learner with better ways of integrating and testing the knowledge he has acquired than other available technologies... It follows that the impact of CAL will for the most part be adding to rather than replacing current learning mechanisms."

The Commission argues (albeit with perhaps too much faith in the survival of the most fitting) that CAI at its best is insufficiently superior to alternative technologies to justify its continued dominance in the field of computer assisted learning. Although confined to the Higher Education sector, this argument is consistent with the findings of the most authoritative review of CAI in the schools, that of Jamison, Suppes and Wells (1974). Summarising all the available evaluation studies, overwhelmingly of the controlled comparison type based on achievement scores, they conclude that CAI is no more than equally effective as an alternative to traditional instruction.

Because of the dominance of CAI, and perhaps because of its susceptibility to experimental/control group comparisons, there have been few attempts to assess the effects on learning of computer based approaches which do not fall within the CAI bracket. The Carnegie Commission thought it might be four or five years before evidence of the effectiveness of "enrichment" applications became available.

When we turn to the National Programme and look at the pattern of use across the projects we can immediately see the extent to which the Programme has anticipated the Carnegie Commission's recommendations in terms of its development targets. The Programme has sponsored a portfolio of applications of considerable diversity, but with an overall emphasis on types of applications which CAI has neglected.

The Programme has not, however, escaped the legacy of the CAI controversy which, particularly in the early stages of NDPCAL, played a rhetorically strong role in debates between Programme participants with regard to tutorial applications. In the end the debate has shown nothing so much as that the opposition between CAL and CAI is an oversimplification of alternative pedagogies within the Programme - one looks in vain for 'pure' examples of mechanistic (page-turning programmed learning) CAI, and its alleged alternative, imaginative CAL, is a highly differentiated collection of uses of the computer. The CALCHEM project, for instance, reveals the complexity in the way it defines its tutorial approach:

> "enhanced tutorial programs provide a number of alternative dialogues, the routing through which may be determined by the student's current and previous responses, and which may make use of facilities for simulation, calculation, graph plotting etc. within the tutorial sequence."[2]

Another convenient example is that of the Leeds statistics project. This project grew out of an SSRC research project carried out by the Computer Based Learning Project at Leeds University, perhaps the most stable centre of CAL research and development in the National Programme. Its work covers a range of CAL applications from adaptive-tutorial CAL to artificial intelligence (AI) work with Seymour Propert's LOGO system, as well as problems of knowledge acquisition and language comprehension. The NDPCAL-sponsored statistics work of the Project is clearly adaptive-tutorial in character but, unlike 'doctrinaire' CAI, it is not conceived as a self-instructional replacement for a conventional social science statistics course. Such use of the materials is regarded by the Project as "sub-optimal": ideally, the CAL work supports and deepens students' understandings by providing opportunities for practice and guided problem-solving in statistics.

To characterise and evaluate even the Programme portfolio requires that we move outside the assumptions of CAI thinking and try to bring to bear on the CAL experience that wider range of educational perspectives which seems to have guided its various practices. In the section which follows we suggest three analytic frameworks (paradigms) within which CAL can be understood, and discuss the possible emergence of a fourth. We hope that the example of CALCHEM will serve to remind the reader of the dangers of polarising and stereotyping project work through a rigid application of these frameworks. Computer managed learning (CML) and computer assisted training (CAT) are discussed in subsequent sections of the chapter.

EDUCATIONAL PARADIGMS FOR CAL

The National Programme has spawned some thirty-five projects and studies involving the computer in educational and training processes. To understand them adequately, each has to be studied in its own terms and circumstances. Summarising across their diversity is a difficult, even dangerous business, but it is the business of this chapter, and we propose to begin it by proposing three paradigms of education through which we may grasp the major ways in which the developers of computer assisted learning conceive the curriculum task. We have called these paradigms, the 'instructional', the 'revelatory' and the 'conjectural', although the labels themselves may be less helpful than the profiles which they summarise. It should be emphasised that few of the projects which we allocate to these paradigms explicitly call them forth in explaining and justifying their work; they are our 'inventions', intended to help the reader to relate CAL to the general field of educational theory and practice.

The Instructional Paradigm

This paradigm is strongly associated with classic drill-and-practice programs of American CAI, and with adaptive-tutorial projects in NDPCAL. Much of the work of Glasgow mathematics, CALCHEM, Leeds statistics, and the Post Office technician training projects fall within this paradigm. The theory was at one time derived from Skinner's doctrine of operant conditioning based on the reinforcement of successful responses and the atomisation of complex tasks, moved through an "instructional psychology" phase which drew its support from theorists like Gagne and Glaser, and has more recently taken up theoretical trends concerned with knowledge acquisition and language comprehension (eg Freedle and Carroll). In general, the instructional paradigm involves the belief that the knowledge students need to acquire can be specified in language and learned by the transmission and reception of verbal messages.

Key concept:	Mastery of content
Curriculum emphasis:	Subject matter as the object of learning
Educational means:	Rationalisation of instruction, especially in terms of sequencing presentation and feedback reinforcement
Role of the computer:	Presentation of content, task prescription, student motivation through fast feedback
Assumptions:	Conventional body of subject matter with articulated structure; articulated hierarchy of tasks; behaviouristic learning theory
Idealisation/Caricature:	At best, the computer is seen as a patient tutor; at worst it is seen as a page turner
NDPCAL Project closest to the paradigm:	Glasgow mathematics, which has the linear characteristics of traditional programmed learning

The Revelatory Paradigm

Simulation and some kinds of data-handling programs are rooted in this paradigm. Within the National Programme, projects such as CUSC, Glasgow Medicine, the Engineering Sciences Project and the RNC Greenwich Project can usefully be looked at within this framework. In terms of the underlying educational psychology, theorists such as Bruner (the spiral curriculum) and perhaps Ausubel (subsumption theory) would be most supportive. Typically, the view of learning emphasises closing the gap between the structure of the student's knowledge and the structure of the discipline he is trying to master. It could be labelled the 'conceptual' paradigm because of the importance attached to the key ideas of established knowledge fields. We call it 'revelatory' because these key ideas are more or less gradually 'revealed' to the learner.

Key concept:	Discovery, intuition, getting a 'feel' for ideas in the field, etc.
Curriculum emphasis:	The student as the subject of education
Educational means:	Provision of opportunities for discovery and vicarious experience
Role of computer:	Simulation or information-handling
Assumptions:	(Hidden) model of significant concepts and knowledge structure; theory of learning by discovery
Idealisation/Caricature:	At best, the computer is seen as creating a rich learning environment; at worst, it makes a 'black box' of the significant learnings
NDPCAL Project closest to the paradigm:	CUSC (Computers in the Undergraduate Science Curriculum) which attempts through simulation to make complex ideas accessible to students. Each simulation package is built around a mathematical model of a physical system; as the student manipulates it, he is expected to develop an intuitive understanding of the model. This understanding helps him to appreciate the theoretical formalisation of the model.

The Conjectural Paradigm

This paradigm may be appropriate for modelling and Artificial Intelligence packages and for computer science applications. An assortment of NDPCAL projects including CPTL at Surrey University, the Programme-related work at the Cambridge University Department of Applied Mathematics and Theoretical Physics, and the London Business School Management Decision Making Project, fall within it, although in each case many of the important student experiences take place away from the computer. People who operate within this paradigm tend towards the view that knowledge is created through experience and evolves as a psychological and social process. Authoritative theorists of this persuasion are Piaget (adaptation through interaction with the environment), Popper (conjectures and refutations) and, within computer learning theory itself, Papert.

Key concept:	Articulation and manipulation of ideas and hypothesis testing
Curriculum emphasis:	Understanding, 'active' knowledge
Educational means:	Manipulation of student inputs, finding metaphors and model building
Role of computer:	Manipulable space/field/'scratch pad'/ language, for creating or articulating models, programs, plans or conceptual structures.
Assumptions:	Problem-oriented theory of knowledge; general cognitive theory
Idealisation/Caricature:	At best, the computer is seen as a tool or educational medium (in the sense of milieu, not 'communications medium'), at worst, as an expensive toy
NDPCAL-related Project closest to the paradigm:	Cambridge DAMTP (Department of Applied Mathematics and Theoretical Physics) where the use of the computer as an alternative to analytic methods simplifies the process of mathematical investigation, allowing students to construct models of physical systems and test the assumptions of the models by computing their consequences.

Learning, Labour and Emancipation - a fourth paradigm?

Although the precise terminology we have used in delineating the three paradigms may be somewhat idiosyncratic, the style and broad content will be familiar enough to students of education and will, we hope, give a grip on the CAL field. They may, however, by emphasising those attributes of CAL which it shares with other educational practices, miss some important issues, and we wish at this point to explore a perspective on CAL which takes as its starting point an aspect of the computer which is held to be its most important characteristic in applications outside education, namely its power as a labour-saving facility.

It is possible to conceptualise the activities of students (and of teachers) as 'labour' and therefore to consider how CAL, as a labour-saving device, affects their work. To do this it is helpful to distinguish between authentic labour (valued learning), and inauthentic labour (activities which may be instrumental to valued learning, but are not valued for their own sake). The justification of some forms of CAL is that it enhances authentic labour, for others that it reduces inauthentic labour. Much curriculum reform and development is of the first kind: making difficult ideas more accessible, making learning more 'relevant', or more fully engaging students' own interests. Examples of CAL which attempt to enhance the authenticity of the learning experience include CUSC simulations (as in the Schroedinger equation package which allows students to interact with the model and thus to learn its characteristics), the Glasgow Clinical Decision-Making Project's packages (which give students a 'feel' for the problems of diagnosis and patient management normally only achieved in clinical work) and CPTL (where students learn to write programs to solve physical problems).

The three paradigms we have already outlined are generally compatible with the idea of enhancing the authenticity of student labour. The instructional paradigm does so by leading the student through a body of subject-matter in a rationally-organised way, the revelatory by bringing the student to the 'heart' of a problem and helping him to feel its significance, and the conjectural by allowing the student to explore the ramifications of his own ideas.

The computer is peculiarly suited to reducing the amount of inauthentic student labour, however, and many CAL applications exploit the information-handling capacities of the computer to improve the quality of the learning experience by taking the tedium out of some kinds of tasks.

The idea of using CAL for this purpose suggests the possibility of a fourth paradigm, one which is yet unarticulated in detail. It is by no means as coherent as the three primary paradigms; perhaps it is a kind of inverse image which can appear in association with any of the others. This fourth paradigm we have called emancipatory. Insofar as it has any coherence, its key concept is the nation of reducing the inauthenticity of student labour. Its curriculum ephasis and educational means are derived from the primary paradigm with which it is associated - for it never appears in isolation except as an impulse to curriculum reform. The role of the computer is calculation, graph-plotting, tabulation or other information handling. Examples of this emancipatory paradigm in CAL include Napier mathematics (where the computer is used to carry out otherwise tedious calculations and where the curriculum reform away from the computer is of a revelatory kind, emphasising mathematical concepts rather than techniques), the Suffolk Local History Classroom Project (where the computer tabulates census data for the pupils and where the curricular reform away from the computer is conjectural, emphasising history as hypothesis-testing and the use of evidence), the Imperial College CAL work on fluid flow and heat transfer (a part of the ESP Project) where the computer allows numerical solutions to be found for real-life problems which are analytically-intractable, and where the curriculum reform away from the machine is more revelatory, elaborating the notions of fluid flow and heat transfer in more complex and industrially-interesting situations), and some of the CALCHEM work (where the computer reduces the inauthenticity of the learning situation by plotting graphs or carrying out calculations for students as a separate but complementary role to its enhancement of the authenticity of the learning experience in enhanced tutorial CAL). The work of the CALUSG Project in Geography which produces difficult-to-generate quantitative data for classroom use might also be considered emancipatory, but is as much a saving of labour for the teacher as for the student.

Whether or not we wish to dignify this emancipatory interest of curriculum reform with the label 'paradigm', there can be no doubt that it is a compelling impulse. The 'information explosion' has emphasised the problem for teachers of how to reduce the complexity of subject-matter for students and has posed the companion problem of finding criteria by which the reduction can be justified. Common criteria for justifying the inclusion of a topic in the curriculum are its significance (to teachers or other subject matter authorities) and the utility of the information (to students or their prospective employers). The potential of CAL as a labour-saving device which can reduce the amount of time students spend (or, rather, waste) in inauthentic labour may thus be welcomed by teachers as a way of easing the complexity problem. As many have argued for the hand calculator, CAL may divert students from tasks not valuable in themselves (and which are understood in principle) to other, more highly-valued activities.

These three or four paradigms are essentially ways of thinking about the curriculum tasks faced by the CAL developers. We have discussed them in terms of the place of computer-based education in the wider environments of teaching and learning, and it is not surprising therefore that they reflect the aspirations and educational values held by their developers. But how CAL can realise these aspirations is a separate question, and one which poses major research and evaluation questions. It is to these questions that we now turn.

Student Learning: A CAL Typology

The main research question to be faced in considering the educational value of CAL concerns the nature of learning itself. In what language can the educational processes and learning outcomes be discussed? This section attempts to gain purchase on the issue by developing a typology of student-CAL interactions. The reason for this line of attack is straightforward - it is in the process of interaction (learning in a CAL environment) that the promises for an effective computer-related pedagogy are delivered or denied. Using the typology it is possible to describe, virtually on a moment-by-moment basis, the process of computer assisted learning.

As we indicated earlier, in discussing American CAI, the tradition of student learning evaluation in CAL is an arid one which has yielded little understanding of the distinctive nature of the learning experience. As evaluators of the NDPCAL we decided to turn our attention from tests of attainment to the processes of learning. This is partly because such tests will be equivocal about the merits of CAL, partly because they will rarely have been constructed so that they are valid tests of the particular kind of learning the CAL experience promotes. To get to the heart of the issue, we dispensed with the notion of providing an actuarial summary of achievement and instead focussed our attention on the CAL experience itself, attempting to formulate a scheme within which the kind of learning which goes on when the student and the CAL technology come into contact can be described. In this way, we reasoned, it might be possible to define the educational potential of CAL whether tests used to assess student attainment are valid or not.

To achieve this, we have developed a typology of student-CAL interactions[3]. The 'types' themselves are derived on the one hand from the research literature on learning, and on the other from the claims made in justification of CAL. The literature provides ways of thinking about the nature of learning, while the claims of CAL developers yield insights into the values by which CAL may be judged. And it is in the processes of interaction in CAL environments that promises of education are fulfilled or frustrated.

Each of the following five 'types' refers to the interactions between the student and the immediate CAL context. What distinguishes the types is the kinds of opportunities they offer for learning, and what the typology does is to make explicit the kind of learning that might be claimed on the basis of specific student interactions with the CAL technology.

Type A: Recognition

In the case of recognition-type interactions, the student is merely required to indicate whether or not the information presented by the machine, in the form of a question or incomplete statement, has been presented previously.

Multiple choice or binary choice (yes/no) items occurring in CAL interactions are sometimes of this type. We have found no examples of Type A in the National Programme.

Type B; Recall

Recall-type interactions require the student to do more than recognise information presented, but they do not call for understanding. They require the student to reproduce textual information in either verbatim or transformed verbatim (rearranged syntactically or logically, but not in terms of meaning) forms.

Recitation, sentence completion and cloze-type test items exemplify verbatim recall interactions; some kinds of sentence completion, free recall, matching, and some kinds of low-level logical inference questions, exemplify transformed verbatim interactions.

Example (From an (atypical) CUSC package)*

Text: The spin QN of an electron can take two values: $+\frac{1}{2}$ and $-\frac{1}{2}$.

Question: What are the two values of the spin QN?

Answer: $+\frac{1}{2}$, $-\frac{1}{2}$

Type B interactions involve only a superficial engagement of the student with the material; within the National Programme, they do not feature frequently and seem to occur only in tutorial modes in higher education and in technician training.

Type C; Reconstructive Understanding or Comprehension

This kind of interaction is by far the most pervasive in the CAL materials produced under the sponsorship of the National Programme, ranging from some quite elementary types of comprehension to some fairly subtle ones.

These types of interaction do not depend on the superficial features of the information presented as with Types A and B; rather, they engage the student in meaningful operations on the content presented. He may be

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* Note that this interaction takes place via a VDU terminal. The text disappears from the screen before the question appears; question and answer are displayed together.

called upon to reconstruct statements, concepts, or principles, but this will generally be within the limits of what has been presented; the boundaries of what is learned will always be more or less clearly determined by the semantic content of the information given in the interaction. The following example (again from CUSC) illustrates a type C interaction calling for the understanding of a principle.

Example

Question: How many planar nodes are there in the wave function of a 7 D electron?

Answer: 2

Our comment: To answer this question, the student must make a new inference on the basis of a simple principle and a statement. He must apply the principle in the stated case to answer the question. He knows from previous learning that ℓ = number of planar nodes, and that the value of ℓ for a D electron is 2. So he can deduce that a 7 D electron has two planar nodes.

Type D: Global Reconstructive or Intuitive Understanding

These interactions are much more difficult to describe. They often involve prolonged activity and are directed at 'getting a feel' for an idea, developing sophisticated pattern-recognition skills, or developing a sense of strategy.

The emphasis is on experiential learning which might develop an awareness by the student of his actions in the context of a constellation of problems or ideas recognised by experts as critical to understanding a field of knowledge. Here, more than in types A, B and C, understanding must be demonstrated in what the student does, and it will be judged accordingly by teachers. (It cannot be judged by explicit criteria stored in the machine.)

Type D CAL interactions involve such activities as discovering principles behind simulations, developing a 'feel' for diagnostic strategies, problem-solving using classical techniques, and the like. Type D interactions are common to all sectors of the National Programme with the exception of industrial training.

Take for example, the emergency simulation packages of the Glasgow medical project. Learning the diagnostic strategies of the expert physician takes place through Type D interactions, where the student tries out courses of action in the form of alternative tests and treatments. The aspiration is to develop the clinician's sense of the appropriateness of different courses of action in different contexts.

Type E: Constructive Understanding

Type E interactions are extremely open-ended and involve the student in 'creating' knowledge. Because the creation of new knowledge almost always takes place against a context of old knowledge, Type E interactions are usually intertwined with other kinds, especially Type D. Because of the type of use of the machine in Type E interactions, however, the learning process may be taking place away from the terminal. In Type E interactions, the student engages in 'open' enquiry: he is not working towards solutions which are necessarily within the known structure of the discipline. From his point of view he is going beyond what is known. He may be testing his own hypotheses, developing his own methodologies and drawing conclusions based on his own work. Type E interactions look like genuine research, not just exercises on the content and methods of fields already known. Examples of Type E within the National Programme can be found in higher education (although Types C and D are more common there), in management education, and in the use of data bases in the schools sector. In the last case, a pupil in the history class interrogates a data base to explicate and to test hypotheses about the conditions of life of nineteenth-century agricultural labourers. In part, his work conforms to what is already known about nineteenth century rural industry and the methods of professional historians (which look like Type D interactions though they are not student-CAL but student-teacher or student-print interactions), but he is writing new history himself, not learning what others have discovered.

The Paradigms and the Typology

Readers may wonder why we have offered two analytic schemes (the paradigms and the typology) where perhaps one might have served. The answer is that the two schemes address different levels of discourse about CAL, the first being about curriculum and the second about learning processes.

Discussions about CAL, we have found, take place at both levels, so that discussions of what teachers want to do is likely to take place at the paradigm level, while discussion about what teachers want students to learn are likely to take place at the learning-process level. As might be expected, the two levels overlap to some extent. Although each paradigm will in practice create opportunities for a range of types of interactions, critical interactions within the instructional paradigm are likely to be of Type C, within the relevatory paradigm Type D, and within the conjectural paradigm, Type E. The emancipatory paradigm will not be exclusively associated with any particular type of interaction. Table 1, though an oversimplication, summarises these relationships:

Paradigm	Interaction Type				
	A	B	C	D	E
Instructional	←	—	*	→	
Revelatory			←	*	→
Conjectural				←	*
Emancipatory					

Table 1: Possible relations between paradigms and interaction types.

A final note of caution might be added before we leave this schematic overview of CAL. The schemes themselves, merely by ordering curricular and learning-process perspectives on CAL may appear to offer guarantees of its educational worthwhileness. It would be a mistake to draw such a conclusion. They are more appropriately seen as indicating kinds of potential. Actual achievement is a separate issue.

Realising the potential: A cautionary note

We have consistently emphasised the potential of CAL within the several paradigms, but we do not mean to leave the impression that this potential is readily fulfilled. Indeed, every project in the Programme has run into problems: some major, some trivial; some practical, some theoretical; some organisational, some human, some technical. It could be said - and we say it kindly, not to denigrate the work of project personnel - that every project has found new ways to fail. Because of the risk of singling out particular projects' work for attention, we would prefer to treat shortfalls in achievement by reference to our paradigms rather than the projects' own aims. They are intended only to illustrate the kinds of difficulties which arise whenever curriculum developers attempt to transmute curricular aspirations into educational practice.

Instructional: In the National Programme, one can find examples of 'adaptive-tutorial' CAL which require more adaptation of the student to the machine pedagogy than of the pedagogy to the learner. Even where the adaptive-tutorial materials are multi-branching, the student will usually follow a path through the subject-matter designed for him by the developer; even where a range of alternative responses is catered for by the machine, the materials impose their developers' questions and their developers' logic. Unlike advanced artificial intelligence (AI) applications in education (for example, Carbonell's SCHOLAR system), adaptive-tutorial CAL is unlikely to allow the student to pose his own questions or follow lines of his own interest. And student interest is important in the justification of instructional CAL: motivation based on feedback reinforcement may be insufficient in keeping the student engaged in his interaction with the machine.

Revelatory: In one project, we have seen examples of packages in which students have a dialogue with the machine intended to help them in planning experiments. The machine asks a variety of critical questions which guide the student towards a choice of methods and equipment for studying a phenomenon. But the difficulty is that students working on one experiment in the lab are nearly always exposed to other students who are working on other experiments. Since it is practically impossible to seal students off from one another, the social experience of the laboratory will thus tend to preempt the planning packages; the students will have seen how to do the experiment before they arrive at the terminals. They are in a position to "outguess" the machine as it takes them through the planning process.

There are other kinds of difficulties, too, in teaching for 'revelation' - sometimes what is revealed turns out to be an oversimplified version of a complex judgement process, or a black and white version of a grey area of human judgement. Medical students working on patient management case studies, for example, may be presented with diagnosis or treatment options (laid out as if there were no problem of construing the patient's state in terms of options), and have their responses judged by reference to a 'consensus' of expert opinion. At one level, we may speak of the process as one of revelation - revealing expert clinicians' models of practice. At another level, we may see the process as one of subjugation - what is revealed to the student is an apparent consensus among clinicians (who, in fact, disagree about all but the most proper and improper courses of action).

Conjectural: Perhaps the biggest difficulty in practice within the conjectural paradigm is that of developing students to the point where the machine becomes a 'mere' tool for the pursuit of other learning. On the one hand, there is the problem of helping computer-naive students to use the machine as a 'scratch-pad' when the ideas they are pursuing are themselves complex and subtle; then, on the other hand, there is the problem of helping them, after they have reached this mastery of the machine as a tool, to free themselves from the categories it imposes on the way they think about the problems. In one project, for example, the machine imposes the categories of 'concept' and 'element' for purposes of thinking about managers' perspectives on management problems - once the machine has introduced the separation, which it uses to make apparent certain kinds of interrelations between ideas and their objects, it may be difficult for students to think otherwise about perspectives.

Emancipatory: Using the computer to take the tedium out of calculations, may have paradoxical consequences. In some settings, students have traditionally regarded "doing the problems" as both the experience and the evidence of learning: they see the calculation as being the problem. When a project changes the nature of the problem so that it becomes, for example, "seeing the significance of a mathematical model" used in a number of relatively standard situations, the students may act so as to conserve their traditional ways of thinking. They may 'subvert' the new approach, treating the computer as a generator of numerical solutions and report that they have not learned anything from the CAL exercise. Taking inauthentic labour out of the learning process thus does not guarantee that authentic learning will be enhanced - that, too, must be achieved.

Freeing the student from one kind of non-valued activity, however, may still leave problems: sometimes the process of using the machine is sufficiently difficult that students must expend as much energy in using the machine to get solutions as they would in doing the calculations. (This may also be a problem in CML routing, as we will argue below.)

General: In addition to these paradigm-related difficulties there are more general pitfalls awaiting the unwary CAL developer. We have observed machines that were congenitally or acutely unreliable, teachers who found difficulty explaining to students what CAL materials were intended to do, problems of sequencing CAL materials within the general stream of course experiences, materials that underestimated the complexity or the subtlety of the ideas they attempted to convey, the professed ideal of the patient tutor in some CAL rendered as pedantry, packages so sub butle that they defied penetration by students without additional guidance, CAL-related curricular innovations so far-reaching in their implications that they defied implementation except in diluted forms, student-terminal interface software so complex as to demand a kind of 'translation' of communication with the machine into the language in which the subject-matter is usually discussed, and, even in an emphatically teacher-led Programme, the occasional dominance of computer technologists over teachers in the design of CAL materials.

As in all curriculum development, CAL developers in the National Programme are learning by their mistakes. Though these remarks may have alerted the reader to some of the ways it is possible to fail, many CAL developers in the National Programme would argue that it is only by doing, and by making mistakes, that it is possible to gain a practical grasp of the problems of CAL development.

still to check

COMPUTER MANAGED LEARNING

When we turn to what has been termed computer managed learning (CML) we find that the role played by the computer is relatively indirect. Students do not work at a terminal, as they do in CAL, but take part in courses of study in which some of the management tasks have been taken over by the machine. This distinction is significant enough in terms of educational applications to warrant separate treatment, even a separate analytical framework, which we now propose.

The Managerial Paradigm

All computer managed learning applications belong within this paradigm. Its theoretical origins are obscure, and probably lie outside education, in management science and systems engineering. Within education, it derives support from educational technology generally, from such theorists as Bloom (mastery learning) and Glaser (criterion-referenced testing and psycho/technological approaches to learning). In practice, its view of the nature of knowledge typically (though not exclusively) approximates to the 'instructional' view.

Key concept:	Optimisation of the teaching/learning process.
Curriculum emphasis:	Teacher or machine as manager of learning.
Educational means:	Rationalisation of needs/resource matching to improve efficiency of learning for the student.
Role of the computer:	Optimisation of the learner's route through a content field on the basis of his personality, cognitive characteristics, and diagnosed state of readiness.
Assumptions:	Modularised curriculum: they ory of learning styles, student needs and optitutdes.
Idealisation/Caricature:	At best, CML is seen as capitalising on individual learner differences (in needs, cognitive styles, etc.); at worst, it is held to be unnecessary (can be anticipated by teachers or students).
NDPCAL Project closest to the paradigm:	The South Glamorgan Remedial Reading scheme, which attempted (though it failed) to develop an operational system which would use a combination of previous performance and profiles of student characteristics to prescribe tasks for the learner.

Although CML shades across into mass applications of computers in educational administration (the sloughing off of routine clerical tasks to the machine) of more pressing educational interest are the three 'roles' played by the computer in CML systems, testing, routing students through courses of study, and record keeping.

Like CAL, CML is in principle responsive to alternative views of teaching and learning. It does not force the educator to make assumptions of a pedagogically committing kind. Nevertheless there is always a question that might reasonably be posed of any CML system: how does it envisage the interface between the human educators and the supportive machine? Particular CML systems might appear overtly mechanistic (i.e. inflexibly rule-bound), depending on what tasks, construed in what way, are handed over to the machine. The educational assumptions underpinning CML schemes are not in any simple sense packaged into the technology.

The source of demand for CML is frequently said to come from those who wish to individualise learning. Yet the desire to individualise learning itself contains two contradictory impulses. A liberal view might be constructed in terms of allowing more student autonomy. John Cowan, in a paper to the 1976 APLET conference identified a 'hierarchy of freedoms related to learning'. The lowest freedom is freedom of pace, then freedom of method, freedom of content and freedom of assessment. Due to the hierarchical structure, offering one freedom implies offering all lower freedoms. The machine is said to match the intuitive adaptivity of the teacher and meet the claims made upon the instructional system by individual students. But paradoxically CML is also endorsed by those who support the thrust towards a tighter instructional system, based on pre-course or pre-module testing and mastery learning. It is quite possible for a single institution to use CML in both ways. At the New University of Ulster, for example, a 'liberal' (and even at times conjectural) application of CAMOL is found in Harry McMahon's ED204 Curriculum Design and Development and a 'tight' application is found in Tom Black's DE380 Research Design and Structure, an off-shoot of the same project.

It may be useful to consider in turn the three principal roles played by the computer in CML systems, testing, routing and record-keeping.

Testing

The testing role means test marking, test analysis, test item banking and test production (not necessarily limited to formal examinations). It must be obvious that CML requires that teachers fully understand the role of testing in the educative setting. Not all tests, for example, are designed to discriminate between, or 'spread out' a group of students, and CML systems increasingly show the influence of mastery learning and criterion-referenced testing. Yet many teachers are unprepared technically for the sophistication of facilities offered by current CML systems. In the early days this was a problem in the CAMOL application at Brighton Polytechnic, for example. If one took an incremental view of educational innovation it would perhaps be sufficient to claim that the testing facilities offered to tutors in an imported CML innovation would be at least as good, even if imperfectly understood, as those they could generate themselves. Certainly CML testing typically increases the amount of information available to tutors, being greater than they could produce manually.

One form of testing prevalent in CML systems is diagnostic testing. In a 'tight' CML system, diagnostic testing will be based on a somewhat mechanistic assumption - that it is possible to generate decision rules by which learners move from supposedly diagnostic scores or profile characteristics to supposedly appropriate learning materials, having one-to-one correspondence with gaps in the learner's performance repertoire. But diagnostic testing might also be construed more loosely, as background data for making information-based educational judgements about what the students should do next.

Experience with the computer generation of test items is limited. Even when manually generated, it is rare for instructional materials to be rich enough to yield a large number of items. This will be particularly true of courses still under development and in a state of flux. Indeed it might well be argued that the investment of time and effort, in building up items depends on the stability of the instructional materials.

Another problem is that objective testing, favoured by CML because it facilitates machine-marking, is frequently unsatisfactory vis-a-vis the way in which an expert understands the subject. Typically multiple choice questions reward 'surface knowledge' at the expense of 'depth understanding', which may best be tested by demanding a constructed response. It would not be possible, for example, to infer mathematical understanding of a topic from a pupil's successful completion of machine marked questions in the Hertfordshire Computer Managed Maths Project.

Routing

The second role performed by the computer in CML systems is prescriptive, routing students through a course of study on the basis of past attainment and/or individual characteristics and interests. 'Routing' occurs when the machine designates paths to individual learners through learning materials. A typical approach to routing involves dividing a course up into a series of chunky modules or 'blocks'. Students only take those modules to which they are directed. But the claims for CML routing go beyond simple feed-forward systems involving pre-requisites, mastery testing and remedial support. They quickly add up to statements about how this learner with these characteristics should learn within this domain. Consequently machine routing implies that we adequately understand the subject matter, and thus can represent the knowledge structure in some way; that we adequately characterise the learner to whose individual needs we claim to be adaptive; and that we adequately conceptualise a pedagogy.

Although at first sight the question of finding ways to represent knowledge might not seem a problem, Michael MacDonald Ross (1972) has pointed out that this is "a real issue whose clarification is almost a prerequisite for progress in the design of educational systems". One promising technical approach, the so-called behavioural objectives approach, no longer commands universal support, not least because it misrepresents knowledge as a 'list structure' ("it is the interconnectedness of ideas that makes knowledge coherent and this aspect is omitted by any protocol of behaviour". Ross, op cit). Alternative forms for representing knowledge include the hierarchy (in which knowledge is represented as a tree, with everything dependant on what is taught previously) and the relational net (which is rather like the map of the London Underground in that many routes are possible). But in each case the visual metaphor imposes a way of looking at the domain of learning that may or may not be helpful. Is the hierarchy logically necessary or just pedagogically expedient, the choice of a particular instructor? Should the nodes on a network be concepts or learning tasks? There is also the question of consistency. It is possible to find, as in the Havering Biology scheme, a testing system premissed on a list structure and a routing system premissed on a hierarchy or network.

Without an adequate pedagogy for a CML course, judgement on the appropriateness of particular learning materials cannot be made. Yet CML systems are also being pressed to accommodate alternative learning styles, student preferences and variations in the mode of instruction.

There is a parallel between adaptive tutorial CAL and CML routing. Both have attracted strong arguments within what we have called an instructional paradigm, asserting the right of the developer to design paths for the student, and build these in preordinately i.e. prior to the educational encounter. This strong claim insists that branches or routing algorithms can be established in advance, rendering unnecessary any further intuitive adaptivity on the part of the teacher. Such CML routing will tend to be mechanistic and prescriptive. Paradoxically, since CML is often justified in terms of the individualisation of learning, such routing may actually detract from any real individualisation. As David Hawkridge (1974) points out, the basic problem in using the computer to determine the sequence each learner should follow is one of finding reasons for reducing the options open to students at each decision point.

Another interesting aspect of CML routing, which directly affects the 'authority of the system' is whether students are expected to treat the machine and its advice as a mysterious 'black box', in principle closed to them. An alternative is to give students a map of the knowledge domain independent of the 'next step' instruction issued by the machine, (the difference might be seen as similar to offering a driver a map of Cornwall rather than an AA Saltash to Bodmin route map) and permit browsing through the curriculum material. This would have the predictable consequence of legitimising the exercise of ordinary judgement as an alternative to accepting the routing suggested by the machine.

Record-keeping

Finally we need to consider the role of the computer in record keeping. This is clearly important but intellectually unexciting, at best where economies of scale are possible over vast quantities of routinely-collected data. Because of the facilities for analysis available in computers, the possibility of tailoring records of student progress (ranging in scale from the individual module to the whole course) to the information needs of different parties becomes a task of imaginative complexity. It is in this light that Ulster College sees its development of Macro CAMOL.

The educational justification for CML will always depend on identifying its goals as desirable and placing a value greater than cost on the differences between the CML system and what it replaces. Part of the justification is that the machine 'frees' teachers for a more personal educational role, what in terms of our analysis might be described as reducing the inauthentic labour of the teacher.

COMPUTER ASSISTED TRAINING

We have less to say about the role of the computer in industrial training, partly because our own experience and expertise lies more in the field of education and partly because the National Programme explorations in this sector have been limited, as the Director points out elsewhere. Our remarks, therefore, should be treated as speculative and thinly grounded.

Of course, the National Programme has indirectly covered a wider area than is shown by its two designated industrial training projects. The Leeds statistics work has clear application in a number of vocations. The Glasgow clinical decision-making project provides vocational training of doctors, and more recently, through transfer of the model, to police officers. And at Leicester Polytechnic, within the Engineering Sciences Project, the visitor may meet day-release HND students from that same Post Office which elsewhere accommodates a project in industrial training.

This leads us to the difficult distinction between education and training, which, though useful, becomes increasingly blurred with the current emphasis on the industrial relevance of education. But the conventional distinction largely holds in some important respects. Training is job specific, and represents an investment in work force competence by employers demanding tangible evidence of enhanced performance. The dominant paradigms are instructional and managerial, with a strong flavour of systems theory. The modern industrial trainer operates through a process of segmenting the learning experience into carefully defined increments. His methods are those of job description and job evaluation, task analysis and performance appraisal. The course designer in training is more likely than his counterpart in education to be able to justify behavioural specification of learning outcomes, and it is not surprising to find that the works of Robert Mager are widely read and applied in the training sector. After all, the competences of interest to the trainer are frequently the behaviours themselves. It is all the more surprising, therefore, that an activity so clearly susceptible to computer 'treatment' should have figured so marginally in the spectrum of Programme applications.

It may be useful to consider briefly the types of job to which CAT might be applied. Our choices here will be illustrative rather than exhaustive.

Technician/Specialist: this job category is represented in the NDP by the Post Office and RAF Locking applications of CAL to electronic fault-finding, and arguably by a similar diagnostic application in the Glasgow clinical decision-making project. The Post Office and RAF Projects are the clearest examples of CAL as straightforward replacements for conventional experience. The ends remain exactly the same (accurate fault-finding) but instead of working with real equipment the faults are simulated and traced through interaction at the computer terminal. These applications contain an element of CML, in that feedback helps the teacher to present the student with faults of suitable complexity, as well as checking the validity of test items.

An issue to be faced here is whether the quality of the experience is significantly altered: the technicians may prefer hands-on contact with real equipment to ensure long term retention of what is learned, and the confidence and facility that that implies: practice effects gained through CAT would ultimately be self-defeating if such practice could not be translated on the job.

Management: applications in this category can usufully be examined in terms of Morris and Burgoyne's (1973) distinction between operational management, where the activity is readily understood, and developmental management, where the manager's activity consists in shaping his own routines. An example might be the comparison between an accountant carrying out an audit according to agreed procedures, and an accountant developing new management control procedures. It is easier to envisage instructional CAT for basic operational skills, than it is to envisage conjectural CAT where pre-determined CAT methods can teach high-level skills for the resolution of undetermined managerial problems. The developmental category must be considered on the boundary between training and education. The London Business School project, for example, avoids treating managers as in need of a describable repertoire of performances, instead seeking ways of reflecting managers' conceptual frameworks to each other.

Clerical: training standards for clerical work can be tightly specified ('the reservations clerk should be able to identify the country of any given airport in 90% of the test items presented'), and such work is increasingly concerned with computers. But relevant skills are then largely specific to the industry's or employer's computer operations, and acquired through training on-the-job.

The Cost Factor in CAT

A significant factor, whatever the job category, is the very different level of student costs in the industrial training sector, and the implications this has for the power balance between provider and consumer. In management education, a middle manager might cost his company a salary of £9,000, plus sizable overheads, and a further £250 per week in course fees, which produces a student cost of £10 per hour. The Post Office technicians, with wages and accommodation included, cost £206 per week of training. True, this gives greater potential savings to any successful CAT application: but it also implies greater costs if an application fails, and heavier accountability to the paying customer.

A corollary is that the manager or unionised technician may feel less willing to accept the impositions of a coercive CAT experience: his student labour has to be clearly authentic. A further corollary is that the costs of low reliability are much more apparent. The Post Office project suffered from poor service from an albeit temporary time-sharing computer, which left technicians kicking their heels. And the London Business School project once had 50 even more expensive managers facing a two-day hiatus when the local mini-computer crashed. Such students cannot easily be re-timetabled, or asked to come back in their free time. A further point on available technology is that both Post Office and SAFARI project have found difficulty in replicating complex circuit diagrams on VDU terminals: Post Office technicians are expected to divide their attention between a printed manual and the VDU screen, whilst the RAF was experimenting with a second terminal to display microfiches of circuit diagrams.

Education and Training

Perhaps the major issue for the future of CAT concerns the viability of the older conception of 'training'. Training, by traditional definition, limits options while education extends. It concentrates on performance rather than the kind of attention to principle that would allow the learner to generate his own code. In a society faced with the likelihood of successive 'retraining' for the changing conditions of employment it is doubtful whether training can remain for much longer within a narrow rubric of task analysis unrelated to broader 'educational' issues.

CONCLUDING OVERVIEW

Innovations cannot always be careful about the company they keep and they run the risk of being damned by association. The computer in the classroom is a newcomer, quite unfamiliar to the vast majority of teachers who will be asked, sooner or later, to consider whether it could then do a better job. But all of them, like the rest of us, know something about the uses of the computer in other areas of their lives, from the relatively mundane calculations of payslips to the exotic selection of a mate. For many it epitomises the depersonalisation of their relationships as individuals to those who employ them,those who manage them, and those who administer the services and exact the demands that society legislates. Its ubiquitous role in organisational life is seen as symptomatic of the technologisation of society, a process popularly associated with dehumanisation and domination. The computer is, in these terms, the instrument of those in charge, and a symbol of their power and inaccessibility to the individual citizen.

This image of the computer is a response to its social history, itself critically influenced by investment costs, which ensured that commercial development would primarily exploit applications of use to organisations which could both afford the capital investment and hope to recover the costs by improving their efficiency. Large business firms and government departments were, and remain still, the principal customers for a facility which, even in its crudest technological form, delivered a quantum leap in their capacity to store, retrieve, and process information for decision making.

This dominance by prestigious customers is rightly a cause of concern, and a reason for watchfulness. The educational consumer in some sense plays second fiddle; the available technology is likely to be shaped by the requirements of others.

But, even if we concede that the computer is the instrument of those in charge, it does not follow that computer assisted learning, as it assumes a role in education, will increasingly paraphrase its role in society at large. We would contend the contrary. In Britain at least, the teacher keeps the gate of the educational process. He is, despite periodic challenges to his professional autonomy, "in charge" of the classroom encounter. The NDPCAL strategies of teacher-led development and teacher-to-teacher diffusion constitute both an acknowledgement and an endorsement of this basic fact of curriculum power. The diversity of CAL developments within the Programme testifies to the educational pluralism which such a system of individualised power promotes, a diversity of educational values, aspirations, and practices which defines the conditions for a successful technology. That the technology of computing has the potential to meet such conditions should not be in doubt. It must be clear from our account of CAL that a technology which can already, despite a development history largely devoted to bureaucratic needs and mass marketing constraints, sustain a wide range of pedagogic thrusts is essentially non-determinist in character.

This is not an argument against vigilance, and certainly not an endorsement of the apparent indifference of the educational community to the stirrings of computer assisted learning. Our purpose in this chapter is to assist that community to pursue a vital evaluation question - what educational uses of the computer ought to be encouraged? But to engage the constructive interest of the community in this issue is no mean task, as the experience of the National Programme has made clear. Indifference is widespread, pervasive, seemingly unshakeable. It has something to do with the social symbolism of the computer, something to do with a generalised technophobia, something, perhaps to do with a deep sense of personal impotence in the face of technology-based change - a belief in technological determinism.

The computer is widely seen as a threat (those who dispute this will look in vain for support in the rhetoric of politicians) and the persistence of this perception continues to frustrate a balanced review of CAL options. Certainly the opportunity for such a review is now with us. The National Programme has explored and defined some of the options, and has laid out its wares for inspection. The next two or three years offer a period for reflection and evaluation before the next major policy thrust in computer-based education can be initiated.

There are dangers, should the opportunity be overlooked, dangers spelled out very clearly by Raymond Williams (1974) in the context of televisual technology.

> "... the history of broadcasting institutions shows very clearly that the institutions and social policies which get established in a formative, innovative stage - often ad hoc and piecemeal in a confused and seemingly marginal area - have extraordinary persistence into later periods, if only because they accumulate techniques, experience, capital or what come to seem prescriptive rights. The period of social decision has then to begin now."

Computing is the one certain technology of the future. In the education process, some of its possibilities are now accessible to public and professional judgement. The future is being shaped now.

UNCAL

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