Strategies for Computer Assisted Learning

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Abstract–This essay discusses some strategies for using the computer as an aid to learning. In order to set the discussion in context, some views of the education scene are outlined in terms of pupil's learning and cognition, the teacher-pupil relationship and the role of the computer in the learning process. Three examples of strategies for computer assisted learning are described and the arguments for and against each reviewed in terms of the education scene outlined.

Introduction

Computer Assisted Learning is already an out-dated term to many, due to the growth in computer developments in education, but is still used by some to define a particular kind of activity using computers. The modern terms, educational computing and information technology ('informatics' is used internationally) refer to a broad area of computer use in schools, colleges and training, where it is found that narrow definitions quickly lose their meaning as the state of the art moves on. This broad area, ranging from pre-school use of computers to beyond secondary school use, is mapped by Hawkridge [1983]. An important development in the field, especially recently, is the use of commercial applications of the computer – such as the word-processor, the spreadsheet and electronic mail – in an educational setting. But in order to limit the discussion, this essay focuses on a particular domain of educational computing, that of Computer Assisted Learning. The term Computer Assisted Learning (hereafter denoted by CAL) is used in this essay to mean an approach that involves the active use of the computer as a participant in a learning situation by the design of applications specifically for this purpose. This domain may be analysed from a number of viewpoints, including the technology itself (Evans [1979]), the national social and political scenario (Linn [1985]) and the problems of introduction at the local institutional level (Bliss et al [1985]). This essay, however, further concentrates on the strategies adopted by some authors in developing CAL at the three levels of pupils' learning, the teacher role and the role of the computer. To begin with, in what ways can such an author view the individual pupil's learning process?

Models of learning

This section discusses psychological models of pupil's learning. Such models may not be explicitly referenced by authors proposing a particular CAL strategy, but it is argued that an implicit model of pupil learning is present in the development of any educational resource. Although there are many such models, for the purposes of this essay, they are divided into those deriving from behaviourist or connectionist theories, in particular those of Skinner, and cognitive theories based on work by Piaget and others (Hill [1977]).

Connectionist models

Connectionist psychologists argue that fundamentally learning can be seen as change in pupils' behaviour. It is argued that a particular behaviour or "response" is observed in connection with a specific stimulus. Thus learning, or change in behaviour, is brought about by "shaping" the pupils' response when presented with an external stimulus. The shaping process consists of providing reinforcement for "correct" behaviour. This reinforcement may consist of the presentation of a "positive reinforcer" or the removal of a "negative reinforcer".

Such models of learning studiously avoid a discussion of the processes that are going on in the pupil's mind, but measure learning as a change in observed behaviour. The motivation for learning is extrinsic, provided by the reinforcement schedule, not intrinsic, deriving from the pupil. The simplicity of this model enables quite precise measurement of the factors leading to a successful learning situation, although it is not clear that such measurement is worthwhile. It is easy to construct experiments and pose questions, based on this model of learning, which identify successful learning materials. Do the authors of these materials make clear the change in behaviour intended? Do they provide appropriate stimuli, at appropriate times for such learning to take place?

Skinner [1958,1960] has proposed "programmed learning" as a practical application of this kind of learning model. This approach is to design a program of teaching and test items where the reinforcement is provided by the pupil's answer matching the correct answer. Such programs are linear in nature, but progress at a gentle pace so that many positive reinforcements are encountered. Individual pupils may be differentiated by their rate of progress through such material.

Others, such as Crowder [1960] have refined such models to include branching paths in response to alternative answers to multiple choice items.

Criticisms of the shaping process are that it is unlikely to have permanent effect, because the reinforcement must be kept up to retain the change in behaviour, and that the use of such methods deny freedom to the learner who is controlled by the person providing reinforcement. A further criticism may be that the teacher may have difficulty in determining the correct response in areas of learning which are open-ended in style.

At a more basic level such theories have been rejected by such as Bruner [1966] when he writes:

> "A great deal of growth consists of the child's being able to maintain an invariant response in the face of changing states of the stimulating environment or learning to alter his response in the presence of an unchanging stimulus environment. He gains his freedom from stimulus control through mediating processes, as they have come to be called in previous years that transform the stimulus prior to response. A theory of growth that does not attempt an account of these mediating processes and of the nature of the transformations they make possible is not very interesting psychology."

Criticisms such as these have begun a reversal in the fortunes of behavioural psychology in recent years, but the dominance and simplicity of this approach still surfaces in strategies for CAL to this day despite the failure of the teaching machine. The computer can be considered as the ultimate teaching machine and as Skinner [1984] has said when explaining this failure:

> "The teaching machines of 25 years ago were crude, of course, but that is scarcely an explanation. The calculating machines were crude, too, yet they were used until they could be replaced with something better. The hardware problem has now been solved, but resistance to a technology of teaching survives."

Cognitive models

Cognitive models of pupil's learning have their basis in cognitive psychology, which despite having a long history has only gradually displaced behavioural psychology as the major focus for psychological understanding (of learning) over the last thirty years. As Mandler [1985] puts it:

> "...cognitive psychology is well on its way to occupying the vacuum left by a dying behaviourism."

Cognitive models of learning are concerned with pupil's understanding rather than with pupil's behaviour. The concentration on empiricism at the expense of theory prevalent in behaviourist psychology is replaced with an approach, which recognises the human mind, the representation of knowledge and the processes that support mental activity. Mandler [1985] summarises the direction of cognitive psychology as:

> "The emphasis is to develop systems and structures that can be said to construct the observable, evidential aspects of thought and action."

Advocates of this view propose that the learning process is about changes in pupils' perception and mental structures. The analysis of such structures enables us to present pupils with appropriate experiences and problems in order to foster the growth of their knowledge.

Piaget, as described by Andersson [1984], proposes that the pupil has a natural urge to explore and learn about the environment, but after some experience finds herself in a situation she does not understand. This disturbance to the equilibrium demands, as in all biological organisms an attempt to restore equilibrium. This takes place by a combination of two means: an effort to assimilate, re-interpreting the experience to fit existing internal structure and, if this fails, an effort to accommodate the new experience, by modification of internal structures. It is argued that when learning takes place, both of these processes are taking place in some degree.

This approach is also the starting point for constructivist models of learning, in which pupils are seen to be engaged in the active construction of their understanding and knowledge. This activity takes place in the face of new experiences, using the pupil's existing mental structures to adapt their understanding.

A common term used in discussing such models is that of 'conceptual framework', which Gilbert and Watts [1983] discuss in much detail in relation to the notion of 'concept' with particular reference to science education. They list three views of the meaning of 'concept', the classical view - a logical-positivistic view of static concepts; the actional view - seeing concepts as active, constructive and intentional and the relational view - which describes concepts in relation to each other. The importance of this discussion is in the approach to pupils' learning - in particular that a pupil's conceptual framework may be treated with as much respect as the 'accepted' conceptual framework of the discipline being taught.

In order to apply these models of learning, as Andersson [1984] points out in relation to science education, we must discover the initial state of a pupil's understanding, the desired end-point and also analyse the topic in terms of reasoning patterns, concepts and key ideas.

Regardless of which model of learning a strategy for CAL adopts, that strategy will fail if it does not also consider the wider environment within which learning must take place.

The classroom

A strategy for CAL should not only take into account the individual pupil, but must pay attention to the realities of the classroom. The pupil is surrounded by peers in most learning situations and is guided by the teacher. Both pupil and teacher have goals of their own, influenced heavily by the school curriculum. Finally there is the role of the computer in the classroom, which may be difficult to establish, particularly when popular mythology elevates the computer to near human power.

The teacher-pupil relationship

For the purposes of this essay, the role of teacher is viewed as described by Hargreaves [1975]. In this analysis, most teachers are considered under the heading of two types, the 'liontamer' and the 'entertainer' which are contrasted with a third type, the 'new romantic'. These types do not represent real teachers, indeed teachers are assumed to draw from characteristics of each type in some degree. Each type can be understood by examining different perspectives on the teacher pupil relationship.

Firstly, how are pupils motivated? The liontamer answers that the pupil is naturally unwilling to learn and must be pushed. The entertainer also feels that pupils are unwilling, but hopes to motivate by making learning fun. The new romantic, on the other hand, believes that pupils are naturally motivated to learn and that her task is to facilitate learning.

The second perspective is on the content of the curriculum. The liontamer believes that this is a matter for her alone and follows traditional subject-based lines. The entertainer also believes that she should decide the curriculum, but subject boundaries are no longer important, especially if they stand in the way of making learning more interesting. As Hargreaves puts it:

> "Thus History is taught with a local bias, mathematics with examples from cricket scores and gas bills, which hopefully will be as potentially useful as they are enthralling."

The new romantic assumes that the curriculum should be left to the pupil to decide, based on collaborative construction with herself, her skills increasingly being seen in the domains of problem definition, procurer of resources and development of courses of study. As Hargreaves says on describing the consequences for the pupil:

> "... ultimately the choice must be his. We cannot make all his choices for him and then wonder why he does not want to learn."

Third is teaching style. The liontamer is a confirmed chalk and talk teacher, seeing herself as an expert and demanding attention to her lectures. Discipline is a matter of being firm and keeping the pupils down. The entertainer is less confident and indulges in alternative methods of conveying knowledge, through audio-visual aids, computers and structured packages. If discipline breaks down it is seen as the teacher's failure to keep pupils busy rather than as a failure on the part of the pupil. The new romantic bases her style on trust. Hargreaves says that the new romantic believes:

> "... that the creation of the appropriate classroom atmosphere, namely one that is non-threatening and acceptant springs directly from the kind of relationship (s)he establishes with the pupils."

Fourthly there is the pupil's role. In the liontamer's classroom, the pupil sits and listens, answers questions and works in isolation. Pupils must adapt to the subject as presented. In the entertainer's classroom the pupil spends more time looking at alternative presentations, works in groups and to some extent, the subject is adapted to the pupil. In the new romantic's classroom the pupil is more self-reliant. Firstly, the pupil must learn that she wants to learn and discover what she wants to learn. Secondly the pupil must learn how to learn and how to question.

Fifth is the question of evaluation. The liontamer evaluates the pupil's work, believing that the pupil is in no position to judge. The entertainer is more prepared to allow the pupil to evaluate their work, partly because they are more prepared to set open-ended problems. The new romantic sees the major problem of evaluation in its personal nature. The evaluation of a pupil's work inevitably involves approval or disapproval of the pupil, although is possible to escape this where an impersonal relationship exists. Hargreaves goes as far to say:

> "A teaching machine can give pure feedback because the machine does not form a personal relationship with the pupil. (Even in this case approval cannot be entirely absent, since the pupil may approve or disapprove himself when the machine tells him that he is making the right or wrong response.)"

The new romantic believes that self-evaluation is most important, and that her role is to become collaborator in the approval-free task of evaluating progress, and that this can only take place when an 'acceptant' relationship has been formed with the pupil. As Hargreaves puts it:

> "Acceptance arises when one makes an active effort not to approve or disapprove but instead shows 'unconditional positive regard', trust and a non-threatening attitude to others."

To summarise, the liontamer is characterized by formality, conflict and the belief that learning is hard. The entertainer believes in happiness, informality and planning to keep pupils busy. The new romantic criticises both these beliefs, preferring to transfer status, power and authority to the pupil. For education as a whole the new romantic presents a challenge, as Hargreaves says:

> "It is perhaps the most disturbing of all the New Romantic contentions that it is the death of teaching which marks the birth of real learning."

But for the purpose of this essay, the importance of the above analysis is to provide a framework for evaluating a strategy for incorporating CAL in the classroom. If the relationship between teacher and pupil implied by a CAL strategy, intentionally or un-intentionally, does not fit that of the target classroom, then that strategy is unlikely to succeed.

The computer

What can the computer do to assist the pupil and teacher? The computer is of course that most potent of devices, a general purpose machine. Its facility with information processing at very high speed and in particular, to be driven by programs, which may modify themselves, makes it very difficult to see simple limits to its potential. The leading edge in the exploitation of such potential is to be found in the field of artificial intelligence, defined by Winston [1984] thus:

> "Artificial Intelligence is the study of ideas that enable computers to be intelligent."

Proponents of the application of artificial intelligence believe that such work will bear fruit in education. One such, Winston [1984] declares that:

> "In schools, computers should understand their student's mistakes, not just react to them. Computers should act as superbooks in which microprocessors display orbiting planets and play musical scores."

and further O’Shea and Self [1983] argue that:

> "If we want to build computer assisted learning programs to answer unanticipated questions and to individualise teaching - and we assume that we do - then we must try to make the necessary knowledge available to the computer."

Understanding pupils' mistakes and answering unanticipated questions have interesting implications for the role of the computer. On the one hand this role encroaches on that of the teacher where her expertise may be challenged. This challenge may be difficult for the liontamer but easier to bear for the entertainer or new romantic. On the other hand there is the implication that a true communication is taking place between computer and pupil. As Hargreaves [1975] explains, from a symbolic interactionist point of view such as that of George Herbert Mead, the primary element of communication is the gesture and an interaction can be seen as a 'conversation of gestures'. Hargreaves continues:

> "Yet a 'conversation of gestures' is not the same thing as communication. According to Mead, the 'conversation of gestures' becomes communication when the gestures become significant, that is, when they arouse in the organism making the gesture the same response that the gesture arouses, or is intended to arouse, in the other organism."

This implies that the computer must be capable of responding to its own gestures (outputs) in the same way as the pupil using the computer. In order for this to take place, we must on the one hand understand pupils' responses in some detail and on the other be able to write programs to model such responses. It is thought by some that the former requires a deeper and more precise understanding in cognitive psychology than we have at present, and the latter requires programming techniques and computer power which are still to be developed.

These views may be taken by those with a working knowledge of computers - the experts; teachers who are unaware may see things differently, as Bliss et al [1985] in a case study of the introduction of computers to a secondary school report:

> "Some other teachers said they saw the computer as just a sort of toy - not important for their work; yet others saw it as a 'glorified' calculating machine; quite a few commented that it could easily be misused and end-up becoming just another gimmick!"

Whether the potential is over or under-estimated, there are few who would disagree with O'Shea and Self [1983] when they say:

> "It is difficult to believe, however, that learning cannot be improved by capitalising upon the computer's distinctive properties, which, to recapitulate, are:
>
> 1. It can make decisions...
>
> 2. It is reactive...
>
> 3. It understands...
>
> 4. It can control other devices...
>
> 5. It is itself worthy of study...
>
> 6. It is not designed to accord with any specific educational theory..."

although item 3 on their list is open to question.

MacDonald, Atkin, Jenkins and Kemmis [1977] make a clear analysis of the role of the computer as observed in the projects spawned by the National Development Programme in Computer Assisted Learning (see Hooper [1977]). There analysis is based on

> "... three paradigms of education through which we may grasp the major ways in which developers of computer assisted learning conceive the curriculum task. We have called these paradigms the 'instructional', the 'revelatory', and the 'conjectural' ... they are our 'inventions', intended to help the reader to relate CAL to the general field of educational theory and practice."

MacDonald et al explain that the theory behind the instructional paradigm is derived from Skinner's work, and is based on the belief that pupils may acquire knowledge through transmission and reception of verbal messages. The revelatory paradigm is theoretically related to work by Bruner and Ausubel in which knowledge is acquired through the gradual revealing of concepts in the subject discipline. The conjectural paradigm is related to the theories of both Piaget and Popper and views knowledge as evolving through experience. Some of the main features of these paradigms are summarised in the following table:

Educational Paradigms for Computer Assisted Learning MacDonald, Atkin, Jenkins, Kemmis [1977]			
	INSTRUCTIONAL	**REVELATORY**	**CONJECTURAL**
Key concept:	Mastery of content.	Articulation and manipulation of ideas and hypothesis-testing.	Discovery, intuition, getting a 'feel' for ideas in the field etc.
Curriculum emphasis:	Subject matter as the object of learning.	Understanding, 'active' knowledge.	The student as the subject of education.
Educational means:	Rationalisation of instruction, especially in terms of sequencing presentation and feedback reinforcement.	Manipulation of student inputs, finding metaphors and model building.	Provison of opportunities for discovery and vicarious experience.
Role of computer:	Presentation of content, task prescription, student motivation through fast feedback.	Manipulable space/field/'scratch pad'/language, for creating or articulating models, programs, plans or conceptual structures.	Simulation or information handling.
Assumptions:	Conventional body of subject matter with articulated structure; articulated hierarchy of tasks, behaviouristic learning theory.	Problem-oriented theory of knowledge, general cognitive theory.	(hidden) model of significant concepts and knowledge structure; theory of learning by discovery.
Idealisation / Caricature:	At best, the computer is seen as a patient tutor; at worst it is seen as a page turner.	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.	At best, the computer is seen as creating a rich learning environment; at worst, it makes a 'black box' of the significant learnings.

If one were to ask the computer user outside education what role the computer can play, the most frequent answer would probably be that it replaced tedious and costly labour. MacDonald et al continue their analysis by pointing out that a useful distinction may be made between authentic and inauthentic labour by pupils and teachers. Authentic labour is that which is directly concerned with valued learning; inauthentic labour may be instrumental to valued learning but is not valued in its own right. They continue:

> "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 task."

This leads to the idea of a fourth paradigm, the emancipatory paradigm, in which the key concept is the reduction of inauthentic labour, but this does not occur in isolation to the three paradigms initially defined, since each reduces such labour to some extent.

These paradigms are intended to provide a framework for an analysis of the curriculum task faced by those developing CAL. It could be argued that there are strong connections between the three main paradigms and the analysis of teacher types by Hargreaves as outlined before. The liontamer, with her attitude of teacher-as-expert will closely identify with the instructional paradigm. The entertainer will identify with "Provision of opportunities for discovery and vicarious experience" and "creating a rich learning environment" in the revelatory paradigm. The new romantic, on the other hand, would appreciate the active learning and student autonomy implicit in the conjectural paradigm.

If teachers are involved in the development of strategies for CAL, and in many cases the enthusiastic teacher does seem to be central to CAL development, then it may be suggested that their inclinations in terms of Hargreave's types may well influence the balance of paradigms in their CAL work, especially if their view of the computer's role, albeit unconscious, is that of replacement or collaborator for their own role in the classroom. Such a view would be less threatening to many such developers than the view that computers have a new role, possibly 'better' than that they can perform.

Some Strategies

The three examples of strategies described and evaluated here are drawn from the CAL paradigms as outlined above. Firstly, an example from the instructional paradigm - a strategy for training patients in the use of kidney dialysis equipment (Homer [1985]). Secondly, an example from the revelatory paradigm - a program for learning about landscapes in Geography for secondary school students (Watson [1987]). Thirdly, an example from the conjectural paradigm - the programming language LOGO (Papert [1980]). This evaluation does not attempt to gauge the actual success of the strategies outlined, for this would involve a proper research study, but merely to examine the aims and methods as expressed by some of those involved and evaluate them in relation to the educational perspectives outline above.

Computer Aided Training in a Renal Dialysis Ward

Patients with kidney failure must (in the absence of a transplant) use a dialysis machine on a regular basis. Such machines are complex devices and require constant supervision. Traditionally, patients are trained to operate such machines by experienced nurses. Some difficulties arise, due to the distractions of learning in a busy hospital, the medical condition of the patient and the problem of illustrating fatal conditions. Homer [1985] describes a strategy for improving the situation by the use of a computer method.

The solution (called CELLS) consists of a computer linked to a television screen, an audio cassette recorder and five keys labelled 1-5; these are provided for the interaction which takes place when the cassette is started. A 'lesson' is carried out by a sequence of items. Each item is enacted by the presentation of a diagram on the computer screen, the playing of an audio message followed by the learner pressing one of the five keys. After the pressing of a key, the computer will respond with a yes/correct message or a no/incorrect message and then proceed to the next item. The tape may be stopped at any point and paused or re-wound to replay a previous item.

New lessons can be designed by the nurse by removing the cover of the device to gain access to the full computer keyboard.

At a superficial level, the lesson is in the control of the learner, since the tape recorder may be stopped and started at will. Nevertheless, the approach is clearly in the instructional paradigm, close to a simple page turner. The learner's task is to master the facts as presented. The content is designed by the teacher, no doubt to follow a rational order of presentation with appropriate feedback reinforcement, but with no branching or adaptation to different pupil's understanding. The content of the lesson is not under the learner's control, but firmly in the hands of the expert who prepared it. The role of the computer is to present the content and give rapid feedback to the student.

Homer declares that:

> "Clearly, any CAL device needs to be interactive in that the device offers instruction and explanation and tests the student's comprehension of that lesson by presenting the student with strategically placed questions or tests."

The quality of the interaction can be judged by the following statement by Homer:

> "An important aspect of the CELLS approach is that the correct answer is rewarded with the appropriate audio response from the teacher. Similarly, if the patient gets the answer wrong, then the audio response is geared to that incorrect answer, perhaps telling the patient what the correct course of action should be in dealing with this emergency etc. The use of two audio responses... 'Yes, you are correct...' and 'No, you are wrong... ' greatly improves the acceptability and the realism of CELLS as a CAL device."

Although no reference to a learning model is made by Homer, it may be argued that this approach is based on a behaviourist or connectionist model of learning but with no refinement whatsoever. What explanations there are must always be in terms of right and wrong, centred on the teacher's view of the subject matter. The paucity of the interaction is reminiscent of the extreme liontamer in action, with no regard for the learner's view or conception.

Finally, it is claimed that:

> "However, CELLS and similar CAL approaches can enhance the learning process considerably. The quality of student comprehension is greatly improved"

This statement is hard to accept, firstly because no evidence for such enhancement and improvement is presented, but secondly because it would not be expected that "quality of comprehension" would be improved by such an approach, but that changes in behaviour might be achieved.

Landscape Analysis

This CAL unit was designed by a group of teachers working with the Computers in the Curriculum project (CIC project). The design process and the decisions taken are described by Watson [1987], who explains:

> "The key educational problem ... is the fact that it is very hard to teach pupils that a map with contour lines is a representation of a real three dimensional landscape."

The group decided to ease this problem with the use of a computer program which would present a choice of contour maps on the screen, enable interaction with the pupil and draw requested cross sections and perspective views of the landscape defined by the chosen contour map.

In order to specify more closely the details of this computer program the group discussed and proposed answers to questions posed in an 'Outline of a Proposed Unit' or OPU. This pro-forma provides a framework for thinking about the CAL design process under three section headings as follows:

A THE TOPIC

1. Curriculum area and year (intended age group)

2. Specific topic

3. How is the topic currently taught?

4. List two or three questions which students should be able to answer after studying the topic.

5. What aspect of the topic will the computer cover?

B COMPARISON WITH TRADITIONAL TEACHING

6. What are the difficulties faced by students in their study of the topic?

7. How is it envisaged that the new unit will help with these difficulties or improve students understanding?

C PROGRAM DESCRIPTION

8. Outline sample dialogue showing parameters which the student will control and the form of the output.

9. What model is to be used? What parameters are unseen by the student?

10. What limits to student input should be (a) mandatory and (b) educationally recommended?

It seems clear that the OPU, and particularly items 8 and 9, guide the CAL author according to the revelatory paradigm, in which there is the assumption of a "(hidden) model of significant concepts...". That is of course the teacher's model to be discovered by the pupil.

As Watson describes, initially the group listed a series of questions for the student to answer under section 8. Some of these questions deciding the cross-section and view (parameters of the model), others seeking simple facts in liontamer style in other words a mixture of revelatory and instructional paradigms. As work proceeded the group dropped the factual questions, concentrating solely on the revelatory aspects of the program and introduced a modicum of conjectural paradigm by focussing more closely on the way in which students might control the views and cross-section in order to pose their own questions.

It is interesting to speculate whether the group where fully paid up entertainers, or whether in the course of the development they became more so from an initial position more reminiscent of a liontamer!

As Watson further reports, a program was produced and sent for school trials. As a result, as well as a concern about identifying the height at a point in the landscape, a major revision was requested by trial schools - the teachers wanted to enter their own data to define a landscape. If followed through, and made available to pupils, the development would begin to have a true conjectural element, where pupils might design their own landscapes. In the event the feature could not be added due to technical and resource limitations.

The strategy adopted, with its clear emphasis on the revelatory paradigm and a strong concern with existing curriculum structure, was adopted to achieve acceptance amongst current teachers and to improve the chances of success of the innovation. The new romantic might hope for some more radical strategy.

LOGO

Papert [1980], in the introduction to Mindstorms, states:

> "It is not true to say that the image of a child's relationship with a computer I shall develop here goes far beyond what is common in today's schools. My image does not go beyond: It goes in the opposite direction."

He continues by describing his image of the relationship as based on the child programming the computer rather than the computer programming the child, and in order to do this children learn LOGO.

LOGO is a programming language for computers, derived from the programming language LISP (which stands for list processing). The fundamental program structure in LOGO is the 'procedure' or sub-program. LOGO applications are usually constructed from a number of procedures inter-related in a hierarchy, that is some are sub-procedures of others. The fundamental data structure is the 'list' which is an ordered collection of words, numbers or other lists, possibly mixed together. It is simple to construct hierarchical data structures by making lists of lists. In order to make such a language useful, some primitive procedures are provided which enable list processing, arithmetic and workspace management functions to be performed. An important set of primitives, from the point of view of learning, are centred around an object called the 'turtle' (other objects are the computer screen, keyboard etc.). The turtle has two properties, a position in two dimensional space and a heading or compass bearing. It can be made to move a particular distance in the direction it is facing and turn to the left or right by some angle.

The turtle is important for learning, because it is one of a set of "objects-to-think-with". As Papert puts it:

> "The Turtle serves no other purpose than of being good to program and good to think with."

As Papert explains, programming is introduced through the metaphor of teaching the turtle a new word (procedure). Procedures to draw a square or triangle are quickly discovered, and then may be combined to draw the structure and roof of a house. In the process of trying to make a house many 'bugs' will occur, that is unintended faults in the turtles behaviour. The process of 'debugging' takes place when the pupil examines their procedures to explain the behaviour and correct it.

Many would argue about precisely what can be learnt through this process. Pea [1983] describes one view:

> "Programming is viewed by many of its devotees as a 'Wheaties of the Mind'. a panacea for the ambiguities of everyday cognition. It is alleged that in the demands which programming activities make on the mind - of precision (in requiring a specific sequence of instructions for controlling the operations of the computer); of problem decomposition (into component subproblems); and of debugging (systematic efforts to eliminate discrepancies between the intended outcomes of the program and those brought about through the current version of the program) - programming renders salient the general utility of such cognitive activities in problem-solving efforts, and that such generalizations will be made spontaneously by the programmer to problem spheres above and beyond the microcomputer environment."

Pea goes on to point out the similarity with the claims for literacy, mathematics and logic as 'cognitive amplifiers'. Pea also describes a study in which pupils' programming comprehension and transfer of planning skills to other activities were tested. He found no evidence for such transfer and points out that others have found that there is difficulty in transferring problem-solving strategies between dissimilar problems or content.

Nevertheless, clearly the model of learning is cognitive, the paradigm is the conjectural and equally clearly LOGO fits the new romantic's idea of active, autonomous learning for the pupil. Especially interesting to the new romantic is the notion that in the LOGO philosophy, errors (program bugs) are not a reason for being right or wrong, are not judgments given by computer or teacher, but are observed by the pupil herself and are the basis for further motivation to understand.

How does the liontamer or the entertainer use LOGO? Some research in inner London schools (Rhodes [1987]) seems to point to a 'curriculum of LOGO', classes of pupils following strict instruction on how to draw squares, triangles, houses and streets of houses where incorrect diagrams are classed as wrong! If repeated elsewhere this approach might explain the mixed success of LOGO as a strategy for CAL. For LOGO to become the centre of a computer culture for children involved in active learning as Papert would wish, the relationship between teacher and pupil might have to be developed alongside that of the pupil and computer.

Conclusion

This discussion suggests that the types of teacher that Hargreaves identifies and the paradigms that MacDonald et al propose are closely linked by their assumptions about models of learning and the pupil-teacher and pupil-computer relationship. These links are summarised as follows:

Teacher type	Paradigm
liontamer	instructional
entertainer	revelatory
new romantic	conjectural

It is further proposed that the paradigm chosen by an author developing CAL, may be strongly influenced by the type or types of teacher to which that author is sympathetic.

Lastly, it is argued that for a CAL strategy to be successful, the CAL author should be aware of the types of teacher that will be expected to implement that strategy and either design for that audience or expect relatively little take-up, until more teachers are converted to the cause they espouse.

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