Fallible, Distractible, Forgetful, Wilful and Irrational Learners

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INTRODUCTION

This chapter is about the interaction of Artificial Intelligence (AI) and the domain of education. From an educational point of view, the discipline of building computational theories of communication, learning and teaching is a powerful tool in our attempts to understand educational processes. In particular, we view teaching as a specialised form of ordinary human communication. Human teachers learn their trade by extending and exploiting their existing rich stock of communicative competence, not just by applying some free-standing, self-contained body of expertise. This makes the task of understanding and duplicating this behaviour all the more difficult.

In addition, the subject knowledge of human teachers (e.g. in mathematics, language, science or whatever) is also grounded in their everyday common sense, knowledge and skills. While one can at present, build tolerably good machine teachers for narrow domains, with limited tutorial and diagnostic abilities, such enterprises will always be limited by their lack of common sense. Trying to unpick the exact nature of this common sense is one of the goals of Artificial Intelligence in Education.

The central problems viewed from an AI perspective shift slightly depending on whether one's main focus of interest in education is the teacher side of the role, the student side or the educational interaction itself and the cognitive tools that support this. Much of the work in Artificial Intelligence in Education has concentrated on the teacher and assumed that it is the underlying goals of the teacher which shape the overall direction of the interaction with the pupil. Even where the preference is that students take more responsibility for their own learning, for example, through the use of learning environments or project work, it is still normally the teacher that sets the broad parameters within which this student-centred learning takes place.

Among the plethora of issues facing teachers and designers of educational tools and environments are the following two questions:-

- How to engage and motivate students so that they are willing to attempt to learn.

- How to ensure that what is learned during the educational interaction can be applied effectively outside that context.

A human or machine tutor that attempts a more student-centred educational strategy will in addition have to address such issues as:-

- How to detect what the goals of the student are (if any) and whether they are consonant with the teaching goals of the teacher (if any). This is a problem which can be especially hard when the student is unable to state his or her own goals clearly. In this case the issue may turn into that of how to help the student formulate learning goals.

- How to make available to the student, both gracefully and effectively, the resources of the teacher, the educational environment in general (including other students) and of the student himself (or herself) to assist in the achievement of goals.

In concentrating on the interaction issues, the teacher needs to solve such problems as:-

- How to maintain focus and coherence in the interaction despite interruptions, asides, misunderstandings, embedded conversations, the long passage of time and so on.

- How to play the conversational role of the teacher intelligently e.g. (a) how to make one's intentions to the learner clear, how to formulate explanations succinctly (given one's beliefs about the student's beliefs), or how to provoke the situation with an appropriate open-ended or highly specific question, when to repeat oneself and with what emphasis, (b) how to tease out from the student explanations, views, beliefs when these are partially or poorly expressed.

- How to argue and convince

Finally, if one's interest is in the design of cognitive tools and educationally rich environments, the interesting problems include:-

- What makes an environment educationally rich: is it the sparseness and versatility of (say) empty cardboard boxes? or the richness and specificity of (say) LOGO? or some other factors altogether?

- How does one choose what assistance might be helpful and how does one offer that assistance in such a way so as not to undermine student's sense of control of the interaction?

Few of the above questions can be asked in a vacuum. Typically teacher and student encounter each other in an educational and cultural setting that provides institutional goals, constraints and resources within which each is to operate. All these resources carry with them affordances built upon time and

specific to a particular culture. The educational context includes other teachers (possibly other machine tutors) and other students who may in their turn frustrate or enhance the education of an individual.

Artificial Intelligence in Education is a broad discipline encompassing cognitive science, educational psychology, computer science and artificial intelligence to name but four. It includes those who wish to develop theories of human learning and their application in effective learning environments as well as those interested in theories of teaching and their application in effective teaching systems. Clearly in many cases there is overlap between these two kinds of theories as well as a fuzzy boundary between learning environments and teaching systems.

In many ways Artificial Intelligence in Education is in a state of flux. People sometimes talk of one of its subfields, Intelligent Tutoring Systems, as an outmoded technology that has, in some sense, "failed" (see e.g., de Oliveira & Viccari, 1996). The emphasis today has shifted to exploring the possibilities of newer technologies such as virtual reality, the internet and is particularly concerned with learning environments and collaboration. However most of the traditional hard problems still remain — adjusting the environment to meet the needs of the learner(s), determining what to say to learners and when to say it and so on (i.e. student modelling).

One aspect of the issue of teaching *vs* learning crystalised into the issue of whether the educational system should attempt to model the student or not (Lajoie & Derry, 1993). Modelling the student allows, at least in principle, the system to adjust its behaviour or to react to that student as an individual, or at least as a representative of a class of individuals (see e.g., Shute, 1995). The argument for not modelling the student arises because it is hard, indeed some regard it as inherently impossible, or because it is thought unnecessary. The argument goes that if a learning environment is well-designed and operated by the student within a supportive educational environment, we can rely on the students themselves to manage their own learning without having the system individualise its reactions in any way.

In some ways the heat has gone out of the debate between the modellers and the non-modellers. Although both camps have coexisted throughout the history of Artificial Intelligence in Education, there is a stronger realisation that both approaches have something useful to offer. Indeed both approaches are now sometimes to be found inside a single system, where an ITS of a traditional architecture may be but a single component of a more general, possibly distributed, system offering the learner a variety of different kinds of learning experience from which they can choose (see e.g., Mitchell, Liddle, Brown, & Leitch, 1996).

To try to get a sense of where the field is now, this paper reviews current issues in Artificial Intelligence in Education drawing strongly, but not exclusively, on the the fifty-nine papers included in the Euroaied Conference held in Lisbon in September 1996. This was a gathering of researchers, drawn predominantly from Europe, attempting some reflection on the field of Artificial Intelligence in Education. The conference had an unusual structure. Prospective participants were invited to submit papers against a predefined list of questions. After refer-

eeing there was some recasting of the questions and the papers were organised into sessions, each dealing with one set of questions (Brna, Paiva, & Self, 1996).

This review does not follow the session structure of the conference nor does it give equal weight to the papers. It represents a very personal view of what I thought was interesting, so some major pieces of work are only mentioned in passing and sometimes a minor detail of a paper is given more attention than perhaps its author(s) might expect or wish. It represents my attempt to understand the kinds of issue on which the field of Artificial Intelligence in Education is now concentrating, at least in Europe.

LEARNING AS A PROCESS

The main shift of focus of Artificial Intelligence in Education has been from learning considered simply as epistemology to learning as a psychological process operating under a number of constraints. For example, there is the complex interaction between the domain presentation offered to the learner and the consequent nature of the learner's own internal representation of that domain (see e.g., Scaife & Rogers, 1996). In this area computers as cognitive tools offer many possibilities for re-representing a domain. Further, there is the interaction between the learner's experience of "doing learning" and the consequent degree of reflective awareness of what they had learned (Ainsworth, Wood, & Bibby, 1996; Barnard & Sandberg, 1996; Whitelock & Scanlon, 1996). Again, computers as cognitive tools open up new possibilities as devices to record students' actions for their later analysis.

This chapter develops this notion of learning as a process by considering five of its aspects. The first is "affect": the fact that the learner's motivation (or lack of it) is a crucial factor in the learning process. The second is "dialogue" — now of central interest in Artificial Intelligence in Education through its focus on collaboration. Third is "knowledge organization" and this splits into issues to do with "context" and issues to do with "fragmentation". It is not just that learning always takes place in some external context that can affect the general outcome of what is learned, but that at least some of our learning (and therefore our recall) is episodic, i.e. highly context-specific. Moreover our concepts in a particular domain are often unevenly developed and we are able to tolerate gaps, discrepancies and contradictions in what we know. Fourth is "representation", both external and internal, as mentioned above. Finally there is the issue of learning "style" and the way that teaching might be adapted to accommodate (or not) the learner's preferences for particular kinds of perspectives, learning methods, approaches and organizations of material.

Affect

The shift of emphasis from the 'what' to the 'how' of learning reflects an undermining of the idealization of the learner as some disembodied, entirely rational learning mechanism. A similar shift is evidenced by the willingness to acknowledge the affective dimension.

Students' motivation in learning is crucial and some progress has been made in delineating its dimensions and in describing how teaching can take account of

the motivational state of the student (see e.g., Keller, 1983; Malone & Lepper, 1987; Lepper, 1988; Lepper & Chabay, 1988).

One of the few system to incorporate motivational modeling and planning into its teaching is del Soldato's MORE system (del Soldato, 1994; del Soldato & du Boulay, 1995). This system used the amount of student effort and the student's self-reported comments about her own motivation to adjust the difficulty of problems and the kind of help it offered.

Issroff and del Soldato (1996) provide an analysis of the main dimensions of intrinsic motivation, culled from the educational psychology and cognitive science literature. These dimensions include Curiosity, Challenge, Confidence and Control and have been incorporated into MORE by del Soldato (1994) which makes decisions about how to adjust the nature of learning tasks based on an explicit motivational theory. The work presented in Lisbon goes beyond the issue of how to make motivationally well-informed teaching decisions for a single learner by considering the issue of how best to motivate groups. This latter is concerned both with how to promote collaboration within a group as well as how to promote competition between groups.

A very formal approach is adopted by Errico (1996) who uses the Situation Calculus as the basis of a general purpose student modelling system that includes primitives for reasoning about what an agent (e.g. the student) *wants* to know or is indifferent about knowing. Of course, this is a long way from the kind of experiments by Whitelock and Scanlon (1996), described later, which are a good example of the difficulties of constructing too easy an equation between what one might regard as motivating or demotivating and learning outcomes. Part of the current view of learning is the notion of sharing and the qualitatively different experience we have of undertaking a task purely privately as opposed to collaboratively. In addition, the exact nature of the collaboration can have dramatic effects. As yet progress in this area is slow, but motivation is now clearly on the agenda.

The notion of provoking and maintaining effective goal-directed behaviour is a crucial issue and one which potentially unites the modellers and the non-modellers in a common cause. Here the arguments are not so much whether or not one needs a tutor (either human or machine) to be associated with the simulation, but rather on how best to integrate tutorial capabilities in the simulation itself. While taking a weaker line on the need for integrating a tutor into a simulation based environment, Moebus (1996) is concerned with the design principles of such systems which would most effectively allow hypothesis generation and hypothesis checking by users.

A specific acknowledgement of the affective dimension in terms of systems development is to be found in the work of van Joolingen and de Jong (1996). They present an authoring system to assist trainers in the design of learners' activities in simulation-based discovery environments. In some ways they provide a system that contains the means-ends rules of a classical ITS architecture from which the trainer can select according to the expected training situation. Some of the attributes built into the system include such affective dimensions as "fear of failure" and "degree of motivation" whose values will have a profound effect on the success of different kinds of interaction with the system.

Their concern is to stimulate goal-directed (rather than aimless) behaviour on the part of the learners. In a similar vein, Forte and Forte (1996) specifically mention the dimension of "challenge" where the idea is not simply to provoke goal-directed behaviour but to stimulate the learner's desire to learn through a challenging issue or problem to solve with the simulation system.

A similar concern with motivational issues is shown by Vassileva and Wasson (1996). Their versatile reactive, dynamic planning system can (in principle) assess both its planned sequences and its reactions to the student based on assessments of the motivational consequences of such reactions (an issue also explored by Issroff & del Soldato, 1996, above).

Lewin's (1996) work on developing an automated tutor for reading is concerned with both trying to detect the child's motivational state and its aptitude and predisposition to use different strategies. The management of different problem-solving methods by the learner is a central issue for Lewin in her work on children learning to read, where they may use a wide variety of strategies — whole word, phonic, initial letter, context and so on. Feedback is also a special issue for her in that it is important to stimulate the child's interest and maintain her self-confidence, while still leaving space for her to learn from her mistakes in a productive manner.

Dialogue and Insight

This section brings together papers on two kinds of dialogue: the internal dialogue within a single learner reflecting about learning and the external dialogue between separate individuals. Of course the two are related (see for example, Vygotsky, 1986; Pask & Scott, 1975). Born and Lusti (1996) describe a blackboard architecture for tutoring systems based on a number of communicating knowledge sources. The system is designed to use the internal communication between the knowledge sources as a basis for constructing an external explanation to the learner.

Internal — Reflection

Self-explanation as described by Chi, Bassok, Lewis, Reimann, and Glaser (1989) is apparently a rather useful form of reflective or metacognitive behaviour. It is an activity that good problem-solvers are said to engage in and it seems to provide a way for the learner to more completely and more effectively establish what is being learned via what s/he already knows and to more fully explore the ramifications of the new material.

So if some researchers are concerned, at some level, with ensuring that learners are properly engaged with the material, others are concerned with ensuring that the maximum gains are made by the learner as a result of that engagement. The paper by Barnard and Sandberg (1996) nicely illustrates the difficulty in practice of systematically provoking self-explanation as a reflective behaviour in learners.

Barnard and Sandberg built a learning environment for the domain of tides to help students understand why, where and how tides occur in relation to the

movement of the earth, moon and sun. Despite encouraging their students to engage in self-explanation so as to reveal areas of the tidal process which they did not understand, students were loathe to do this and in general they had little insight into how partial their knowledge of these deceptively simple processes actually was.

The students were interested in learning the domain and they knew how to ask themselves questions, but they did seem to demonstrate a genuine willingness to accept fragmented and non-systematic understanding as their norm. This emphasises the fact that learning is hard work and self-explanation may only be worth the extra effort if the learner has some reason to believe that they will actually need the enhanced understanding for some future task. However it leaves open the question as to whether the students knew that that they had gaps and contradictions in their knowledge, and did not care, or whether they did not appreciate that the gaps were there. Perhaps self-explanation is as much about motivation as it is about reasoning.

Barnard and Sandberg suggest that it is not simply a matter of showing learners how to do it. Their learners, although "engaged" in the task of learning about tides, showed great propensity to learn the material in a fragmented and non-systematised way. It is clear that doing self-explanation consistently is harder work than learning piecemeal and that the issue of motivation and the reason the student is trying to learn the material at all will be of crucial importance (see e.g., Laurillard, 1979).

Others working on self-explanation start from the premise that self-explanation is hard to achieve and offer technological solutions to generating the domain-specific 'self-explanative questions' to the user in the hope that at least the learners will be exposed to these questions (at least for that domain) even if they do not learn how to undertake self-explanation as a general skill. It remains an open question as to what is the relation between offering students ready-made questions that they might ask themselves about the domain and prompting the students to generate questions for themselves about that domain. For instance, does a system that offers opportunities for reflection on past learning undermine the very skill it is attempting to foster by reducing the metacognitive agency of the learner. Barnard and Sandberg (1996) suggest that tool builders have have to be open to this undesirable possibility.

Fung and Adam (1996) show how, in principle, self-explanation questions can be generated from a domain representation based on Sowa's (1984) conceptual graphs, and Kashihara, Okabe, Hirashima, and Jun'ichi (1996) offer a system that engages the user in a constrained form of concept mapping based around self-explanation.

To some extent aspects of machine learning deal with a similar reflective process, in the sense that they are concerned with what kinds of more general hypotheses can be deduced by a student modelling system from the lower level data about the student; for instance, inducing the nature of a general misconception about Prolog from instances of individual bugs (Sison & Shimura, 1996). A lesson for ITS and ILE design that seems to emerge from this is the importance for students to self-explain both correct examples and answers (as per Chi et al., 1989) but also incorrect answers; i.e. human students need to

undertake the kind of self-modelling activities that would be undertaken by the student modelling component of an Artificial Intelligence in Education system.

The educational utility of less than perfect answers is also indicated in the work of Faro and Giodano (1996). They describe a system for teaching about Information Systems Design, one element of which is a case-based reasoning component which stores both teacher-annotated and unannotated student designs. They argue that critiquing a poor design by another student is an excellent way to learn.

The paper by Pain, Bull, and Brna (1996) is also concerned with reflection but in the more narrow sense of re-assessment of a view. It uses a version of a student model as a "conversation piece" between teacher and student — the one to defend the model as an accurate depiction of the knowledge of the student, the other (i.e. the student) to either agree or, more often, to disagree and offer refinements. In addition to perhaps producing a more accurate assessment, it also provides a way of provoking the student to think about exactly how much they have and have not learned. One could imagine such a scenario augmented with the specific self-explanatory schemas suggested earlier by Fung and Adam (1996) and by Kashihara et al. (1996).

A rather different stance is offered by Swaak and de Jong (1996) who argue for the value of "intuitive" knowledge and the utility of simulations to promote this. Intuitive knowledge is knowledge that is not verbalizable, and thus is not open so easily to a reflective internal dialogue. In some ways their argument is similar to that of Sime (1996) whose experiment suggests that learners benefited from being exposed to a qualitative before a quantitative perspective on a domain.

External — Collaboration

One of the most important factors in the recent development of Artificial Intelligence in Education has been the increasing interest in collaboration, normally between learners but also between teacher and learner. Email, computer conferencing and the World Wide Web turn computers into cognitive tools that enable collaboration that bridges space and time constraints and which would have been impossible before.

The collaborative possibilities opened up by simple audio links is explored by Whitelock and Scanlon (1996). They studied collaborative learning by pairs of adults in the domain of physics problem-solving. Much of the communication within each pair was concerned with the difficult task of establishing a "Joint Problem Space" (Teasley & Roschelle, 1993). Whitelock and Scanlon (1996) adjusted the gender mix of the pairs and the mode of interaction. In one mode pairs worked side by side and in the other members of the pair were in separate locations with an audio-link. The authors were interested in such issues as the subjects' degrees of curiosity, interest, tiredness, boredom, expectation, challenge, partnership, control and attentiveness.

The intriguing result from the work is that the pairs linked by audio showed greater learning gains than those who had worked side by side. Moreover these greater learning gains were achieved despite pairs in this condition reporting

greater tiredness and greater feelings of not being on the same wavelength as their partner and (not surprisingly) reporting difficulties of shared reference. On the positive side pairs linked by audio liked the resulting possibilities for a certain degree of autonomy in their work.

One possible explanation of the greater learning gains despite the narrower channel of communication lies precisely in that narrower channel. In order to solve shared reference problems and synchronise their problem-solving (when they so wished) the participants would have had to engage in much more careful analysis of their mutual understanding. Those sitting side by side were perhaps lulled into a false sense of being on the same wavelength that did not require the same conscious attempts to maintain the mutual understanding that was needed to make the audio-only link work. In a way impoverishing the communication link forced mutual and self-explanation to the fore.

For de Oliveira and Viccari (1996) collaboration acts both as a design metaphor for intelligent learning systems and as an architectural principle. The metaphoric aspect is important to them because it signals a shift away from the one-to-one, over-controlled, and knowledge-focussed ITSs of the eighties. This mixed interest in the metaphoric and the practical is also in evidence in the work of Cerri (1996) and Paiva (1996), though these two offer fairly explicit architectural details: in Paiva's case as an attempt to make the learner modelling aspect of system design application independent.

Plotzner, Hoppe, Fehse, Nolte, and Tewissen (1996) explore the subtle interactions between representation and learning. Like Sime (1996) they are interested in qualitative and quantitative perspectives in science and like Ainsworth et al. (1996) they are interested in multiple representations. The extra factor for them, however, is the way that having students build concept maps supports learning and reflection when undertaken collaboratively. While the end product of building a concept map might look like a small hypermedia system, it is clear that pedagogically *building* a concept map is a wholly different task from exploring a ready made map (see e.g., De Vries, 1996). In an empirical study with two phases, students initially learned a topic in mechanics either in qualitative or in quantitative terms. Pairs of subjects were then formed (one qualitatively trained, the other quantitatively trained) and the pairs had to cooperate on tasks that required coordinating their separate qualitative and quantitative knowledge. All subjects increased their scores following the first phase, and all subjects learned to relate the qualitative and quantitative in the second phase. However, students who had initially learned the material qualitatively gained significantly more from the second, collaborative phase than those who had originally been exposed to the same material quantitatively. This result strongly echoes that of Sime (1996).

Plotzner et al. (1996) have developed an environment that enables students both to work on their own at building concept maps *and* work cooperatively to combine such maps, e.g. by adding annotations or by encapsulating parts of the map in higher level concepts. The tool and the educational methodology reifies the activity of reflection through the collaborative phase. While this tool is simply a device to build concept maps, they are developing a new version that contains a declarative hypertext model of the domain which will additionally

enable students to undertake explorations in the style of De Vries (1996).

Another collaborative theme is that of teacher as "master of ceremonies", taking part in collaborations directly or stage-managing collaborations between learners. Leroux, Vivet, and Brezillon (1996) describe a multi-layered model of cooperation (a weak form of collaboration) in which pedagogical assistants work with a small group students on a micro-robot programming task and these groups themselves interact in a reflective phase. The use of intermediaries between the teacher and the learners is also explored by Hietala and Niemirepo (1996). They describe an experiment in which students learning equation-solving could enlist the help of companions (distinct from the teacher) with differing degrees of expertise. Like Barnard and Sandberg (1996) they are interested in the issue of whether roles routinely played by human participants in an educational setting can be undertaken by the machine without violating the students' expectations of what are reasonable roles for a machine.

The question of exactly how self-questioning, self-explanation and reflective learning can be assisted by dialogue is being explored by several researchers. Cook (1996) offers an analysis of educational dialogues and a dialogue mark up scheme. This can be used to annotate naturally occurring dialogues as a step towards implementing either computer tutors, computer peers or indeed dialogue referees (see e.g., Inaba & Okamoto, 1997) who could intervene in peer group discussions. His analysis is focused on the kinds and patterns of dialogue moves which promote reflection, monitoring, reasoning and motivation.

A similar approach is taken by Pilkington and Mallen (1996) but their focus is particularly on the issue of exactly how dialogues promote learning and on the roles played by different participants in a dialogue. Given the general interest in peer group learning, whether with human or machine peers, Pilkington and Mallen are looking at the issue of whether more learning takes place when the one member of the interactive pair takes specific responsibility for provoking reflection, i.e. acts as a teacher as opposed to simply a co-learner. As with Cook (1996) the analysis is seen as an initial empirical/theoretical step towards the design of effective tutors able to be interactive through dialogue. Burton and Brna (1996) are interested in building a system to take part in collaborative dialogues. As a step towards that goal they have developed a theoretical model based on Dialogue Games that attempts to allocate a dialogic role for each utterance. Their approach is an interesting contrast to that of Pilkington and Mallen (1996) who are also interested in Dialogue Games and are working at the same fine-grained level but, empirically, starting from from naturally occurring dialogues.

A similar interest in the roles played by different participants in collaboration is explored by Issroff and del Soldato (1996). Here they are concerned, *inter alia*, about the nature of the kinds of pairings on learning outcomes and on the distribution of control of learning and the control of the tool (e.g. keyboard) in paired problem solving tasks. They point out that the way a pair works together is not just a matter of the individual capabilities of the pair but is also dependent on the social and educational context within which they are operating and the degree to which that context supports or undermines collaboration.

In addition to being interested in the fine detail of collaboration, two groups are developing interfaces to support and *shape* collaboration. In many ways the work of Baker and Lund (1996) is similar to that of Plotzner et al. (1996), described above, in that they provide an interface for students to co-construct graphical concept maps in physics. One difference is that those aspects of the interface concerned with communication between partners are given greater prominence. Baker and Lund compare two different communication interfaces. One, "Chat-box", enables relatively unconstrained dialogues to occur. The other contains specific buttons to introduce different kinds of domain level sentences associated with concept map building, such as "what is its name?" ("it" being a chain in the concept map), as well as specific buttons to enable the participants to manage the dialogue itself, such as "What should we do now?". In their experiment, both interfaces produced about the same ratio of dialogue to domain level activity in concept mapping, but the dedicated interface seemed to provoke more in the way of task-specific communication than Chat-box. Dillenbourg, Traum, and Schneider (1996) also experimented with a multi-modal interface (via a shared graphical whiteboard, a textual MOO environment and an audio link), though the task was to solve a murder mystery rather than map out a sub-domain of physics. Wide variations were found in the way that pairs of subjects performed the task, in particular in the way that subjects established a common understanding of some part of the problem — recall how hard this was for Whitelock and Scanlon's (1996) audio-linked adults solving a physics problem. In particular, the experimenters found that the same subjects would use a variety of different methods to establish common understanding at different points in the process and that these methods would make differential use of the available modalities.

Knowledge Organization

There are many studies which show that with increasing experience of a domain, intermediates and then experts structure their knowledge of that domain differently than novices (see e.g., Chi, Glaser, & Farr, 1988). It's not just that experts know more, they also know differently (see e.g., Schmidt & Boshuizen, 1993, for an example drawn from medicine). Even over the shorter term how someone comes to (partially) understand a topic is very dependent on the idiosyncratic features of the learning experience in which they have engaged. Factors that affect knowledge organisation include the overall context within which the learning takes place, what learners already know and what kinds of activity they engage in as a learning experience. An outcome of this is that acquired knowledge can be patchily understood, and can contain gaps and contradictions, i.e. it can be fragmented.

Context

The episodic nature of learning is addressed by Specht and Weber (1996). They echo the distinction between content planning and delivery planning articulated by Wasson (1996). Specht and Weber are concerned with adaptivity

in delivery, in particular in providing prompts, reminders and explanations that refer to problems of a similar kind that the student has met before. So they envisage an interaction between a student and a learning system that will endure over many sessions and allow for references to sessions from much earlier. One can see this as a means to promote reflection in problem solving as their system is specifically aimed to sensitize the student to similarities and differences between the current problem and previous ones of a similar type.

Context-specificity of a non-episodic kind is described by MacLaren and Koedinger (1996). They explore the phenomenon that students are more reliably able to solve algebra problems when they are embedded in a story problem than when they are presented as a word equation and even better than when they are presented simply as a symbolic equation. In some ways this seems counter-intuitive since solving the symbolic equation would appear to be a subtask of solving a story problem. In their modelling work they are interested in characterising zones of proximal development for their domain in a way similar to Luckin's (1996) attempt to define them in the area of simple ecology. Their work supports the notion of cumulativeness offered by Akhras and Self (1996, and also this volume) in that it was the very "cumulativeness" of the story problem in the student's existing rich experience of the context of the problem that enables the superior problem solving.

Both the problem-solving context-specific nature of learning and the way that people will often attempt to avoid learning if at all possible is addressed by Oppermann and Thomas (1996). They describe how in the workplace people often prefer to go and ask a knowledgeable colleague rather than use the manual. They also describe how casual users of a system often have to re-create the same solution to the same problem each time they meet it because little effective learning took place at the time the problem was first solved. They offer a technology, "demotheque", for an individual or a group to build up a personal or group specific set of annotations, possibly multimedia annotation, on how to solve specific problems in a computing environment. The educational value of glossaries, and a technology to assist in the construction of glossaries, is presented by Colazzo and Costantino (1996) as a related technological fix to a "context" problem. They are concerned especially to ensure that the educational context of the learner (assumed to be reading a hypertext page) is disrupted as little as possible by the method of calling up and displaying a glossary definition.

Activity

The issue of how new knowledge and skill are constructed (as opposed to the content of that knowledge and skill) is what was most centrally addressed in the work of Akhras and Self (1996). Their concern is with the activities in which the learner should engage in order that they can effectively construct their own new knowledge. As this work is explored in much more detail elsewhere in this book, the following is only a brief pointer. Instruction in their scheme is not primarily concerned with sequencing exposure to pre-defined objective knowledge, but with sequencing activities or situations in which the learner can

operate. They are concerned to define a topology of situations and patterns of interaction. In particular they refer to two properties of learning processes, namely "cumulativeness" (using prior knowledge) and "constructiveness" (elaborating prior knowledge) — these seem not dissimilar to the Piagetian terms of assimilation and accommodation. A challenging issue here is the extent to which it is possible to provide a theory of action in Artificial Intelligence in Education terms that is more than a theory of the knowledge that the action touches upon.

Akhras and Self argue that a commitment to a constructivist position on learning does not make the notion of instruction self-contradictory. Rather that instructional planning in such a rationale is no longer driven directly by the structural properties of the expert's view of the knowledge. It is now driven by a concern to sequence the interactive activities of the learner in an effective manner such that the learner can come to construct a personal understanding that has some structural resemblance to that of the expert. Even if we allow for the infinite variety of how each one of us knows some topic, there have to be some commonalities between different ways of knowing otherwise it is not clear how any kind of communication is possible.

The importance and value of planning, and its neutrality as an activity with respect to to one's learning theory, is stressed in the papers by Vassileva and Wasson (1996) and by Wasson (1996) herself. Wasson offers a constructivist continuum from "radical" through "mild" to instructivists. "Mild constructivistism" seems to be the dominant view in these papers and this view retains a place for instruction and thus for instructional planning. As a side issue, I find it sad that ITSs have come to be associated by some researchers with a non-constructivist approach, as if a constructivist never wrote a paper or delivered a lecture. For powerful counterarguments to this (see e.g., Mayer, 1997; Derry & Lajoie, 1993).

A similar concern with action (or the 'how' rather than the 'what') is shown in Luckin's (1996) work which applies a Vygotskian perspective to instruction. One focus of her work is to provide an operational definition of Vygotsky's notion of the Zone of Proximal Development. As with Akhras and Self (1996), the idea is to reason about the sequence and character of the activities of the learner. In Luckin's case the issue is to find the balancing point between what a child can do unaided and what he or she can do with expert machine teacher assistance. Luckin (1998) compared three variants of a system to teach simple ecology and found significant process and outcome differences among the subjects depending on the way the system variant played the role of the more able partner.

Fragmentation

The issue of the fragmented nature of learning is an ongoing issue. For instance, it figures centrally in the work of Barnard and Sandberg (1996) described earlier. It also arises in the work of Karlgren and Ramberg (1996) who stress two issues. First the fragmentary nature of our own and our students' knowledge and its high context specificity (see earlier), and also the importance

of language and the use of language in coming to understand a new domain: an issue that links us via Vygotsky to Luckin (1996). To involve language is to involve the social dimension and then to open up the issue of the role that the social context plays in what we know and *how* we know it. They stress the notion of language games and see instruction as a process of learning how to reason and how to use the language of the new activity.

The unevenness of learning progress, or fragmentation over time, is explored by Giangrandi and Tasso (1996) who offer a logical foundation for modelling the evolving beliefs of the student and the evolving beliefs of the tutor about the student's belief. Their scheme allows for the essentially non-monotonic nature of both these processes — they have a nice example of a Socratic Dialogue produced as a sequence of formulae in their calculus. The passage of time during learning is also an issue raised by Issroff and del Soldato (1996) who are concerned with the way that affective issues have some kind of time profile that needs to be taken into account. This is reminiscent of the work of Specht and Weber (1996) who describe a mechanism for reminding the student of the context of earlier problem solving episodes (see earlier).

While some domains are, in principle, "neat" and yet lead to fragmented and contradictory learning, others are inherently "scruffy". Two papers consider the issue of ill-structured (scruffy) domains from rather different perspectives. De Vries (1996) explores the issue of the nature of the links in a hypermedia system, and is described later. A more student-centered approach is adopted by Schroeder, Moebus, and Thole (1996) who describe a system for medical diagnosis to build diagnostic models of complex medical domains. In some ways the idea is for the student doctors to impose some neatness and structure on what otherwise would be a fragmented set of individual items of knowledge. Here the links built by the student doctors are links in a (hidden) bayesian network rather than a hypermedia network, but one could imagine the two technologies coming together to provide an interesting simulation environment.

Presentation and Representation

An ongoing issue in mathematics, science and engineering education is finding the right balance between developing students' qualitative reasoning and understanding about some phenomenon as well as extending their ability to deal with the same issues in quantitative terms. This is an instance of the provision and exploration of multiple models of a particular domain, (see e.g., White & Frederikson, 1987, for an elaboration of this issue for tuition in electricity). For example, students with well-developed intuitions about the qualitative aspects of a process (say) can conduct an internal conversation in the style described by Chi et al. (1989) about whether the answer to a quantitative problem that they have solved "makes sense". A similar issue occurs in early arithmetic education where some children are willing to offer clearly nonsensical answers to sums they have worked symbolically or on calculators because the semantics of the calculation are not (able to be) considered.

Sime (1996) describes the results of an experiment in engineering where there was an attempt specifically to get novice and non-novice students to view

and experiment with the same topic from each of three different perspectives. The students approached each of these perspectives in both a quantitative and a qualitative manner, i.e. 3 x 2 views: the belief being that expertise is associated with versatility of approach. An issue that immediately arises is the order in which the different perspectives should be sequenced in learning.

The system in question was a Model Switching Process Rig Demonstration, a dynamic physical system. The system could be studied through a model of the heat transfer process, a model of the gas flow process and through a combined model. Sime was attempting to find evidence in support of an hypothesis derived from Cognitive Flexibility Theory (Spiro, Coulson, Fletovich, & Anderson, 1988) which predicted that the highest learning gains would be achieved if the sequence through the perspectives obeyed the constraint that perspective *n* should differ from perspective *n-1* by only a single dimension in the 3 x 2 space. That is, a student could move in one "jump" from qualitative heat flow to qualitative gas flow, or from the quantitative combined model to its corresponding qualitative view, but not from qualitative gas flow to quantitative heat flow.

Contrary to her expectations, Sime found that the greatest learning gains arose for those students who were exposed in general to qualitative before quantitative models. This produced slightly better learning gains than the more selective method that traversed the 3 x 2 matrix by changing only a single dimension at a time. One possibility is to see the result as an indication of the need for the students to grasp the subject in its entirety in qualitative terms before attempting to deal with some particular aspect via quantitative methods. Another explanation might be that the shift in perspective between qualitative and quantitative is cognitively more costly than that between different aspects of the domain (e.g., heat flow and gas flow) in which case making the shift once only would be beneficial.

Sime has a further interesting negative result in that the *novice* group who were exposed to quantitative before qualitative perspectives had lower post-test than pre-test scores and so seemed to have gained little from the interaction. Sime points out that in many engineering curricula the quantitative tends to precede the qualitative, and that therefore they may be organised non-optimally for the novices they are educating.

Ainsworth et al. (1996) are interested in the issue of developing children's ability to undertake numerical estimation of sums that they were unlikely to be able to compute exactly in their heads, e.g. 84 x 44. They are also interested in the development of children's ability in "prediction" by which they mean the ability to judge the accuracy of an estimation: is it an overestimate or an underestimate? is it likely to be wide of the mark or close to the accurate answer?

They conducted an experiment to examine the effect of multiple representations in the interface of a computer-based tool on children's ability to estimate, where the representations provided varying means of displaying the accuracy of the estimate. The system offered tools to help undertake the estimation where the degree of assistance could be faded with increasing expertise, as well as a means for the children to record results. Children were encouraged as part of the interaction to reflect on the relative accuracy of different kinds of estimation

methods.

For example, a child working on the problem of estimating 387 x 123 might be helped to go through the following steps:

1. Produce the intermediate solution:
   — round to 400 x 100
2. Predict the accuracy of the estimate based on the intermediate solution:
   — not very close to the exact answer
   — lower than the exact answer
3. Produce the estimate:
   — 4000
4. Compare how well the answer matched the prediction.

From Ainsworth et al. (1996); page 338.

Each child's predictions and comparisons were displayed via a pair of representations, one showing the magnitude of the deviation of the prediction from the true answer categorically, and the other showing both the magnitude and direction of the deviation as a continuous value. The children were intended to learn how to estimate better, and learn how to predict the accuracy of their estimates, by observing the size and nature of the deviation of their estimate from the true answer via the given representations.

Each of these representations was offered either in "mathematical" form, i.e. a histogram and a numeric display, or in "pictorial" form, i.e. an archery target and a "splat wall". Children in the experiment worked either with two mathematical representations, or with two pictorial representations or with mixed representations consisting of one mathematical (numeric display) and one pictorial (archery target).

Ainsworth and her colleagues looked at two measures. One was the change in the children's ability to make accurate estimations, i.e. how near to the true answer was their estimate. The other measure concerned the children's insight into the quality of their estimate, i.e. their prediction about the accuracy of the estimate.

So, for example, we can imagine a situation where the child estimates that 84 x 44 is equal to roughly 3200 on the grounds that the product is close to 80 x 40. Now this is not a bad estimate but the child may believe incorrectly that it is a very accurate estimate. So she would score fairly well on estimation but not so well on prediction.

All the children in the experimental groups learned to estimate better over the period of the experiment compared to a control group. However when it came to predictive accuracy, children who had worked either with two mathematical representations or with two pictorial representations improved, whereas children who had worked with mixed representations did not.

One possibility is to regard the two tasks, estimation and prediction, as relatively independent and assume that the extra work involved in dealing with

mixed representations reduced learning performance in the prediction task. Certainly the result underlines the issue of the sensitivity of problem-solving performance to changes in representation, e.g. as already indicated in the section on Sime's (1996) work above.

Another possibility is to see this as an intriguing finding, indicating a situation in which a skill, estimation, had been improved but insight, prediction, of the learner into that skill had not improved in tandem. If this were the case one would need to investigate why the mixed representations were poorer specifically at supporting reflection compared to the coordinated representations — an issue that reminds us of Barnard and Sandberg's (1996) students' problems with self-explanation.

The work of Ainsworth et al. (1996), Sime (1996) and De Vries (1996) illustrates how sensitive learning is to choices of representation. In these cases the alternative representations were offering different perspectives on the subject matter, but were offering these perspectives at essentially the same level of granularity. The issue of combining representations is also tackled, for Modal Logic by Oliver and O'Shea (1996) and for Prolog by Good and Brna (1996). In the latter case, the authors explore the possibility that a particular kind of representation may only be needed as a transitional device to help students at a particular stage in their learning and thereafter that it can be largely dispensed with as too cumbersome to reason with.

It is often the case that during problem-solving or design one needs to tackle a problem at very different levels of generality at different stages of the process. An intelligent system to teach such a process would therefore itself need to be able to represent and discuss the evolving solution or design at whatever was the most appropriate granularity for that stage. This kind of multi-level approach is adopted by Mayorga and Verdejo (1996) in their analysis of the design cycle involved in authoring systems. A similar acceptance of the need to work at different levels of granularity at different stages is taken by Pemberton, Shurville, and Sharples (1996) in their analysis of the tools needed to support the process of writing.

With the rise and rise of the World Wide Web and the improvement in quality of Virtual Reality (VR) technology, the educational aspects of the representations that they afford are of considerable interest.

World Wide Web

Work in Artificial Intelligence in Education has been influenced by the increasing use of hypermedia and of course the World Wide Web (see e.g., Brusilovsky, Ritter, & Schwarz, 1997). One of the areas of interest is the degree to which a system can intelligently adjust the links available to the learner in a given hypermedia system. An ongoing issue both within and outwith Artificial Intelligence in Education concerns navigation — providing an effective means of constraining useful paths to follow, determining one's current position in the network or revisiting past pages of interest.

De Vries (1996) explores the issue of the nature of the links in a hypermedia system. Her experiments compared two hypermedia systems with link types

defined in different ways where the actual nodes of information so linked were identical. She was thus interested in the *structure* of these systems. She produced two systems. In each case the nodes consisted of descriptions of concrete objects or events in the domain of energy and energy transfer (e.g. a turbine) in physics. In one system ("the network structure") the links were based on an energy-theoretic conceptual analysis of the domain, e.g. in terms of energy transformers, reservoirs and transfer. In the other system ("the index system") the overall structure was provided via an index node that gave the titles of all the available nodes, and via which all inter-node movement had to pass. Although the energy-theoretic terms were mentioned in the node titles they did not of themselves form the basis of the linkage as in the "network structure" version. So the comparison was between a multiply-connected (though not a hierarchic) network whose very structure was determined by energy concepts and a network with a rather looser, radial structure centred on an index node.

In one of her experiments students were invited to explore both hypermedia systems in order to select three nodes according to a given criterion, and then later solve an energy problem. As the hypermedia system was implemented in Hypercard, the nodes were referred to as "cards". The card (node) selection task existed in two forms. The first was "conceptual" and invited students to select three cards according to a criterion related to the basic concepts of the domain, e.g. "Select three cards that display objects producing heat". By contrast a "superficial" task of the same surface form invited subjects to select cards according to some incidental common feature, e.g. whether the card featured something using water.

De Vries was interested in the degree of exploration of the 54 cards of each network and in the outcomes of the card-selection and problem-solving tasks. She found that many more cards were visited by subjects using the network structure version of the hypermedia system compared to the index version (whether one agrees with De Vries that this is a good outcome is, of course, open to question). This differential exploration was true for both the superficial and the conceptual card selection tasks. In nearly all cases the selection tasks were completed correctly. Contrary to her expectation, performance on the problem-solving task was the same for both hypermedia systems.

Of course it is possible to critique the methodology and the results of this experiment: was there a ceiling effect in the card selection task or a floor effect in the problem-solving task? Were there both semantic *and* organizational differences in the structure of the two systems? Were the results significant? What exactly was the nature of the problem-solving task? However there are intriguing issues here. The domain-specific link types encouraged roughly double the amount of exploration of the domain. However the learning outcomes on the problem-solving task, which should have been improved by this exploration, were no better. By the same token the domain specific links were less efficient in helping the students solve the given card selection problems, in the sense that they chose to look at more cards in order to solve those problems.

Virtual Reality

A careful analysis of the potential values of VR technology, especially in the

area of conceptual learning is provide by Whitelock, Brna, and Holland (1996). Taking a more evangelistic line, Roussos, Johnson, Leigh, Vasilakis, and Moher (1996) illustrate some of the potential problems of high-fidelity representations especially when entertainment and education are intermixed without due care. The emphases in the following quotation are mine:

> The main constructive activity is to build and develop small local ecosystems on the bare parts of the island ... Various seeds for planting garden vegetables and trees are stored in crates and serve as starting points for building micro-ecosystems on the island. *Additionally, the child can elicit the assistance of several genies, such as a cloud genie to provide rain, or the fire-flies to illuminate the vast underground expanse.* Our immediate plans are to have the genies make their actions explicit, in the case where the child cannot perceive the cause and effect right away.
>
> When the user drops a seed on the ground, the corresponding plant, flower or tree will start to grow. The pace in which this happens can be predetermined; we may choose to see the system grow very quickly, or, *in the case of a school project, extend it over the period of a semester.*
>
> The tomatoes, carrots, pumpkins and other plant objects contain a set of characteristics that contribute to their growth. They all have values for their age, the amount of water they hold, the amount of light they need, their proximity to other plants of their kind ... Visual cues aid the child in determining the state of the plant or flower. *When the cloud has been pouring rain over it for too long, the plant opens an umbrella; when the sunlight is too bright, it wears sunglasses.*
>
> From Roussos et al. (1996); page 132.

There seem to be two potential difficulties here. First is the issue of whether the system is supposed to be teaching science or providing entertainment: of course, the two are not mutually exclusive but there do seem to be mixed messages here about which parts of the simulation are intended to be taken seriously by the child as a model of the world and which parts are there for fun. The second difficulty is concerned with the value of simulations *vs* the real phenomenon — my vote would be for growing real seeds in real earth if a whole semester is available.

While VR heads toward high fidelity landscapes, there still remain many subtle issues to examine concerning both the conventions of graphic output and learners' understanding and misunderstanding of simple diagrams. On the first issue, given the many possibilities for high-quality graphical output in educational systems, the system designer needs guidelines (and ideally a theory) to assist in the choice of which kind of graphical convention to use for what kind of purpose in which kind of context. Some very interesting principles of visual communication have been developed by Percoco and Sarti (1996) together with a number of useful rules of thumb. On the second issue, Laborde (1996) is

concerned with learners' reasoning about geometric properties from figures and constructions as compared to reasoning from symbolic representations of geometric objects. The very concreteness of the figure and its possible accidental alignments and other visual properties are both a support for reasoning and a source of misreasoning. Laborde's (1996) careful analysis of how visual perception can sometimes get in the way of reasoning is a useful counter-argument to those who argue that more graphics and more VR *must* be better.

Style

The variability of preferred learning styles was an issue for various researchers. The idea is usually to vary the availability of learning resources in general, the sequencing of the specific material and, possibly, the nature of the learning activities to suit the predisposition of the learner. Of course one could argue that this adjustment might be just the wrong thing to do consistently in that it might be a recipe for not provoking reflection and self-explanation — but that is purely speculation.

Kommers and Lenting (1996) provide a very high-level model of educational interaction and argue for the versatility of "telematic supported co-operative learning" to support a wide variety of learning styles and educational needs. Dobson and McCracken (1996) adopt a position based loosely on Conversation Theory (Pask & Scott, 1975) and offer a means, also in the context of distance learning technology, to allow for learners with either "holist" or "serialist" tendencies. Like Cook (1996) and Pilkington and Mallen (1996) they are also working towards capturing the essence of naturally occurring dialogue interaction, but in the context of remotely situated partners rather than face to face partners as in the other studies. So for them there are several extra dialogue issues to worry about concerning the effective maintenance of shared common workspace and view of problem at hand — one of the problems addressed by Whitelock and Scanlon (1996).

The more radical, and indeed versatile, suggestions for capturing learning style and personality issues and then tailoring the following educational interaction accordingly is provided by Du Plessis and De Kock (1996). Their idea is to make the student undertake a battery of pre-tests and then use the scores obtained to adjust the kind of interaction that the system offered the student. The following paragraph gives a flavour of the kind of analysis that their system will undertake, using fuzzy logic to tie together pre-test scores to educational treatments:

> "A typical engineering student may have been classified as a converger by Kolb's LSI, as an introvert/sensory/thinking/judging type by a MBTI test and a Mel[ancholic] phleg[matic] by La Haye's temperament test ... this student prefers sensory information, a deductive approach to learning, a good mixture of both actual and reflective processing of information, and a structured learning environment. His temperament blend suggests that he may need help in goal setting, and that he may be gifted and therefore needs

> special and extra explanatory material ... It continues to specify specific presentation elements that can be used to support these goals ... mind maps, descriptions, explanations, examples, demonstrations, diagrams, flow and step charts, drill and practice exercises, step by step tutorials, theoretical and practical readings, case studies and teaching games."
>
> From Du Plessis and De Kock (1996); page 178.

In a way, one can view this as attempting to perform a similar kind of analysis as Akhras and Self (1996) except at a coarser level of granularity, though the relationships embodied between personality variables and activity types are perhaps more ad hoc in Du Plessis and De Kock's (1996) case.

MODELLING

Given the state of Artificial Intelligence in Education, researchers are attempting reflection on various subfields. For example, Whitelock et al. (1996) delineate the potential for VR in conceptual learning; Fenley (1996) undertakes a similar task for multimedia; Salles, Pain, and Muetzelfeldt (1996) compare different kinds of qualitative reasoning schemes in terms of their utility for modeling ecological processes.

One of the most ambitious synthesizing projects is that of Mizoguchi, Sinitsa, and Ikeda (1996). They have embarked on the task of constructing an ontology for Artificial Intelligence in Education. This can be seen as a preliminary to the development of a versatile authoring system able to reason about different kinds of educational interaction and their probable outcomes. In some ways the goal is a more general version of what Errico (1996) is attempting via the Situation Calculus, in that it is attempting to model not only the student's possible changes of state of knowledge but also all the other aspects of educational interactions.

Sometimes it seems hard to make substantive progress. For example, Desmoulins and van Labeke (1996) describe a logic programming based system for critiquing student's geometric constructions, much in the style of classical work by (Goldstein, 1975). Despite the overall change of emphasis in the field many standard modelling problems have emerged, though sometimes stated in different terms.

The Student

It is clear that shifting the focus of instructional planning towards planning the nature of the educational interactions rather than planning the traversal of the experts' view of the domain does not make the problem of student modelling go away — it just changes it. In such a system the student modelling issue will be concerned with exactly the extent to which a particular activity may or may not be, or may not have been, successfully cumulative. So the focus of student modelling shifts into a model of *how* the student learns and away from *what* the student learns.

Even in simulation-based environments there will be the need to try to relate explanations from the system to the goals of the student and to interpret

actions on the simulation or hypotheses about the behaviour of the simulation in terms of what the student knows and does not know.

A striking example of the tension that can be provoked by the phrase "student modelling" is shown in the paper by Forte and Forte (1996). They linked a pedagogical hypertext (PHT) to a simulation system augmented by a mechanism to propose specific activities to the student: typically to find a route within the simulation, from a given start state to a given goal state. For them the "classical" notion of a student model is "useless" but they had a means to select preferred routes through the PHT for different purposes and they wished to discriminate between different classes of student, in terms of their conceptual gaps, in order to select the most useful of the preferred routes. This may not be classical student modelling, but it seems to me that it is still student modelling.

The Domain

A classical issue that has driven the evolution of most systems has been that of modelling the domain of interest explicitly. A recurrent theme has been the fact than an intelligent learning environment has modelled some domain *D*, where the learner is actually supposed to be learning a higher level domain *Dprime*. For example, the early Sophie system provided an interactive learning environment for electronic troubleshooting where the learner made measurements and replaced components in a simulated circuit (Brown, Burton, & de Kleer, 1982). The system could report the effects (and the utility) of these changes but could not directly engage the learner in a discussion about troubleshooting *per se*. Here the domain *D* was the behaviour of the circuit under various conditions, but the domain of interest, *Dprime*, was the higher level skill of troubleshooting. Later versions of Sophie addressed this issue. A similar evolution occurred in the development of Guidon where the initial domain *D* was based on a diagnostic expert system where the diagnostic theory, *Dprime*, was implicit within the system. In order to engage the learner in activities which focussed on diagnosis itself it was important to re-engineer the system in such a way that *Dprime* was modelled explicitly and was not just an emergent property of *D*.

This tension between *D* and *Dprime* is still in evidence. We already noted the issue in the section on Reflection in relation to a concern as to whether systems that prompted students with questions about a domain (see e.g., Fung & Adam, 1996) would teach the skill of self-explanation itself. In a similar vein, Auzende (1996) describes a simulation of a complex electrical supply system. It has a clever mechanism to generate an explanation of the behaviour of the system consequent on certain changes (i.e. *D*) but cannot, I believe, interact with the user at the level of *Dprime*, i.e. fault diagnosis. By contrast, in the work of de Koning, Bredeweg, and Breuker (1996) one can see something like a Socratic dialogue emerging semi-automatically from the model of the beakers on a balance that they used. Augmenting an expert system based trainer with a hypertext system is another way of helping the student deal with a domain at different levels of generality. Reinhardt (1996) integrated two such systems to provide an environment in which students could learn how to classify flowers,

be critiqued on their classification expertise as well as on their ability to deal with realistic visual data.

The *D* and *Dprime* issue is explored by Mitchell et al. (1996) in the area of industrial training where the typical high fidelity simulation (e.g., a flight simulator) operates at the *D* level and a human tutor is required in order to get the student to focus at the *Dprime* level. Proponents of the value of virtual reality in education tend to stress "immersion" at the *D* level and assume that reflection on the experience will happen on its own. One of the constructive lessons of the years of work on LOGO was that the subjects' explicit attention needed to be focused on problem-solving rather than LOGO as such in order to bring about improvements at the *Dprime* level. Indeed the very immediacy of the experience of producing interesting visual effects could act as a hindrance to generalisation. We are in danger of repeating this kind of mistake if we accept uncritically all the promises about the educational value of virtual reality systems.

The Teacher

A standard methodology in Artificial Intelligence in Education is to observe skilled human teachers and then try to formalize their skills in machine teachers — for example, when to take charge, when to withdraw, when to help and so on (see e.g., Lajoie & Lesgold, 1989). But an issue that arises immediately is whether techniques that work for human teachers (Lepper, Woolverton, Mumme, & Gurtner, 1993) will also work for machine teachers, especially when the techniques are concerned with motivation. del Soldato (1994) found that students were rather surprised when *the machine* refused to help when requested or told them it was too soon to give up on a problem. A similar point is made by Barnard and Sandberg (1996) investigating the promotion of self-explanation by students. They argue that strategies that can be adapted by a human teacher to provoke reflection and self-explanation may not work when the teacher is known to be a machine.

CONCLUSION

In part the argument between the modellers and the non-modellers can be seen in terms of the different motivations that drive researchers to work in the field of Artificial Intelligence in Education. One motivation is a worthy interest in improving education. With this motivation in mind, people rightly point out that you do not necessarily get better educational outcomes from a technically more complex (intelligent) educational system compared to a simpler system (see e.g., Larkin & Chabay, 1992, for a collection of papers exploring this question). For some of them the manifest difficulties of modelling can seem counterproductive when equally good (or even better) education can be achieved without modelling. Another motivation stems from an interest in a particular technology and a belief that this technology offers something of potential value in education. *Proponents* of Hypermedia, the Internet or VR fall into this camp. For them the issue of modelling can be a distraction from

the technology of interest. Yet another motivation is an interest in trying to understand the processes of learning and teaching as fascinating phenomena in their own right irrespective of whether the research has immediate educational applications. For these people, especially in the context of Artificial Intelligence in Education, modelling is at the heart of the enterprise, as it is their method of reifying and testing their theories. For them the notion that intelligent tutoring systems (say) might have "failed" is the wrong kind of criticism. The question for them should rather be "How good a model of teaching does such a system offer?" or "How good a model of learning underpins the system?". If the models are impoverished and inadequate, how are they so, and how can they be improved?

The perspective offered in this review is much coloured by the third motivation, i.e. learning and teaching are fascinating phenomena in their own right. Indeed some of the intriguing empirical results could perhaps be summed up under the slogan that educational outcomes are hard to predict from experimental conditions.

The field of Artificial Intelligence in Education has gained much from its roots in artificial intelligence, but it has perhaps been overly influenced by a view of learning dominated more by epistemology than by genetic epistemology. The strength of this particular reflective event, and perhaps the strength of the field of Artificial Intelligence in Education in Europe, is its concern with learning as it actually occurs — not an idealization of learning.

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