British Journal of Educational Technology Vol 29 No 1 1998 73–82

Implications of educational theory for the design of instructional multimedia

Martyn Wild and Clark Quinn

Martyn Wild is Senior Research Fellow, Edith Cowan University, Western Australia. He has published in diverse fields of information technology research, including, IT use in teacher education; interactive multimedia and learning; instructional design in on-line and multimedia environments; interface design; and human-computer interaction. He is currently developing performance support systems for teaching and learning.

Clark N. Quinn is on leave from a position as a senior lecturer in the School of Computer Science and Engineering at the University of New South Wales, and is currently serving as Director of Development for the Access Australia Cooperative Multimedia Centre. Prior to receiving his doctorate in psychology at the University of California, San Diego, with Donald Norman, he designed educational computer games with DesignWare. Clark teaches interface design and does research on designing engaging learning environments.

Address for correspondence: Martyn Wild, Department of Information Systems, Edith Cowan University, Western Australia 6018. Tel: 618 9273 8333; Fax: 618 9273 8332; e-mail m.wild@cowan.edu.au

Abstract
Interactive multimedia provides a useful vehicle to reconsider the place of educational theories in the design of interactive learning environments. This paper serves to address a number of such theories, especially those centred on student learning, and in particular, attempts to draw out the implications they present for designing effective instructional multimedia. It is argued that we need to develop coherency rather than divergency, in our theoretical perspectives so that we might optimise the development of new technologies in teaching and learning. This rationale is then used to advance one such perspective, based on the role of dynamic modelling tools.

Introduction

As technological advances offer new learning opportunities, there must be recourse to educational theory to guide design. Indeed, a number of themes emerge in any discussion about educational theory, learning and instruction, any one of which may be of use in informing our application of these technologies for pedagogical ends. It is growing important, however, to look for a synergy in our educational deliberations, to use a range of coherent theoretical perspectives to optimise the use of new technologies

Published by Blackwell Publishers, 108 Cowley Road, Oxford OX4 1JF, UK and 350 Main Street, Malden, MA 02148, USA.

in teaching and learning. Interactive multimedia, in particular, provides a powerful tool for both teachers and learners and, consequently, an opportunity to reconsider the place of educational theory, and particularly theories centred on student learning, in the design of learning environments.

Here, we consider a variety of theoretical perspectives and use our considerations to advise on ways in which one might optimise both the role and design of interactive multimedia in bringing about effective learning. We then use our thesis to support an argument for a particular approach to the use of technologies in learning—the use of dynamic modelling tools to represent learner's thinking and doing. We do this through a consideration of the learner, the learning context, and the role of education.

What is meant by "learning"?

In the context of this paper, it is suggested that learning should be seen in terms of cognitive change. That is not to suggest that other learning of an affective or psychomotor sort is not of importance, or that interactive multimedia does not provide for such learning, but rather, in tertiary contexts at least, cognitive development in learners is perhaps the central aim of most instruction. Laurillard (1993) describes the academic knowledge necessary to cognitive development in domains studied at tertiary level, as being different to other levels or types of knowledge, particularly everyday knowledge. That is, learning at tertiary level necessarily includes not only learning knowledge in realworld contexts (experiential learning) but also learning others' descriptions of the world (academic learning) (Saljo, 1984).

The goal of learning is to develop frameworks or schemas (Rumelhart and Norman, 1988) that provide explanatory and predictive power across situations. Whereas learning about descriptions of the world forms the basis of academic learning, the ability to internalise and "own" these descriptions, providing for transfer of that learning to new problems, only comes from the reconciliation between experiential learning and the academic learning. We believe that this reconciliation primarily comes from reflecting on and abstracting from one's own experience.

As a first approximation then, we can consider the process of learning to be through cycles of action and reflection. The great strength of computers is that they can be programmed to provide interactive activities, such as those focused in simulations and models, which have the potential to promote reflection in the learner. It is currently not feasible to design technology applications to facilitate reflection directly—this requires the development of sophisticated intelligent tutoring systems (eg, Self, 1990). However, technologies can mediate and encourage reflection in several ways, such as providing a communication link between learners, providing tools for knowledge and outcome representation during activities (Hedberg *et al.*, 1994), or simply displaying a record of the learner's activities (Schauble, Raghavan and Glaser, 1993).

The learner

At the level of the individual learner, there are probably three distinctive influences at play that impact on cognitive change: the learner's existing knowledge and experience, the learner's "style" or predisposition to learning, as well as their acquired and individual approach to learning. Much has been made of ascertaining and individualising learning based upon the learner's background, including both their general world knowledge and their specific experience with the particular domain of study, but the other two areas have been less developed. Learning styles and learning approaches represent two different perspectives on student learning processes, each of which appear to influence academic achievement (Murray-Harvey, 1994). Also, both are conceptualisations that provide a framework for understanding how students learn and why there are differences between student's learning, in terms of learning outcomes.

Broadly speaking, the theory underpinning measurement of learning styles is that students possess pre-determined learning preferences in respect of environmental, emotional, sociological, physical and psychological conditions (Price, Dunn and Dunn, 1991). Varying preferences for each of these learning conditions, combine to provide an individual learning style profile. For example, there is some indication that learners have a preference for the representational format they tend to think in; indeed, learners have been differentiated on whether they are visual, auditory, or kinaesthetic learners. In addition, since preferences are largely biologically determined, a learner's learning style will necessarily be resistant to change, implying that instruction needs to take account of learning styles rather than trying to change them (Murray-Harvey, 1994).

It follows that we need to support different styles of learning in multimedia. One means of doing this would be to provide fixed paths through a multimedia learning experience, each corresponding to and supporting, different styles of learning. A more flexible solution is to provide multiple paths of navigation through the instructional materials, and to support the learner in their choice of path—for example, whether first to obtain information resources, sample problems, or practice opportunities. This approach accommodates well, differing suggestions as to whether problems (eg, Barrows, 1986), conceptions (eg, Laurillard, 1993), or skill applications (eg, Collins, Brown and Newman, 1989), should be presented first in any given instructional sequence. Moreover, we recommend that there be specific support for learners to identify their own learning style, to experiment with other styles and to be aware of what pitfalls exist for each learning style (Ritzen, 1995).

In stark contrast to the conceptualisation of learning styles, Biggs (1987a, 1987b) suggests that the process of learning is determined by students' approaches to learning—that is, a composite of students' motives and strategies (to learn) as well as their perceptions of tasks. Importantly, different approaches to learning (and their are four prime approaches: surface, achieving, deep and deep-achieving), are open to change and development, according to changes in motives, strategies and task perceptions (Biggs, 1987a; Biggs, 1987b). Furthermore, it is contended that deep and deep-achieving approaches to learning are more likely to result in better learning outcomes (Biggs and Moore, 1993, p. 321); and as such, instruction should be provided to encourage students to develop these approaches to learning.

Although we know quite a lot about the characterisations of the four main "prototypical approaches to learning" (Biggs and Moore, 1993, p. 316), it is not so obvious how we might develop deep or deep-achieving approaches in learners, in instructional multimedia. However, there are pointers to how this might be done. For example, it is important to induce in learners, a conceptualisation of the task being tackled that leads them to consider the structure rather than the detail of related knowledge. This is achieved by providing for appropriate tasks, so that learners are not reduced to retaining and producing discrete and unrelated facts. However, perhaps the most influential variable in determining deep approaches to learning, is locus of control (Biggs, 1987a)—where, by encouraging the development of internal locus of control in instructional multimedia, learners are more likely to develop deep approaches to the tasks presented. It is important to note that not all learners will necessarily be ready to handle an internal locus of control, and providing learner control over system, process and content functions in instructional multimedia in this way may not coincide with more effective learning on the part of all learners (Kinzie, 1990). In designing multimedia learning environments, then, it becomes important not to place the learner in a "sea of content" (Schwier, 1995, p. 123) without the tools or structural supports necessary for effective learning to occur. It is also important to recognise that the metacognitive demands placed on the learner increase in less structured environments, where the expectations for learner control are high (Park and Hannafin, 1993). In this light, we would argue that learner control together with coaching or scaffolding (ie, what Laurillard (1993) terms, "guided discovery") is likely to be more effective than the provision of total learner control in functions such as unstructured browsing, as the learner is not always capable of maximising use of these functions (Hannafin, 1992).

Context and situation

It is often argued that context and situation are all important in providing for learning at all levels, and should influence in particular, the design of instructional multimedia (eg, Herrington and Oliver, 1995). Collins describes situated learning thus, "situated learning is the notion of learning knowledge and skills in contexts that reflect the way the knowledge will be useful in real life" (Collins, 1989, p. 2). In the same context, Collins, Brown and Newman argue strongly for the effectiveness of cognitive apprenticeship models of pedagogy, where, it is suggested, "teaching methods should be designed to give students the opportunity to observe, engage in, and invent or discover expert strategies in context" so that they might best learn both cognitive and metacognitive skills (Collins, Brown and Newman, 1987, p. 12).

It is not clear, however, that the concept of situated learning allows for the levels of abstraction required for understanding in many domains of knowledge, particularly those studied by university students. For example, Laurillard (1993) argues cogently that learning in situated contexts does not, by itself, allow for a learner to make abstractions from the particular context and therefore be able to generalise or apply what is learnt to new situations or contexts. This has, in particular, an important implication for learning what Laurillard classifies as "academic knowledge"—she considers academic knowledge to be different to everyday knowledge, drawing a distinction between learning "percepts" in everyday life and learning "precepts" in education, implying that learning precepts necessitates students building understanding in a deeper (abstract) sense, a level of understanding which cannot be provided for simply by situating the learning experience (Laurillard, 1993, 23–29).

However, we would argue that while the requirements for abstraction and transfer require more than "situated context" alone, it is probably true that problem-based learning is best situated in contexts meaningful to the real domain of practice. Moreover, these problems should also be ones that the learner finds cognitively and affectively engaging (Quinn, 1994). One way to approach this is to determine those attributes of an activity or task that provide for high levels of engagement in practitioners, and then seek to represent these attributes in the contexts of problems provided for learners.

When considering the requirements for abstraction and transfer, we need to be mindful of findings from research into analogical transfer, which provide a strong source of evidence for the lack of transfer of context-specific knowledge. For example, it would appear that subjects presented with problems that contain structural similarities to previously seen problems have little likelihood of recalling and using previous solutions unless the problems were also similar in detail as well as structure (Gentner, 1986), or were given an explicit hint (Gick and Holyoak, 1981), or had seen several examples of problems with the same underlying structure (Gick and Holyoak, 1983). This implies that abstraction and transfer require practice across vastly different examples, together with scaffolded reflection.

We suggest, then, that instructional multimedia needs to provide for problem-based learning in situated practice activities, and further, facilitate the abstraction of commonalities across a range of different examples of problems and contexts. This would encourage learners to abstract the underlying structure in solutions to existing problems and then transfer these solutions to new problems.

A note on constructivism

We should probably not resist the temptation to comment upon the nature and role of constructivism in a discussion of issues related to educational theory, learning and multimedia (particularly since constructivism is often misconstrued and misrepresented). There are a whole range of theories concerned with the way in which students learn which together inform what is usually meant by "constructivism"; some theories emanate from a cognitivist tradition, others from a social psychological, interactionist or experiential perspective (and the list could go on).

Briefly, the unifying concept here, is that understanding is constructed by the learner and that there is of necessity an interpretation of the concept in the mind of the learner rather than the gradual acquisition of the concept. However, in much of the current and recurring debate about the role of educational and learning theory in instructional technologies (especially multimedia), there seems to be a readiness to polarise one theory of learning (behaviourism) with a metatheory (constructivism), and, further, to present the former as grossly deficient and the latter as the only credible explanation of student learning.

The difficulty here is that such a polarisation is entirely philosophical, and as such represents fundamentally different views on what is meant by knowing, the role of education and the nature of learning. The polarisation, outside of a philosophical debate, is certainly not helpful in determining effective instructional design. For example, even although the main components of behaviourism (or at least the behavioural theory of Skinner) were largely discredited as general truths in the 1970s, the principles of contiguity, repetition, reinforcement through feedback and motivation are still recognised as important in processes of learning (Entwistle, 1987, p. 10).

Indeed, there are various dimensions in different theories of learning, and not all fit along an imaginary continuum connecting two supposed extremes—this is where Reeves' work on the evaluation of instructional technologies, postulating just such a continuum, may be misleading (Reeves, 1994). If we need a metaphor to represent learning or educational theories as a whole, a series of corresponding and opposing objects, each with its own attributes, some common, some unique, is ultimately a more accurate and useful metaphor than a simple, linear path connecting two poles or extremes. Further, we would prefer to work towards a converging model for the inclusion of theories into instructional design approaches, drawing on the various elements of each theory that clearly have a useful role in explaining learning in multimedia environments.

Anderson, Reder and Simon (1996) have taken on a straw-man version of constructivist arguments, on the basis of empirical research. In the process of debunking the more extreme claims of constructivism, they effectively present just such a convergent model, one that emphasises the role for active exploration on the part of the learner, as well as guidance through a process of mediated dialogue towards developing internal models. It is this very process, we would argue, that can be effectively addressed through technological mediation as well as through one-on-one tutoring.

Conditions of learning

From the phenomenographical research of Marton, (Marton, Hounsell and Entwistle, 1984; Marton and Ramsden, 1988), Saljo (Saljo, 1984) and Thomas and Harri–Augustein (Thomas and Harri–Augustein, 1985), it is useful to consider the notion of the ultimacy of individuality in learning, that learning is different for individual learners; and that learning involves a negotiation of meaning (in the form of conversation), within and between learners, which leads to understanding. To describe what is successful in learning, in this context, is to describe successful interactions between learner, context and instruction. Thus, it is not possible to distil from such interactions a set of prescriptive conditions of learning, since the interactions that might be described will be rooted in a particular context and therefore are likely to be context specific and nongeneralisable.

Given this premise, if we take it as so, how is it possible to reconcile an approach to instructional design that strives to describe the necessary conditions of learning for all learners and for all learning situations? Well, quite simply, it isn't. However, for instructional technologies at least, the influence of Gagne's *The Conditions of Learning* (Gagne, 1977), and more lately, Merrill's work (Gagne and Merrill, 1990), continues to have a tremendous impact on instructional design, particularly for instructional multimedia. Merrill has even computerised this approach to instructional design (Merrill, Li and Jones, 1990).

Indeed, Merrill has recently published a defence and rationalisation of instructional design as a science, against the encroachments of what he terms, "those persons who claim that knowledge is founded on collaboration rather than empirical science, or who claim that all truth is relative ..." (Merrill *et al.*, 1996). In this recent work, he makes a number of crucial points, attempting to re-establish the authority of an instructivist and philosophically uncompromising approach to instructional design, namely:

- There are known instructional strategies. The acquisition of different types of knowledge and skill require different conditions for learning (Gagne, 1977). If an instructional experience or environment does not include the instructional strategies required for the acquisition of the desired knowledge or skill, then effective, efficient, and appealing learning of the desired outcome will not occur.
- These instructional strategies (conditions of learning) can be verified by empirical test.
- Appropriate instructional strategies can be discovered, they are not arrived at by collaborative agreement among instructional designers or learners. They are based on natural principles which do exist, and which nature will reveal as a result of careful scientific inquiry.

The problem is that a collection of disparate instructional strategies does not constitute an overarching theoretical framework within which to prescribe applications of interactive multimedia, reconciling our desire to incorporate individualisation, active learning, and a capacity to abstract. When the educational objective can be as abstract as the ability to recognise and apply a particular framework to a new problem, it is not clear that the "known instructional strategies" (Merrill *et al.*, 1996) can provide prescriptions for design.

Cognitive tools

A way of achieving a satisfying synthesis, of embracing the findings of phenomenography and using these to provide for new models of instructional design, within a coherent design framework that is not premised on prescribed instructional strategies, is to consider the role of the computer as a cognitive tool (Jonassen, 1995, 1996). This synthesis occurs through conceptualising the computer as tool to engage the learner in interactions—principally with their own meanings or understandings, as well as those of others, in order to build a more complete, richer, understanding.

By providing interactive and perhaps multimedia, environments on the computer, which are able to accommodate learners' representations or models of conceptual phenomena, we are providing the means by which learners can represent, explicitly, their own understandings, interact with others' (teacher's or student's) representations and come to understand a range of conceptual meanings in relation to their own. The computer, in the shape of a cognitive tool, allows the learner to externalise their thinking, to enrich it, manipulate it and change it, all by interacting with one or more conceptual models on the computer, in the form of a dialogue (whether that dialogue is real and conducted with others, or whether it occurs in the learner's head).

In particular, one outcome of advanced understanding in a domain should be the ability to explain and predict outcomes. Understanding the world in terms of systems, through the use of "mental models" (Gentner and Stevens, 1983) that capture the causal relationships between entities in the world, provides this sort of capability. The development of causal thinking, initially at a qualitative level and then supplemented with quantitative accuracy, is a component of most disciplines at a tertiary level. Johnson-Laird explains mental models thus:

"Understanding certainly depends on knowledge and belief. If you know what causes a phenomenon, what results from it, how to influence, control, initiate, or prevent it, how it relates to other states of affairs or how it resembles them, how to predict its onset and course, what its internal or underlying "structure" is, then to some extent you understand it. The psychological core of understanding, I shall assume, consists in your having a "working model" of the phenomenon in your mind. If you understand inflation, a mathematical proof, the way a computer works, DNA or a divorce, then you have a mental representation that serves as a model of an entity in much the same way as, say, a clock functions as a model of the earth's rotation." (Johnson-Laird, 1983, p. 2)

Thus, instead of designing instruction in the form of predetermined instructional goals, each matched with an artificially constructed learning event (Gagne, 1977), it is possible to enable the learners themselves to design by expressing their representations or models of understanding, and by doing so, engage in meaningful cognitive interactions. Jonassen and Reeves describe this process thus:

"Instead of specialists such as instructional designers using technology to constrain students' learning processes through proscribed communications and interactions, the technologies are taken away from the specialists and given to the learners to use as media for representing and expressing what they know." (Jonassen and Reeves, forthcoming)

For the computer to act as a cognitive tool, it is important then, in terms of mental models theory, to allow for the building of computer models, which are beneficial to the processes necessary in constructing accurate and appropriate mental models (Wild, 1996). There are two crucial roles for interactive multimedia here, corresponding to two distinct but complementary levels of computer modelling—exploratory and expressive (see Mellar *et al.*, 1994); which, in turn, correspond to two different types of cognitive activity—exploring and building. In this sense, the tools and functionalities that may be provided in multimedia are well adapted to provide for both types of computer modelling and hence, both forms of cognitive activity.

Conclusion

We have argued in this paper, then, that there is a case to be made that advocates the development of a coherent model or models of instructional design in multimedia, based fundamentally upon a range of attributes in various learning theories that coalesce effectively in a single and overarching framework. This framework is necessarily characterised by the deliberate facilitation of cognitive processes, provision of information resources, and scaffolded reflection, so that the learner might engage, explore and build.

We have also suggested that systems thinking is a cognitive skill that technological developments, particularly in multimedia, have made more addressable. The ability to understand processes is a potentially powerful mental attribute, and we encourage further exploration of the means by which we might support learners in acquiring this attribute in their use of instructional multimedia.

References

Anderson J R, Reder L M and Simon H A (1996) Situated learning and education *Educational Researcher* **25** (4) 5–11.

Barrows H S (1986) A taxonomy of problem-based learning methods *Medical Education* **20** (6) 481–486.

Biggs J B (1987a) *Student approaches to learning and studying* Australian Council for Educational Research, Hawthorn, Victoria.

Biggs J B (1987b) *The study process questionnaire (SPQ) manual* Australian Council for Educational Research, Hawthorn, Victoria.

Biggs J B and Moore P J (1993) *The process of learning* (3rd edn) Prentice Hall, Sydney.

Collins A (1989) *Cognitive apprenticeship and instructional technology* (Technical Report No. 474) BBN Laboratories, Cambridge, MA, July 1989.

Collins A, Brown J S and Newman S (1989) Cognitive apprenticeship: Teaching the craft of reading, writing, and mathematics *in* Resnick L B (ed) *Knowing, learning and instruction: Essays in honor of Robert Glaser* Lawrence Erlbaum Associates, Hillsdale, NJ.

Entwistle N (1987) *Understanding classroom learning* Hodder and Stoughton Educational, Sevenoaks.

Gagne R M (1977) *The conditions of learning* Holt Rhinehart and Winston, New York.

Gagne R M and Merrill M D (1990) Integrative goals for instructional design *Educational Technology Research and Development* **38** (1) 23–30.

Gentner D and Stevens A L (1983) *Mental Models* Erlbaum, Hillsdale, NJ.

Hannafin M J (1992) Emerging technologies, ISD, and learning environments: critical perspectives *Educational Technology Research and Development* **40** (1) 49–63.

Hedberg J G, Harper B, Brown C and Corderoy R (1994) Exploring user interfaces to improve learning outcomes *in* Beattie K, McNaught C and Wills S *Interactive Multimedia in University Education: Designing for Change in Teaching and Learning* Elsevier, Amsterdam, 15–29.

Herrington J and Oliver R (1995) What situated learning tells us about the design of multimedia *in* Oliver R and Wild M (eds), *Learning without limits: Proceedings of the Australian Computers in Education Conference, 1995, Volume 1* Educational Computing Association of Western Australia, Perth, WA, 177–186.

Johnson-Laird P N (1983) *Mental models: towards a cognitive science of language, inference and consciousness* Cambridge University Press, Cambridge.

Jonassen D H (1995) Computers as cognitive tools: Learning with technology, not from technology *Journal of Computing in Higher Education* **6** (2) 40–73.
Jonassen D H (1996) *Mindtools for schools* Macmillan, New York.
Jonassen D H and Reeves T C (forthcoming) Learning with technology: Using computers as cognitive tools *in* Jonassen D H (ed) *Handbook of research on educational communications and technology* Scholastic Press in collaboration with the Association for Educational Communications and Technology, New York.
Kinzie M B (1990) Requirements and benefits of effective interactive instruction: learner control, self-regulation, and continuing motivation *Educational Technology, Research and Development* **38** (1) 5–21.
Laurillard D (1993) *Rethinking university teaching: a framework for the effective use of educational technology* Routledge, London.
Marton F, Hounsell D J and Entwistle N J (1984) *The experience of learning* Scottish Academic Press, Edinburgh.
Marton F and Ramsden P (1988) What does it take to improve learning? *in* Ramsden P (ed) *Improving learning: New perspectives* Kogan Page, London.
Mellar H, Bliss J, Boohan R, Ogborn J and Tompsett C (eds) (1994) *Learning with artificial worlds: Computer based modelling in the curriculum* Falmer Press, London.
Merrill D, Drake L, Lacy M J and Pratt J (1996) *Reclaiming the discipline of instructional design* Available, LISTSERV@UGA.CC.UGA [on-line] IT-FORUM, 19 February 1996.
Merrill M D, Li Z and Jones M K (1990) Second generation instructional design (ID2) *Educational Technology* **30** (2) 7–14.
Murray-Harvey R (1994) Learning styles and approaches to learning: distinguishing between concepts and instruments *British Journal of Educational Psychology* **64** (3) 373–388.
Park I and Hannafin M J (1993) Empirically-based guidelines for the design of interactive multimedia *Educational Technology Research and Development* **41** (3) 63–85.
Price G E, Dunn R and Dunn K (1991) *Productivity environmental preference survey (PEPS manual)* Price Systems Incorporated, Lawrence, KA.
Quinn C N (1994) Designing educational computer games *in* Beattie K, McNaught C and Wills S (eds) *Interactive Multimedia in University Education: Designing for Change in Teaching and Learning* Elsevier, Amsterdam, 45–57.
Reeves T (1994) Evaluating what really matters in computer based education *in* Wild M and Kirkpatrick D (eds) *Computer education: new perspectives* WA: MASTEC, Edith Cowan University, Perth, 219–246.
Ritzen M M J (1995) Study Skills, Multimedia and Business Economics. Paper presented at *EdMedia 95: World Conference on Educational Multimedia and Hypermedia* Graz, June 1995.
Rumelhart D E and Norman D A (1988) Representation in memory *in* Atkinson R C, Herrnstein J J, Lindzey G and Luce R C (eds) *Handbook of experimental psychology* Wiley, New York.
Saljo R (1984) Learning from reading *in* Marton F, Hounsell D J and Entwistle N J (eds) *The experience of learning* Scottish Academic Press, Edinburgh.
Schauble L, Raghavan K and Glaser R (1993) The discovery and reflection notation: a graphical trace for supporting self regulation in computer-based laboratories *in* Lajoie S and Derry S (eds) *Computers as cognitive tools* Erlbaum, Hillsdale, NJ, 319–337.
Schwier R A (1995) Issues in emerging interactive technologies *in* Anglin G J (ed) *Instructional technology: past, present and future* Libraries unlimited, Englewood, CO, 119–130.
Self J A (1990) Bypassing the intractable problem of student modeling *in* Frasson C and Gauthier G (eds) *Intelligent Tutoring Systems: at the Crossroad of Artificial Intelligence and Education* Ablex, Norwood, NJ.
Thomas L and Harri-Augustein S (1985) *Self-organised learning* Routledge and Kegan Paul, London.
Wild M (1996) Mental models and computer modelling *Journal of Computer Assisted Learning* **12** (1) 10–21.