Mainstreaming AIED into Education?

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Abstract. What will Education look like in 2010, and what will be its problems? Will AIED have anything substantial to offer, and what can we do to maximise its contributions? We argue that Education is, for understandable reasons, the discipline of classroom teaching and learning, with some attention paid to learning by individuals but very little indeed to teaching that is effective in a one-to-one situation. Further, it is not strong in formulating precise theories of learning and teaching. It is therefore not well-equipped to support the inevitable increase in learning activities that will be undertaken at computers. We argue that AIED has made great progress in adopting broader and more sophisticated conceptions of learning, and should thus at last be able to communicate well with Education. It can offer ways to develop and test precise theories, and also important concepts relevant to individualised learning that have largely been overlooked by Education, such as that of learner modelling by teachers. By 2010 AIED has the potential to be making a much broader contribution to Education. If this optimistic prediction can be achieved, and the educational mainstreaming of AIED does occur, both AIED and Education will benefit.

INTRODUCTION

It is a safe prediction that learners will make more and different use of computers and telecommunications by 2010, alongside ever-valuable human interactions. We leave it to other 2010 contributors to speculate how and to what extent. Our focus is on Education (where the capital 'E' signals 'the discipline of') and the challenges that computer use will pose for it.

AIED is AI *in* education, but AIED can scarcely claim to be *in* Education. Within AIED there is sometimes an attitude of superiority to the apparently soft discipline of Education: AIED feels it will eventually solve problems Education can only toy with, so AIED can appear insular. Can AIED draw on what Education has to offer and achieve communication with Education? Conversely, does Education take seriously anything from AIED? Does AIED have anything to offer anyway?

There will certainly be greatly increased 'demand-pull' from Education for insights and techniques that can enhance learning with computers; we argue that AIED should be able to match this with 'supply-push' of precise theory, practically valuable techniques and conceptual insights of value to Education. Further, AIED has made great progress in broadening its perspectives on learning and so should be able to communicate with Education. In short, mainstreaming of AIED into Education will be justifiable. Achieving this outcome will however require great effort by AIED.

We focus our 2010 essay on Education because we believe that AIED's relation with Education will be a crucial indicator of AIED's future health and the extent of its contribution. We start with our view of AIED development then turn to Education.

By referring to AIED and AIED researchers we do not intend to imply sharp classifications. Leading workers in the field typically publish in discipline journals—whether of computer science, psychology, education or another discipline—as well as in recognised AIED outlets.

OUR TELLING OF THE AIED STORY

In the early days AIED was to some extent computer scientists at play. AI was itself under criticism from outsiders but to insiders promised wonderful things. The focus in AIED was on technical possibilities for knowledge representation, reasoning, and even natural language. Scant attention was paid to pedagogy or learning. The model of learning underlying many systems was implicit and naïve, often amounting simply to tell-the-student, or fill-the-vessel.

There were important exceptions. Carbonell in SCHOLAR (1970) discussed mixed initiative dialogue between learner and system, thus giving the learner the scope to set the agenda. Burton and Brown (1982) adopted 'guided discovery', aimed to have their learners develop divergent skills, and discussed with insight their need for a pedagogical model.

However AIED was largely the study of Intelligent Tutoring Systems (ITSs) and most effort went into technical exploration rather than conceptual or empirical analysis of learning or pedagogy.

In the late 1980s came a striking sea change. ITSs were recognised as narrow and brittle. The learner became the focus and learning environments (LEs) were accepted in AIED alongside ITSs. Wenger's (1987) massive review marked the end of the old. His organising metaphor of 'knowledge communication' was, from the perspective of earlier days, enlightened, but it quickly became widely criticised because the field was moving beyond such a one-way view of learning to a collaborative conception, with learner initiative assigned a central position.

Lawler and Yazdani (1987) brought together ITS and LE papers and spoke of 'the exciting prospect of the "coming together" of the two traditional streams of "tutoring systems" and "learning environments"…' (p. vii). Self, who had initially recognised (1974) the central role learner modelling must play in AIED, advocated (1990; also Cumming & Self, 1991) a broader conceptualisation of learner models, in tune with the broader concept of learning. The learner model should not be the secret dossier of an authoritarian ITS, but another resource placed before the learner by a LE seeking to support the learner's efforts.

In the last decade AIED has continued to draw on advances in AI but the most spectacular development has been the flowering of broadened concepts of learning and pedagogy, and these have to some extent merged with similar concepts and debates in Education. Many AIED researchers would be happy to be described as cognitive scientists.

Andriessen and Sandberg's recent IJAIED paper (1999) makes a detailed and convincing case that AIED has broadened its conceptions of learning and pedagogy, as we also argue here, and discusses how AIED can develop and apply its techniques to a range of diverse educational needs. This paper is an example of the excellent tendency for contemporary AIED to emphasise educational demand-pull over technical supply-push.

Many AIED researchers are not only aware of important currents in Education but are leading participants in the debates—in Education, psychology and cognitive science. For example Collins, Brown and Newman (1989) and Brown, Collins and Duguid (1989) are widely-cited papers on expertise and the situated view of education published in mainstream outlets by noted AIED researchers. Similarly Anderson, Reder and Simon (1996, 1997) and Greeno (1997) debated the situated paradigm in a leading Education journal.

Taking richer views of learning does not undermine the need for knowledge representation, learner modelling and the technical expertise of AIED. Even taking a situated view of learning does not remove the need for modelling (Clancey, 1997, 1999), which endures as a major focus for AIED.

Naïve views of learning can still be found but our conclusion is that AIED has broadened remarkably to take seriously fundamental issues of learning and pedagogy. AIED is participating in important current developments in Education and cognitive science. In these ways AIED has lifted its game greatly, and should no longer be dismissed by Education as technically-bound, and pedagogically narrow and naïve. This is one aspect of mainstreaming AIED into Education and it is occurring.

So AIED is embracing Education, but is the converse occurring, and can it be justified?

THE DISCIPLINE OF EDUCATION: LEARNING IN GROUPS

Here we examine Education's capacity to make best use of computer possibilities to enhance learning. We argue that Education is not comfortable with precise theories and is predominantly the study of learning in groups, and for these two reasons is not well-prepared to exploit technology optimally in the service of learning; further, Education has very little knowledge of AIED. We then examine the subfield of Educational Computing and ask what relation it has with AIED.

Mention within Education of a precise theory of learning is likely to bring to mind behaviourist models, rightly dismissed long ago as simplistic and narrow. Education regards its advance to richer models of learning and to qualitative and hermeneutic approaches as precluding precisely specifiable theories. This is a strong preference about types of theory, and its corollary is that tutoring systems, which are seen as based somehow on precise models, are also viewed with suspicion and distaste.

Turning to the second reason, in AIED individualisation is a central goal, but Education has developed overwhelmingly to support schools, class teachers and teacher training. Individualisation is recognised as the one manipulation that can substantially improve learning (Bloom, 1984), but even so Education is, understandably, almost exclusively about learning in groups.

There are strands within Education that study individual learning, for example phenomenography (Marton, 1981), and constructivism (Cobb, 1994). Piaget's studies of cognitive development in individuals are extremely well-known, but educational psychology largely takes theory and findings about the learning and memory of individuals over into an Education discipline concerned with groups. The overwhelming emphasis is on understanding learning and teaching in the ubiquitous class-size group.

There is especially little study of how teachers can effectively teach individuals. (By 'teach' we include guide, instruct, advise, support, explain, assess, reflect, motivate…) Goodyear (1991, referred to also below) sought examples in Education of studies of one-to-one tutoring expertise but had to turn to music and sport.

In Education there is research on teachers' thought processes (Berliner, 1987; Clark & Peterson, 1986) but again the context is almost always the classroom and the focus is usually on response to student behaviour rather than cognitive aspects of tutoring individual students.

We contend further that Education has very little knowledge indeed of AIED. We have not carried out analysis of citations to support this claim but examination of Education handbooks found little more than one isolated reference—Winne (1994) in a discussion of information processing theories of teaching cited Self (1990) on difficulties of student modelling—and one insightful discussion of AI possibilities in relation to mathematics education (Kaput, 1992).

Educational Computing

Educational Computing is concerned with using computers for learning across and beyond the curriculum, mainly in schools. Constructivist views of learning are often taken (Papert, 1980, 1993), and practical issues receive much attention, for example curriculum rigidity, staff development and resources in schools. To an AIED researcher many issues would be familiar, including tools, simulations, learning environments and collaboration.

In stark contrast however most practitioners and researchers in Educational Computing know little of contemporary AIED. Mention of AIED is likely to elicit a strong negative reaction, bringing to mind despised authoritarian transmissive views of learning and fears of allegedly intelligent tutoring systems that administrators might use to displace teachers. The 'AI' label undoubtedly contributes to the negative reaction.

Parental and political pressure is largely for teaching *about* new technology and mainstream software applications, in the hope of enhanced employability. These applications are used across the curriculum, often with benefit, but practitioners and researchers in Educational Computing are seeking more fundamental enrichment of learning. The pressure to have Microsoft Office as the main focus is seen by many as a large threat. AIED and tutoring systems can easily be seen as one further way that an impoverished view of learning might be forced on teachers and their students.

Educational computing should be the area in Education most receptive to AIED, but at present it may be even more rejecting than Education in general.

Education is not equipped to support future learning with technology

Education's great strength is its practical understanding built on rich conceptions of learning, but it is dismissive and suspicious of the modelling precision that powerful computer systems are likely to need. It is dismissive both of precise theory and of computational systems for learning that are based on these. That, plus its focus in the classroom and neglect of individual tutoring, leaves it poorly equipped to be effective in maximising the benefits of technology for learners. In addition Education knows little of AIED, and educational computing in particular often has negative reactions to AIED.

Is the situation hopeless? Does AIED have reason for optimism, and what needs to be done?

WHAT AIED HAS TO OFFER

AIED can claim educational legitimacy because it now embraces sophisticated views of learning. This is the prerequisite for entering debates about how technology can best serve learners.

That first strength was recently acquired, but AIED's second major strength was foundational. In the words of Self (1999), at least part of AIED '…has as its scientific goal to make computationally precise and explicit forms of educational, psychological and social knowledge which are often left implicit.' (p. 1)

AIED's modelling abilities will be the basis for claims it can make a major contribution to future education that uses technology. We return below to modelling after considering some less well recognised things AIED has to offer.

Research on one-to-one teaching

AIED needs to understand one-to-one teaching, and has realised that Education has little to say about this. An early insightful statement was that of Burton and Brown (1982):

> In general, solutions to these problems [of designing tutoring interventions] require… explicit tutoring principles about interrupting and advising. These, in turn, require a theory of how a student… learns, and when he is apt to be most receptive to advice. Unfortunately, few, if any, existing psychological theories are precise enough to suggest anything more than caution. The requirements that evolve from designing coaching systems should provide useful goals… for future cognitive theories. In addition, the coaching systems themselves should be good test environments for such theories. (pp.80-81)

Burton and Brown identify:

- AIED's need for a precise model of one-to-one teaching.
- The inability of psychology (or Education) to provide such theories.
- That AIED's requirements and experience should help shape these.
- That AIED systems provide a good testbed for developing theories of individual learning and teaching.

Psychology has since made progress on the second point (Anderson et al., 1996, Ohlsson, 1991), but the observations are still largely valid.

A large proportion of what little research has been carried out on one-to-one teaching has been the work of AIED researchers, or at least inspired by AIED needs. Some notable examples such as Collins and Stevens (1983) have achieved recognition within Education but most are little known beyond AIED.

Putnam (1987) studied elementary school teachers giving tutoring to individual children or to a computer simulation of a student. The results were interpreted in terms of teachers' curriculum 'scripts', and contrasted with a detailed diagnose-then-remediate strategy often attempted in ITSs. This research was published in Education but was we believe primarily prompted by AIED. Such research is of great value to AIED but also deserves wider recognition in Education.

Goodyear (1991) collected papers about the teaching knowledge needed by AIED. He referred to the study of a wide range of one-to-one teaching situations, including music and sport coaching, therapy, computer help desk, and individual academic tutoring (p. 13). However it is notable that the great majority of research mentioned in the book on one-to-one teaching had AIED origins. The one chapter clearly from Education (Calderhead, 1991) concerned the cognition of class teachers and pointed out the difficulty of extrapolating to AIED needs. Goodyear lamented that AIED's 'methods of mining this literature [Education research on teaching] are still primitive' (p. 13). This may be so but it is very hard to find nuggets in Education concerned with teaching of individuals.

Having obtained knowledge about one-to-one teaching this then needs to be used in the development of learning systems; Graesser (in press; Wiemer-Hastings, Wiemer-Hastings, & Graesser, 1999) describes AutoTutor, whose design is based strongly on analysis of human tutoring.

Education could have studied individual tutoring but it seems that AIED has generated much of what is known on the topic, and is now applying this knowledge to enhance learning with technology.

Learner modelling by teachers

It is simple logic that response individualised to a particular student must be based on some information about that student. In AIED this realisation led to learner modelling, which became a core or even defining issue for the field. In Education however there has been little or no use of the idea that a teacher giving individual guidance must have constructed and be using some sort of model of that learner. Calderhead (1991, p. 274) and Brophy (1991) recognised the importance of teachers' use of learner information, but could only urge that it be taken up in future research.

In the Mayday project (Cumming, Sussex, Cropp, & McDougall, 1997) we attempted to identify the learner information used by expert human teachers. We observed interactions as a teacher advised a learner of English as a Second Language who was working at lexical tasks at the computer. We analysed video records and teachers' commentaries and concluded that expert teachers use a very wide diversity of types of individual learner information, some specifically acquired by questioning, but it is typically fragmentary and conjectural, and often mistaken. There is a striking contrast with the AIED strategy of constructing a more or less complete learner model, of domain knowledge only. Self (1990) had earlier noted the need for AIED to include a much wider variety of information in learner models.

A better understanding of how teachers use learner models will be valuable for AIED. Further, if Education is to understand individualisation it needs to start to study teachers' use of learner information. The importance of learner modelling in individualisation is a basic insight AIED can offer Education.

Further contributions from AIED

Aptitude-treatment interactions (ATIs) have long been sought in Education, but with little success (Cronbach & Snow, 1977). Shute and colleagues (e.g. Shute, 1992) have presented what may be the largest and strongest evidence of ATIs. Much early ATI work was with whole classes and gave noisy data, but in Shute's work individual learners worked at computers to be tested for aptitudes and to carry out learning activities with an ITS, so the analysis of potential ATIs could be much more fine-grained.

More broadly, many writers have emphasised the value for Education of using ITSs or LEs as research settings. Individual data are easily collected and control is good of the materials, guidance and opportunities presented to learners.

Ohlsson (1991) argued not just that AIED affords rigorous testing of precise educational theories, but that such testing is the core business of AIED. Implementing another tutoring system is not a worthwhile research contribution unless it allows testing of an educational process or model. AIED, argued Ohlsson, should and will merge into cognitive psychology—now we might say cognitive science.

AIED is concerned with individualisation but also increasingly with collaboration and learning in groups (Andriessen & Sandberg, 1999). All the AIED issues of knowledge representation, learner modelling and formalisation of pedagogical expertise are relevant also for collaborative and group learning. AIED is only beginning to look seriously beyond the single learner but as it does its findings will be more immediately relevant to group-oriented Education.

Theory, artefacts and insight

Thinking more generally about AIED's offerings mentioned briefly above we propose three broad ways AIED should be contributing to Education.

1. Theory in Education and precise models of learning

Some in AIED may wish simply to build systems that work in practice, but most recognise that AIED will be a coherent and cumulative scientific field only if great attention is paid to building sound theory. Computationally precise models of learning and teaching are core business. It is within modern AIED that this focus on detailed modelling co-exists with recognition of rich, sophisticated concepts of learning. Education has the latter but is suspicious of the former, and so is alienated from AIED.

It would be a wonderful contribution if AIED can show that rich conceptions of learning are not antithetical to modelling, but can indeed be made more solid and comprehensible by precise modelling. Some writings from the situated viewpoint are highly relevant to this endeavour (Clancey, 1997, 1999). Education should welcome precise theory, and is likely to do so if it can be persuaded that precision is not imcompatible with richness of conception. Making this case may be AIED's greatest potential contribution to Education, and a very large step towards mainstreaming.

2. Computer-based learning systems found effective in practice

These are the target applied artefacts of AIED. When such systems are used by learners in realistic settings, give good measured learning gains and are well-received by students and teachers (Koedinger, Anderson, Hadley, & Mark, 1997), then Education will have to take notice. Better appreciation by Education of the theory and design underlying the systems should follow, and lead to constructive engagement of AIED and Education theoretically as well as in practice.

3. New insights afforded to teachers and researchers in Education

The Logo community has formed something of a bridge between AIED and Education, especially in the 1980s. One powerful idea to emerge was that of Sylvia Weir (1987): she argued that close observation of a learner working in a learning environment can give a 'window on the mind'. Of course any insightful teacher will say it is illuminating to observe a learner's behaviour; Piaget made a career of this. The claim is that particular sets of tools, Logo procedures for example, can be especially valuable. Further, computational tools based on some modelling of knowledge, or cognitive processess or structures, are particularly promising; so much the better for AIED!

A striking experience for one of us (AM) was a class in 1981 for trainee maths teachers in which the BUGGY project (Wenger, 1987, chapter 8) was described. The project's goal was a computer system to diagnose and remediate, but it was the educational analysis and findings that excited the would-be teachers. Children can make mistakes in so many ways! The thinking underlying a mistake can be somewhat sensible! Teachers are usually those who when younger did not have the difficulties themselves, so it can be particularly instructive for them to understand better the various ways children's thinking can be imperfect. It did not matter that the tutoring system was unavailable, or even that later work might show it not to be especially effective. Our conclusion is that educational analysis by AIED researchers was seen by teachers to give valuable insight.

Thinking further about this far-reaching if speculative issue of educational insight that AIED might afford, we are struck by a certain amount of parallelism between Education and AIED, with lack of good communication between the fields. For example both give attention to the study of misconceptions and how they might be overcome. We speculate that mainstreaming would bring valuable synergy between these endeavours, with precise modelling being a notable contribution from AIED.

We made brief claims above about the value for Education of consideration of teacher's learner modelling. Further speculations belong in this subsection. We suppose that a teacher is led to think about what learner information underlies some teacher comment, or range of possible comments the teacher is considering. A likely result is that the teacher becomes more reflective about their practice, in a way that is highly relevant to the effectiveness of their teaching behaviour at the micro level. Speculation could be taken further, but the basis is the realisation, which came from AIED, that specific information about a learner has a central role.

Our conclusion from this whole section is that AIED has methods, theory and empirical findings that have not yet attracted the recognition by Education that they warrant.

TOWARDS 2010

Is it just the fantasy of researchers wearing AIED blinkers that the field is wonderful and that, if only the world (Education in particular) understood better, it would be universally loved? Why should mainstreaming of AIED occur by 2010 when it has not happened over the last 30 years?

Trends in Education

The classroom and lecture hall will not have disappeared by 2010 but their resilience will be stringently tested, as Web and other computer-based learning activities expand. Provision of technological possibilities may be skewed towards affluent learners, but to some extent technology-delivered education may be the poorer, cheaper option if costly but essential human teaching is not available also. In whatever ways economic and political pressures are played out in various communities, more of learners' time will be spent with technology.

This increase in computer use will bring to the fore in Education questions of how to design computer-based learning resources that are effective, while retaining allegiance to Education's rich conceptualisations of learning. These are precisely the issues on which newly-enlightened AIED claims insight, so Education should discover that it needs AIED!

Special-purpose computer applications are quickly adopted by learners if their value is clear: for example CD-ROM databases of anatomy and pathology information and hand-held computerised Japanese-English dictionaries have rapidly come into wide use. Many such computer-based information appliances (Norman, 1998) for learning are likely be used in informal settings, so learners may especially appreciate the individualisation that AIED should be able to contribute.

It is not simply a matter of increased learner use of technology: in university education, managers under enormous pressure to reduce costs are prompting rapid expansion of remote delivery of courses in a global market. However the materials are often based on a simplistic transmissive model of learning, to the dismay of thoughtful workers in Education (and AIED!). Education will therefore seek a larger role in deciding how technology is used for learning, with a focus on the learning and teaching needs and processes of individuals. For this reason also Education should be open to discovering that AIED has been working on such things for some time. Most broadly the great expansion of learning via technology is the main reason why AIED's recognition is more likely in the next decade than in the last three.

The challenges to AIED

Education should thus be receptive, but AIED will need to overcome negative perceptions of 'AI', narrow tutoring systems and rejected models of learning. Evaluations of learning systems found effective in practice, like that of Koedinger et al. (1997) are likely to be important. Note that in this case teachers were enthusiastic advocates of expanding the use of the computer-based systems, thus countering fears in Education.

Analysts of innovation in education (Fullan, 1991) make clear that it is not sufficient to demonstrate an improved technique. Wide take-up depends also on many educational, social and political factors. AIED will need to be alert to these, although the two examples of rapid take-up mentioned above suggest that the larger challenge for AIED may be to make sure it is participating as such systems and devices are developed.

A central challenge for AIED is to show that precise modelling can be used with rich conceptualisations of learning. This should be recognised as an important research issue, with one goal being practical results that Education will find persuasive. A related challenge is to exploit the undoubted value (Ohlsson, 1991) of AIED systems for research on theories of teaching and learning, and to demonstrate this potential to Education.

Assessment of student learning has not been much discussed in AIED, but expertise in learner modelling should allow AIED to offer sophisticated assessment of student learning. Achieving this would attract the attention of Education, for which assessment is a central issue.

There are thus a range of challenges for AIED if it is to seek mainstreaming: most broadly it needs to communicate effectively with Education.

What AIED should be doing

To work towards mainstreaming AIED should:

- Reinforce its focus on educational issues, especially (i) adoption of rich concepts of learning and (ii) development of precise models of learning and teaching. Show how these can be combined.
- Take up Goodyear's (1991) challenge to 'mine' Education research for additional insights of value to AIED, especially for any additional understanding of teaching.
- Strengthen AIED's engagement with Education. Ensure AIED is participating in current developments and so can communicate well with Education.
- Explain to Education (and the world) the techniques, theory and findings that AIED has found that should be of value to Education. Emphasise that AIED is theoretically strong as a research field, and increasingly giving rise to applications. Publish in Education and educational computing journals (Cumming, 1998).
- Use evaluations of AIED systems in practical use (Koedinger et al., 1997) to encourage development and use of Intelligent Learning Environments.
- Reconsider the label AIED, especially the 'AI'. Arguably 'AIED' does not describe the contemporary field well. A label that needs explanation, or apology, does not communicate optimally. On the other hand the field deserves a distinctive name.

- Note contemporary pressures for much wider use of computers for individual learning, and use this as a base for the outreach activities listed above.

We are not arguing, defensively, that AIED needs the legitimation of recognition. Rather we are convinced that mainstreaming would strengthen both AIED and Education as research fields. At the same time, inexorable expansion of technology use for learning should prompt acceleration of the application of AIED techniques to enrich such learning. Successful applications will help the mainstreaming we advocate as well as improving learning systems being used by large numbers of learners.

The identity of AIED in 2010

An extreme reading of our mainstreaming argument might suggest we want AIED to disappear into Education. By contrast we wish to emphasise the crucial importance in AIED of computer science and AI expertise of the highest order. AIED, by whatever name, should overlap with cognitive science and have strong links especially with Education, psychology, and AI and computer science. Being such a multidisciplinary field carries the stringent demand that AIED keep at the forefront of all of the contributing disciplines. None of the contributing disciplines need do this, so AIED has the hardest job of all, but being multidisciplinary also underpins the excitement, and now the great practical potential of the field.

A possibly renamed AIED should be contributing strongly in 2010 and beyond, and will do so even more powerfully if it can mainstream with Education.

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