AI and Education - Grand Challenges

Judy Kay,
School of Information Technologies
University of Sydney,
Australia
email: Judy.Kay@sydney.edu.au

(Artificial Intelligence in Education Department)

Abstract—Artificial Intelligence in Education (AIED) is a research area that began at the same time as earliest AI research. Motivated by the goals of creating and exploiting technology to improve education, it has produced a large body of work that both draws upon and contributes to broader AI research and cognitive science. This column outlines the architectural elements of AIED systems and how these are related to diverse aspects of AI and describes the Grand Challenge problems that are linked to AIED.

Index Terms—Applied computing, Cognitive Science, Education, Grand Challenge Problems

1 INTRODUCTION

Welcome to the inaugural article of this new department on AI and Education (AIED). The IEEE Expert editorial board created this department both because of the profound importance of education and the high calibre of AIED research. This makes AIED typically of much AI research, being a combination what has been described in Pasteur’s Quadrant [1] as both use-inspired basic and pure applied research.

The figure below illustrates the way that educational problems drive AIED research to create new learning systems as well as the foundational knowledge that will enable them to be built. The figure also shows the term Intelligent Tutoring Systems (ITS) which is generally considered a near synonym of AIED. The figure shows how these AIED/ITS systems may be created by drawing upon existing AI theories, tools and techniques – the downward arc on the lower left being pure applied research. Equally, the demands of the systems may drive researchers to make advances in fundamental AI, as indicated in the upward arc at the lower right – use-inspired basic research.

AIED research has had a similar relationship to models of human cognition and other aspects, such as affect and motivation. The figure shows that these, too, can be drivers for fundamental AI research and that there is a reciprocal relationship, with fundamental AI serving to create models that inform understanding of cognition. There are additional links between models of understanding of human cognition and AIED systems. Important AIED research includes studies of people, to gain understanding of what makes for effective learning and teaching. Similarly, the gold standard for evaluation of AIED systems measures whether they enhance learning outcomes; this can inform models of cognition.

So what is AIED? One way to answer this question is to look at the key publication venues for the AIED research community:1 The 15th biennial AI in Education conference (AIED) will be held in 2013 and its sister conference, Intelligent Tutoring Systems (ITS) runs in alternate years with AIED, with 2012 being its 11th. Its journal, International Journal of Artificial Intelligence in Education (IJAIED) began in 1989. There has been much that has stayed the same across that time, in terms of the goals of AIED. Of course, with the huge changes in AIED and technology, there have also been important changes. Figure 2 shows the typical architecture of AIED systems. Its boxes show the key elements of AIED systems and the unboxed italicised text shows indicative lists of the AI research that is important for these.

1. http://ijaied.org/about/
Fig. 2. Key elements of AIED systems

The boxes with italicised labels were part of the vision of the earliest AIED researchers who aimed to create personalised teaching systems. They were driven by a vision of enhancing learning outcomes by the huge margins that a highly skilled human teacher can achieve in one-to-one teaching [2]. These can move the performance of the average 50% achieving student by two signams, to the levels achieved by the top 5% of students in typical classrooms. This vision had a focus on the solitary learner. More recent work takes account of the broader learning context, in terms of the other people involved and context of the learning. It aims to gain the benefits of computer supported collaborative learning, taking account of and exploiting the context of the learner. Important it includes other people, notably parents.

Not all AIED systems have all the elements in the figure, not even all the italicised ones. However, one of the most common is the learner model. This holds a representation of aspects of the learner, such as their current knowledge, misconceptions, preferences and goals. It needs to represent those aspects that will drive the whole system, including interpretation of the learner’s actions and the system’s generation of its own actions. This is, arguably, the core of AIED/ITS systems because it enables the system to ‘care precisely’ [3] about the learner; it is the learner model that enables the system to better understand the learner and it drives personalisation of the teaching. It is shown in bold in the figure because its nature has changed, as explained below.

The figure shows the learner model as closely linked to two other key elements, the domain expertise and the teaching expertise. In practice, AIED systems need to have a tight coupling between representation used across these elements; all three need to operate together for effective teaching. The left of the figure characterises aspects of AI that are important for all three of these elements. This is reflected in the core topics of recent conferences [4], [5]. For example, one strand of these aims to improve AI theories, tools and techniques for knowledge representation, semantic reasoning and reasoning under uncertainty. AIED systems need to operate with uncertain, inconsistent and noisy sources of information about the learner. For example, learners make slips and also may good but uninformed guesses. Above all, AIED systems are designed with the goal of non-monotonicity; the model is expected to change, as the student learns!

The fourth element of the classic view of AIED systems is the user interface. This encompasses a very wide range of AIED research across perception, interface generation and intelligent immersive environments. The figure indicates several of these. Many AIED researchers strive to create interfaces that enhance the effectiveness of learning by making the interaction natural and compelling. For example, a long term and important strand of AIED research has aimed to provide natural language interfaces, calling for natural language understanding and generation and, in some cases, speech understanding and generation. Recent AIED research has included strong contributions in creating interface agents [6] in the form of an avatar that provides both language, facial expression and an identity associated with aspects such as their race and gender. There has also been considerable work to create interfaces that interpret the learner’s affective and motivational state. The figure points to some of the other diverse forms of interface, such as simulation and game environments [7].

The figure shows solid vertical lines between the user interface element and the expertise in the domain and teaching. This depiction of an AIED architecture has the teaching expertise element driving the interface actions and interprets the information from the learner, drawing upon the learner model and domain expertise. While there has been a very large body of very diverse AIED research, there have been some important recent trends. An important one has been the establishment of some systems that are founded on cognitive theories and there has been real progress in creating tools that make it easier to build upon components of previous systems. This is important in giving a foundation for exploration of new challenges and for moving towards real world deployment. The exemplars of this are the widely deployed cognitive tutors [8] and constraint-based tutors [9] in current daily use by thousands of students.

The remaining elements of the figure are not part of the orthodox view described so far. They reflect more recent and emerging trends. Notably, the figure shows the learner model as more than simply part of an AIED system. It can have a direct link to an interface as an open learner model [10]. More than this, it can be a first class citizen and exist independently of any single system [11]. The figure also shows that there is a role for models of others. This involves challenges of sharing data. It is also part of the task of supporting the individual learner as part of a broader social and learning group. With increasingly large collections of data about learners...
and their learning processes, there is an important and growing role for machine learning and data mining, reflected in the emergence of the educational data mining community 2 with its own annual conference and journal. [12]

The remaining part of the figure is the domain resources which represents the wealth of learning objects and tools that are available, especially on the web. So, for example, recommender technologies can play an important role for AIED [13]. Broadly, most areas of AI research are relevant to and can be informed by AIED research.

There has been growing recognition of the importance of AIED research. This is reflected in identified Grand Challenges. For example, the Computing Research Association identified just five Grand Research Challenges in Information Systems 3. One of these, A teacher for every learner, describes the potential for computing to transform education, enhancing learning outcomes for all and tranforming the way that people learn, throughout our lives. It describes the Grand Research Challenge “to provide learning environments that approach the effectiveness of one teacher for every learner.” It proposed specific research towards that goal in terms of highly effective personalised teaching systems, simulation-based educational software, massive multiplayer online games, collaborative authoring and learning in context and just-in-time.

The National Academy of Engineering identified 14 Grand Challenges for Engineering. One of these is Advance Personalized Learning 4. It points to successful web-based personalised learning materials and systems and recommender systems that help the learner find the right materials from the vast array available. It points to the potential of educational data mining, which can exploit the digital traces from digital learning activities. Like the figure above, it recognises the two way link between the human brain and engineering of learning systems, based on neuroscience and medical measurement technology.

The UK Computing Research Committee identified nine Grand Challenges in Computing Research. One of these is Learning for Life. It calls for the creation of technology that enables each learner to learn, as they can and want to do, and to partner the right teachers and learners. This challenge notes the need for effectiveness at the levels of the individual, groups and society. Unlike the earlier Grand Challenges, this one goes beyond the individual learner. Another UK Grand Challenge is Memories for Life, recognising that we are defined by our memories. Augmented cognition is linked to a broad view of AIED since our augmented memories are critical to life-long and life-wide learning. A third has the aim of Bringing the Past to Life for the Citizen, a bold vision of exciting learning of history and cultural heritage. In all, about half of these Grand Challenges link strongly with AIED research.

One last example of such visionary statements is the Microsoft Being Human, Human-Computer Interaction in the year 2020 5. It points to a range of aspects of learning. These include formal learning contexts, as well as learning with emerging new forms of mobile and ubiquitous interaction devices. There is recognition of the potential importance of rich and fine-grained data from the learner’s digital footprints. This can change the nature of assessment and provide parents with richer understanding of the children’s progress. There is recognition of the importance of learning in relation to life-long health needs, particularly as people age and need to take account of challenges to health and wellness. Emerging technology can capture valuable data about these and other aspects of life but we need to enable people to make effective use of that information. While this vision is cast as dealing with Human-Computer Interaction, it is replete with AI and AIED challenges. This is characteristic of the nature of AIED.

This introductory article has introduced three key ideas. It noted the two way flow between core AI theories, tools and techniques and AIED research, fundamentally motivated by educational needs. It aimed to characterise the elements of AIED systems. It pointed to the growing recognition of the need for AIED research to tackle recognised long term Grand Challenge Problems for computing and technology and how these comprehensively draw involve most areas of AI. AIED has already achieved much. At the same time, that progress has highlighted the potential to achieve practical and profound improvements in education.

**References**


Judy Kay

Judy Kay is Professor of Computer Science at the School of Information Technologies at the University of Sydney. She is a principal in the CHAI: Computer Human Adapted Interaction Research Group which conducts both fundamental and applied research in personalisation and pervasive human computer interaction. She has over 200 publications in the areas of personalisation and teaching and learning. She has presented invited keynote addresses at major conferences, such as UM’94 User Modeling Conference, Boston, USA; IJCAI’95 International Joint Conference on Artificial Intelligence, Montreal, Canada; ICCE’97, International Conference on Computers in Education, Kuching, Malaysia; ITS2000, Intelligent Tutoring Systems, Montreal, Canada; AH2006 Adaptive Hypermedia and Adaptive Web-Based Systems, Dublin, Ireland. ITS2008, Intelligent Tutoring Systems, Montreal, Canada.

Editorial Positions: Associate Editor, IJAIED, the International Journal of Artificial Intelligence in Education; Associate Editor, IEEE TLT Transaction on Learning Technologies; Editorial Board, UMUAI User modeling and User-Adapted Interaction; the Journal of Personalization Research. She is President-Elect for the AIED Society, (Artificial Intelligence in Education) and on the steering committee for ITS (Intelligent Tutoring Systems) and UM Inc (User Modeling).