AI and Education: Celebrating 30 years of Marriage

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Abstract. This article describes contributions that artificial intelligence (AI) has made and needs to continue to make towards long-term educational goals. The article articulates two challenges in education that require the use of AI: personalizing teaching and learning 21st century skills. This article first describes AI and some of its history and then suggests why AI is invaluable to development of instructional systems. Instructional systems that use AI technology are described, e.g., computational tools that personalize instruction, enhance student experience and supply data for development of novel education theory development. Additionally, some intelligent tutors supply researchers with new opportunities to analyze vast data sets of instructional behavior and learn how students behave.

1 A Brief History of Artificial Intelligence in Education

The field of Artificial Intelligence in Education is focused on research into, development of and evaluation of computer software that improves teaching and learning. Several long term goals have been espoused, such as to interpret complex student responses and learn as they operate; to discern where and why a student's understanding has gone astray, to offer hints to help students understand the material at hand and ultimately to simulate a human tutor's behavior and guidance. Personalized tutors have been envisioned that adapt to an individual student's needs or to teach to groups of students, e.g., classified by gender, achievement level, amount of time for lesson, etc. Another goal is to use Artificial Intelligence (AI) techniques learn about teaching and learning and to contribute to the theory of learning.

AI techniques are needed for almost every phrase in the definition of intelligent tutors above, including *interpret* complex student responses, *learn* as they operate, *discern* where and why a student's understanding has gone astray and *offer* hints. The central problems (or goals) of AI research include reasoning, knowledge, planning, learning, natural language processing (communication), perception and the ability to move and manipulate objects [1]. AIED has been applied to complex domains, e.g. physics, programming, writing essays, and reading. These tutors learn about the strengths and weaknesses of students in these domains and also about students' skills, and emotion. How effective are intelligent tutors? Several tutors have been shown to be very effective in the classroom. Researchers looking at student skills at end of experiments and also at the end of course and large scale standardized testing evaluations found dramatic improvement understanding and learning [2]. Intelligent online tutors are an AI success story [3], though researchers seek to move beyond domain dependence and to support learning of multiple tasks and domains.

To mentor effectively and support individuals or groups, intelligent tutors will assess learning activities and model changes that occur in learners. Estimates of a learner's competence or emotional state, stored in user models, represent what learners know, feel, and can do. When and how was knowledge learned? What pedagogy worked best for this individual student? Machine learning and data mining methods, both derived from the field of AI, are needed to explore the unique types of data that derive from educational settings and use those methods to better understand students and the settings in which they learn (see [2, 4]).

Technology cannot impact education in isolation, rather it operates as one element in a complex adaptive system that considers domain knowledge, pedagogy and environments that students, instructors and technology co-create [5]. AI and Education researchers need to be driven by the problems of education practice as they exist in school settings. The emerging forms of technology described here will challenge, if not threaten, existing educational practices by suggesting new ways to learn [6]. Policy issues that involve social and political considerations, need to be addressed, but are beyond the scope of this document.

2 AI called by a different name: AI behind the scenes

Many components of intelligent instructional systems have their roots in artificial instructional research, e.g., adaptive curriculum, modeling (student, teacher, domain), educational data mining, speech recognition and dialogue systems. All began by using artificial intelligence (AI) techniques. Yet once these algorithms and techniques begin to appear as parts of larger tutors, the tutors are no longer considered AI and AI receives little or no credit for their successes. Many of AI's greatest innovations have been reduced to the status of just another item in the tool chest of instructional designers or computer science. Nick Bostrom explains "A lot of cutting edge AI has filtered into general applications, often without being called AI because once something becomes useful enough and common enough it's not labeled AI anymore." [7] "After all, all smart technologies currently in use (in the classrooms or homes), from tablet computers to smart phones, from Internet search engines to social networking sites, have a growing reliance on techniques derived from AI." [7] The AI effect began in the larger AI field and "occurs when onlookers discount the behavior of an artificial intelligence program by arguing that it is not real intelligence." [7] Pamela McCorduck writes: "It's part of the history of the field of artificial intelligence that every time somebody figured out how to make a computer do something—play good checkers, solve simple but relatively informal problems—there was chorus of critics to say, 'that's not thinking'." [8] AI researcher Rodney Brooks complains "Every time we figure out a piece of it, it stops being magical; we say, 'Oh, that's just a computation.'" [9].

Intelligent personal assistants in classrooms or in smartphones use algorithms that emerged from lengthy AI research. IBM's question answering system, Watson, which defeated the two great Jeopardy champions by a significant margin, was derived from basic AI research in natural language processing, information retrieval, knowledge representation, automated reasoning, and machine learning technologies to the field of

open domain question answering [10]. In addition, the Kinect, which provides a 3D body–motion interface for the Xbox 360 and the Xbox One was derived from basic AI research [7].

AI is whatever hasn't been done yet. Software and algorithms developed by AI researchers are now integrated into many applications, without really being called AI, e.g., speech understanding as part of online travel reservations, expert systems that save companies millions of dollars (US). Michael Swaine reports "AI advances are not trumpeted as artificial intelligence so much these days, but are often seen as advances in some other field."[11] "AI has become more important as it has become less conspicuous," Patrick Winston says. "These days, it is hard to find a big system that does not work, in part, because of ideas developed or matured in the AI world." [12]**.**

3 Impact on Education

A related question about AIED relates to the impact of AI on education and focuses on the extent to which the results of AIED research are meaningful to real educational practice [13]. Does the education community even care? Similar to many fields aspiring to scientific rigor, the AIED community can showcase dozens of studies demonstrating the statistical significance of this or that approach or system or their individual components through rigorously designed studies, but it is not always clear how the results of many of those studies actually translate into real educational teaching and learning practices raising a question as to whether all this rigor may not be happening in a vacuum.

For example, schools in the USA are not thriving. Too many schools *teach in traditional ways* and aren't preparing the next generation to meet new challenges. When today's students graduate, they'll be asked to fill the jobs of tomorrow—ones we can't even imagine [14]. And they'll be asked to tackle global problems like climate change, endemic hunger, and refugee problems. Additionally, the current use of digital resources in K12 and higher education can be described as dysfunctional: many school stakeholders can't find sufficient effective digital resources, while large collections of resources exist and sit online, waiting to be discovered. Some solutions have been proposed to migrate successful evidence-based digital resources into classrooms. One solution is to define a roadmap that moves well-tested resources towards publishers and software companies and ultimately into classrooms.

More than 4 million USA students at the K12 level took an online course in 2011, up significantly from just 1 million three years earlier. During the coming decade education should shift from print to digital and from batch processing to personalized learning [15]. In addition to virtual schools, online learning is increasingly being incorporated into traditional settings that blend the best of online and face- to-face learning. A shift to online learning is happening in K12 in the USA due in part to the need to implement college- and career- ready standards, the shift to next-generation assessments, and the prevalence of affordable devices. Online learning may move

standardized teaching towards more personalized instruction without increasing the number of teachers.

The field of AIED, now nearly thirty years old, has finally achieved some of its oldest goals. Thirty years is calculated from the first Intelligent Tutoring Systems Conference, 1988, organized by Claude Frasson in Montreal, Canada. Some long-term goals are currently being worked on, including understanding and responding to student knowledge, meta-knowledge (thinking about learning), and affect [16-19]. Educational games and new forms of digital learning are being investigated. In many cases evaluation of student progress shows improvement in learning. Some of the success is due to increasing computer power and some due to researchers focusing on specific isolated problems and pursuing them with the highest standards of scientific accountability. The reputation of AIED, in the education world at least, is still not very positive, because few tutors are robust enough to work consistently in a classroom environment.

4 Future directions for AIED to justify and maintain its unique identity

AI techniques are essential to develop new representations and reasoning about cognitive insights, to provide a rich appreciation of how people learn and to measure collaborative activity. Communities of researchers offer distinct clues to further refine individual instruction in online environments and also require far deeper knowledge about human cognition, including dramatically more effective constructivist and active instructional strategies [20].

4.1 Personalize teaching

One-to-one attention is very important for learning at any age. Research has also shown that students' emotions influence achievement outcomes: confidence, boredom, confusion, stress, and anxiety are all strong predictors of achievement [21, 22]. However, teachers are unable to provide attention based on intimate knowledge of each student. Providing personalized teaching for every learner begins by providing timely and appropriate guidance for student cognition, meta-cognition and emotion [20]. In other words, online tutors should determine in real-time what to say, when to say it, and how to say it. This process grows increasingly complex as the topics become more difficult and the required detectors becomes more complex, e.g., detectors for students' knowledge, skills, or emotion. The field of Learning Science has provided a wealth of knowledge about how to deliver effective feedback and how to teach with new methods (e.g., problem-based learning [23]. Rich, multi-faceted models of instruction go beyond providing simple statements about correctness and provide feedback appropriate to each student's learning needs.

Mentoring systems should support learners with decision-making and reasoning, especially in volatile and rapidly changing environments. Learners often need to make informed decisions and justify them with evidence, gathered through collaboration and communication (see [24, 25]). Students need to learn science practices, scientific reasoning and how to apply facts and skills they have acquired. In collaborative

learning, students share their experiences and perhaps persuade others to see their point of view, and articulate what they need to learn more about. They "mess about" and generate their own questions about the targeted science. Groups of students need to be supported as they discuss their methods and results, ask questions and make suggestions.

Respond to student affect. Student emotion while learning is critical to understanding student behavior. Researchers are developing intelligent tutoring systems that interpret and adapt to the different student emotional states [26, 27]. Humans do not just use cognitive processes to learn; they also use affective processes. For example, learners learn better when they have a certain level of disequilibrium (frustration), but not enough to make the learner feel completely overwhelmed [28]. This has motivated researchers in affective computing to produce and creating intelligent tutoring systems that can interpret the affective process of students. An intelligent tutor can be developed to read an individual's expressions and other signs of affect in an attempt to find and guide the student to the optimal affective state for learning. There are many complications in doing this since affect is not expressed in just one way but in multiple ways so that for a tutor to be effective in interpreting affective states it may require a multimodal approach (tone, facial expression, etc.). One example of a tutor that addresses affect is Gaze Tutor that was developed to track students' eye movements and determine whether they are bored or distracted and then the system attempts to reengage the student [29].

AI might be a game changer in education. It provides tools to build computational models of students' skills and to scaffold learning. AI methods can act as catalysts in learning environments to provide knowledge about the domain, student and teaching strategies through the integration of cognitive and emotional modeling, knowledge representation, reasoning, natural language question-answering and machine learning methods [30]. When such tutors work smoothly they provide flexible and adaptive feedback to students, enabling content to be customized to fit personal needs and abilities and to augment a teacher's ability to respond. AI techniques appear to be essential ingredients for achieving mentors for every learner.

User models are being developed that leverage advanced reasoning and inference-making tools from AI, represent inferences about users, including their level of knowledge, misconceptions, goals, plans, preferences, beliefs, and relevant characteristics (stereotypes) along with records of their past interactions with the system. They might also include information on the cultural preferences of learners [31] and their personal interests and learning goals. When modeling groups of learners, the model should make inferences to identify the group skills and behavior.

Finally, providing a mentor for every learning group means improving the ability of intelligent tutors to provide timely and appropriate guidance. In other words, tutors need to determine in real-time what to say, when to say it, and how to say it. This grows more complicated as the skills demanded by society increase in complexity. The learning sciences have provided a wealth of knowledge about how to deliver

effective feedback, but the challenge is to incorporate 21st century skills, such as creativity and teamwork.

4.2 Teach 21st Century Skills

Citizens of the 21st century require different skills than did citizens from earlier centuries [20]. 21st century skills include cognitive skills (non-routine problem solving, systems thinking and critical thinking), interpersonal skills (ranging from active listening, to presentation skills, to conflict resolution) and intrapersonal skills (broadly clustered under adaptability and self-management /self-development personal qualities) [32]. We describe two AI techniques that can improve teaching for 21st Century skills: dialogue systems and inquiry learning.

Dialogue Systems. One key development for teaching 21st century skills is implementation of strong dialogue and communication systems. Human tutors can understand a student's tone and inflection within a dialogue and interpret this to provide continual feedback through ongoing dialogue. Intelligent tutoring systems are still limited in dialogue and feedback. Systems that begin to simulate natural conversations have been developed [33, 34]. However, more research is needed to understand student tone, inflection, body language, and facial expression and then to respond to these. Dialogue modules in tutors should ask specific questions to guide students and elicit information while supporting them to construct their own knowledge [33, 34]. The development of more sophisticated dialogues between computers and students partially addresses the current limitations in human-computer communication and creates more constructivist teaching approaches.

The 21st century worker needs both 'hard' skills (traditional domains, such as, history, mathematics, science) as well as 'soft' skills (teamwork, reasoning, disciplined thinking, creativity, social skills, meta-cognitive skills, computer literacy, ability to evaluate and analyze information). Further, working in today's knowledge economy requires a high comfort with uncertainty, a willingness to take calculated risks, and an ability to generate novel solutions to problems that evade rigorous description. Unfortunately, many of today's classrooms look exactly like 19th century classrooms; teachers lecture and students remain passive and work alone on homework problems that do not require deep understanding or the application of concepts to realistic problems. Our system of education is behind and the gap grows wider each day.

As we know, changes in educational policy, practice and administration tend to happen slowly. For example, in the U.S. about 25 years are required for an individual to receive a sufficiently well-rounded education to become a proficient educator [30, 35]. The impact of that individual's teaching cannot be seen in subsequent learners for another 20 years. Thus the total cycle time for learning improvement is on the order of 45 to 50 years. Very few challenges in research or social policy cover such a long time scale [36].

Inquiry and Collaborative Learning. What type of technology is needed to mentor students as they learn complex, ill-structured problems? How can technology support exploratory behavior and creativity? Open-ended and exploratory inquiry-based

systems support learners to question and enhance their understanding about new areas of knowledge [37, 38]. Innovative instructional approaches, such as preparation for future learning, have uncovered ways to increase comfort with uncertainty and promote development of adaptive expertise [39].

Engagement in the information society often requires people to collaborate and exchange real-time responses over lengthy time periods [20]. A single individual working alone over time often cannot provide enough expertise to solve modern problems (e.g., environmental issues, sustainability, security). Technology is needed to support small groups, class discussions, 'white boarding,' and the generation of questions. To support learners in groups, networking tools are needed to facilitate individuals to learn within communities, communities to construct knowledge, and communities to learn from one another [40-43]. AI software is needed to support students in collaboration, researchers to examine learning communities and learning communities to morph into global communities. For example, how do learning communities sustain, build on, and share knowledge? Students clearly do not construct original knowledge in the same way as do research communities, but they can learn from community-based project work [44].

Support for inquiry and collaboration is needed as students become exposed to diverse cultures and viewpoints. What is the process by which teams generate, evaluate, and revise knowledge? How can we enhance learners' communication skills and creative abilities? Which tools match learners with other learners and/or mentors taking into account learner interests? Finally research is needed to support exploratory, social, and ubiquitous learning. How can software both support collaboration and coach about content? Can technology support continuous learning by groups of learners in ways that enable students to communicate what they are working on and receive help as needed? Learning communities, networking, collaboration software and mobile and ubiquitous computing are being used to create seamless social learning [41]. Socially embedded and social driven learning is pervasive.

In a society built on knowledge, citizens need to acquire new knowledge quickly, to explore alternative problem solving approaches regularly and to form new learning communities effectively [20]. People need to tackle knowledge challenges and opportunities. For educators, this requires rapid revision of what is taught and how it is presented to take advantage of evolving knowledge in a field where technology changes every few years. As an example of rapid change and unpredictability, consider the Internet itself. It first appeared in the mid-1990s. By 2015, 37.3% of the Earth's population uses it. Internet services and applications apply to virtually every aspect of modern human life (e.g., research, banking, shopping, meeting people, health, travel, job seeking). How can education prepare students for a society that changes so dramatically and rapidly? In just 25 years the Internet has become a major factor in nearly every civilized activity and applies to virtually every aspect of human life. At the minimum, students need to be taught how to search it, learn from it, evaluate its information, use it wisely, and contribute to it with well-vetted information. One answer lies in improved and expanded learner competencies. Learners must be more creative, more agile, and more able to learn in groups; they

must know how to learn. Key features include skills in critical thinking, creativity, collaboration, meta-cognition and motivation.

5 Discussion

This article described why AI is vital in Education and identified two challenges: personalized teaching and learning 21st century skills. Specifically, personalized learning should be supported by tools that enhance student and group experience, reflection, analysis, and theory development. Learning 21st century skills should be facilitated by resources that improve human-computer interfaces (dialogue systems) and inquiry-based and collaborative learning. We also expect AI technology to contribute to richer experiences for learners who will then be able to reflect on their own learning. Learning scientists with AI tools will have new opportunities to analyze vast data sets of instructional behavior collected from rich databases, containing elements of learning, affect, motivation, and social interaction.

Research shows that skilled workers have more job opportunities than do less skilled workers [45]. As technology advances, educated workers tend to benefit more, and workers with less education tend to have their jobs automated.

Over the next few years we expect intelligent online instruction to increasingly be a part of the online learning landscape [46]. Maybe in five years, children will increasingly be online with educational games and simulation environments; behind the scene will be intelligent tutoring capabilities adapting the environment. Similar to working with Google, people may not know what the adaptation algorithm is doing, but it is changing the individual search ranking in the background [46]. Algorithms are there and making search more effective. Similarly, students will see action like this in the educational material they use, with intelligence in the background. Intelligent tutors may provide many of the benefits of a human tutor and also provide real-time data to instructors and developers looking to refine teaching methods.

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