Chapter 4
Smart Learning Environments: Potential and Pitfalls

J. Michael Spector

Abstract The history of educational technology in the last 50 years contains few instances of dramatic improvements in learning based on the adoption of a particular technology. An example involving a smart learning technology occurred in the 1990s with the development of intelligent tutoring systems (ITSs). The success of ITSs was limited to constrained and straightforward learning tasks (e.g., learning how to write a LISP function; doing multi-column addition), and improvements that were observed tended to be more limited than promised (e.g., one standard deviation improvement at best rather than the promised standard deviation improvement). Still, there was some progress in terms of how to conceptualize personalized instruction. A seldom documented limitation was the notion of only viewing learning from the perspective of content and cognition (i.e., in terms of memory limitations, prior knowledge, bug libraries, learning hierarchies, and hierarchical sequences). Little attention was paid to education conceived more broadly than simply developing specific cognitive skills with highly constrained problems. Recent technologies offer the potential to create dynamic, multi-dimensional models of individual learners, and to track large data sets of learning activities, resources, interventions, and outcomes over a great many learners. Using those data to personalize learning for a particular learner as they develop knowledge, competence, and understanding in a specific domain of inquiry is now a real possibility. While the potential to make significant progress is clearly possible, the reality is less promising. There are many as yet unmet challenges and pitfalls some of which are mentioned in this paper. A persistent worry is that educational technologists and computer scientists will again promise too much, too soon, at too little cost, and with too little effort and attention to the realities in schools and universities.

J.M. Spector (✉)
Department of Learning Technologies, College of Information, University of North Texas, 3940 N. Elm Street, Denton, TX 76207, USA
e-mail: mike.spector@unt.edu; https://sites.google.com/site/jmspector007/

K.A. Persichitte et al. (eds.), *Educational Technology to Improve Quality and Access on a Global Scale*, Educational Communications and Technology: Issues and Innovations, https://doi.org/10.1007/978-3-319-66227-5_4

1 Introduction[1]

Advances in computer science have historically made their way into educational technology, usually with at least a one-generation delay (see Spector & Anderson, 2000; Spector & Ren, 2015). As *artificial intelligence knowledge and expertise* have advanced in the last 20+ years, there have emerged powerful new technologies and some are finding their way into education as history suggests would happen. However, these new artificial intelligence (AI) technologies should not be embraced simply because they are new or have had some success in non-educational contexts. Dijkstra (1972) suggested in his famous essay entitled, *The Humble Programmer* that computers had not solved a single significant problem on a sustained basis; rather, computers have introduced a new problem—namely, learning to use them effectively. This seems to be the situation in which the world of educational technology now exists with regard to artificial intelligence and various AI devices and technologies.

The main message in this article is twofold: (a) there are indeed many possibilities for smart technologies to improve learning and instruction; however, (b) these possibilities have yet to be realized on a large scale and sustained beyond the efforts of demonstration projects. The challenges to making effective use of AI in education are many and varied, and we should be realistic with regard to recognizing and addressing these challenges.

First comes a context for these remarks. Then there is an elaboration of that context with key definitions. Afterward there is a discussion of some promising demonstration projects, and then there is a discussion of the challenges referenced earlier. Following that discussion, there are closing remarks with a few recommendations for how to proceed in a responsible and productive way with regard to making effective use of smart technologies in learning and instruction. The subsequent discussion is based on a broad view of technology integration in education from an evaluation perspective (see Spector & Yuen, 2016).

In 1978, the President of the American Educational Research Association collected and discussed a number of cases of effective educational research (Suppes, 1978, 1979). Suppes (1978, 1979) noted that educational research had only had a minimal impact on educational practice and policy. This is still the case some 40 years later, and it seems particularly true with regard to information and communications technology, including artificial intelligence and other smart technologies. The goal of educational technology and smart technologies in education research should be to do what is possible to ensure that smart technologies have a significant, sustained, and systemic positive impact on learning and instruction.

[1]A similar presentation and paper was also delivered at the annual Smart Learning Conference in Beijing, China in March 2017.

2 Definitions and Terminology

In order to create a clear and coherent context for these remarks, we begin with a few simple definitions (see Gagné, 1985; Laney, 2001; Merrill, 2013; Spector, in press, Spector & Yuen, 2016).

- *Learning*—learning can be characterized by stable and persistent changes in what a person or group of people know, believe, and/or can do.
- *Instruction*—instruction is that which is designed and/or intended to support, enhance, or improve learning.
- *Education*—education consists of systematic efforts to develop (a) basic knowledge and skills, (b) simple problem-solving skills, (c) productive workers, (d) critical thinkers, (e) responsible citizens, and/or (f) life-long learners.
- *Technology*—technology consists of the systematic and disciplined application of knowledge for a purpose recognized and valued by others.
- *Artificial*—artificial refers to that which is created or caused by one or more humans rather than something that occurs naturally without human intervention. An example of a natural occurrence is a volcanic eruption or the orbiting of planets around the sun in the solar system. There is a fuzzy boundary between that which is natural and that which is caused or created by humans. For example, the increase in earthquakes in Oklahoma might be caused by human activity—namely, fracking by the oil industry as opposed to other naturally occurring earthquakes caused by the movement of earth's tectonic plates (see https://www.bloomberg.com/news/articles/2016-11-08/why-oklahoma-can-t-turn-off-its-earthquakes). A clear example of an artificial device could be one of B. F. Skinner's teaching machines (see https://en.wikipedia.org/wiki/Teaching_machine).
- *Intelligence*—intelligence is even more difficult to define than that which is artificial. Common synonyms for "intelligence" include, among others (a) understanding, (b) comprehension, (c) critical reasoning, (d) smartness. Each of those terms is somewhat fuzzy as well. For example, "smartness" may refer to *street smarts*, which refers to an ability to deal effectively with everyday situations one is likely to encounter, whereas other uses of "smart" include things like being clever, or the ability to solve complex problems. In addition to multiple uses of the adjective "intelligent," there are multiple dimensions discussed about intelligence, including (a) cognitive, (b) emotional, (c) visual, (d) social, (e) kinesthetic, and more (Gardner, 1995).
- *Artificial intelligence*—AI is a branch of computer science, and also of cognitive science, that generally includes the notion of using computers to simulate human intelligence or to perform activities normally performed by a trained and educated person. For example, a house-cleaning person may have previously used a vacuum cleaner or even a broom to clean a floor; now there are robotic vacuum cleaners that can do that task reasonably well without human intervention.
- *Smart learning technology*—a technology that supports learning and instruction in a manner similar to that of a smart person and that is effective, engaging,

efficient, and empowering that typically is also adaptive, context aware, responsive to individual learner interests and progress, flexible, and likely to improve with use; examples include intelligent tutoring systems, as well as systems that track eye movement, emotions, and other learner characteristics that can be used to improve the quality of learning and instruction.

There are now a number of technologies in commercial and popular use that might be called intelligent, including (a) robotic vacuum cleaners, (b) self-parking automobiles, (c) advertising agents that can be found on many commercial sites, and (d) fraud detection algorithms now used by many banks and credit card companies. However, there are also many technologies which are called smart or intelligent that actually do not make use of computer algorithms to make decisions similar to those a smart person makes. Among these technologies that are not genuinely smart in the sense defined earlier are (a) smartphones, (b) smartboards, (c) smart watches, (d) intelligent tablet computers (e.g., iPads), (e) iText used to create and manipulate portable document format (PDF) files (see https://sourceforge.net/projects/itext/), and (f) refridgermagtons that scan your refrigerator and send a message indicating things in short supply. There is a fuzzy boundary with some of these cases. With regard to tablet devices and computers, there is now speech recognition software that allows for and supports a conversational interface, and speech processing is definitely a smart technology.

The devices that are genuinely smart technologies have yet to have an impact on learning and instruction, with the exception of natural language processing. The case for emphasizing natural language processing will become clear in the next section.

3 Trends and Demonstration Projects

Prior to discussing smart technology trends and some demonstration projects, there is a need to provide additional context in terms of lessons learned from educational research in the last 50+ years, as these are worth remembering when evaluating smart technology applications in education. There are at least three major lessons learned about that which predicts learning outcomes (Spector & Ren, 2015):

- Prior knowledge and experience—that is to say that students who have done well in the past are likely to do well in the future and that students with prior understanding in a particular domain are likely to progress more quickly than a novice in that domain; this lesson from the past has implications for using smart technologies to personalize learning and instruction, especially with regard to structuring activities appropriate for specific learners.
- Time-on-task—that is to say that students who spend more time on a particular learning activity or task are likely to do better than those who spend less time of those activities and tasks; this lesson also has implications for using smart tech-

nologies to support learning and instruction, especially with regard to motivation and engagement.

- Formative feedback—that is to say that learners who receive timely and informative feedback during learning activities are likely to develop knowledge and expertise more quickly than those who do not; this lesson has implications for using smart technologies to support dynamic feedback during and immediately after a learning experience and is one of the growth areas for smart technology in education in addition to the important area of conversational interfaces.

There also some lessons that have yet to be learned from past experiences with educational technology. One important unlearned lesson from the past is that replacement strategies rarely take into account the full potential of a new technology. For example, using an interactive smartboard the same way that a whiteboard had been used in a classroom fails to take full advantage of new affordances, such as engaging learners with the technology. Another common shortcoming of the past is believing that a single technology or pedagogical approach will solve most or all learning challenges. For example, some advocates of computer-supported collaborative learning argued that all learning activities should be collaborative, which has never proven to be completely effective (see, for example, Spector & Anderson, 2000). A third example is failing to appreciate the Clark-Kozma media debated of the 1990s (Clark, 1994; Kozma, 1994). In that debate, Richard Clark (1994) argued that what accounted for learning outcomes was primarily the quality of the instructional design, while Robert Kozma (1994) argued that new technologies made possible learning activities that were not possible without that technology or that use of media (e.g., interactive simulations). The resulting resolution of that debate was that new technologies did make new learning experiences possible, but what still mattered most was the design of the learning activities and the use of the technologies.

3.1 Trends in Smart Technologies in Education

One source for monitoring educational technology trends is the New Media Consortium's Horizon Reports (see www.nmc.org). The *2017 Horizon Report: Higher Education Edition* (see http://cdn.nmc.org/media/2017-nmc-horizon-report-he-EN.pdf) is summarized below with discussion of the implications for smart technology in education.

3.1.1 Key Trends

- Short-term (1–2 years): (a) blended learning designs, and (b) collaborative learning.
- Mid-term: (3–5 years): (a) growing focus on measuring learning, and (b) redesigning learning.

- Long-term (5+ years): (a) advancing cultures of innovation, and (b) deeper learning approaches. [The educational community uses “deep learning” to refer to an emphasis on critical thinking and complex problem solving whereas the computing community uses that term to refer to machine recognition of patterns hidden in disparate and large data sets.]

Where smart technology can play a key role in these trends is in measuring learning (especially with regard to dynamic, real-time formative feedback) and in fostering deep learning with regard to critical thinking and complex problem solving.

3.1.2 Significant Challenges

- Solvable: (a) improving digital literacy, and (b) integrating formal and informal learning.
- Difficult: (a) resolving the achievement gap, and (b) advancing digital equity.
- Wicked: (a) managing knowledge obsolescence, and (b) rethinking the role of educators.

With regard to responding to these challenges, the role of smart technology is somewhat less clear.

3.1.3 Important Developments

- One year or less: (a) adaptive learning technologies, and (b) mobile learning.
- Two to three years: (a) the Internet of Things, and (b) next generation of learning management systems (LMSs).
- Four to five years: (a) artificial intelligence, and (b) natural user interfaces.

It should be clear that according to NMC (2017) the major role of smart technologies in education has yet to be realized, and that it will involve natural language processing and conversational interfaces. We noted a few areas where smart technology might have an impact somewhat earlier, but the general point is that the future of smart technology in education has yet to be realized. Here are two statements that might serve as useful reminders: (a) it is not about smart technology in support of learning; what matters in the learning; and (b) it is not about a particular smart technology; what matters is how that technology is deployed and used by teachers, instructors, tutors, and trainers.

These two reminders reflect the interconnectedness of pedagogy, content, and technology (Mishra & Koehler, 2006; Shulman, 1986). Accepting these reminders suggests that how smart technologies are effectively integrated into learning and instruction is much more challenging than their use in non-education sectors. Recall the case of using smart technology to improve online sales. Why that works is due to the company having a profile of a current customer along with records of many other customers. Then, when this customer looks at, or purchases, a particular item, the online system can see what other similar customers who looked at and purchased that item went on to view and purchase. Such an advertising system can then suggest additional purchases to this customer. The challenge for us, however, is the learning context is much more complex. First, it is a challenge to identify other similarly situated learners. Then it is a challenge to see what worked for those learners and use those data to customize a learning experience for this learner. As the *Horizon Report* (NMC, 2017) suggests, there is a long way to go before AI, learning analytics, personalized learning, and more generally, smart technology will have a significant, sustained, and positive impact on a large scale in learning and instruction.

3.2 Demonstration Projects

As previously mentioned, the first major phase of applying smart technology in education involved intelligent tutoring systems (ITSs; see Shute & Psotka, 1994). A typical ITS had a static model of the content to be learned, a static model of common misconceptions and misunderstanding, a dynamic model of what a learner had already learned with regard to the content knowledge, and a system to generate a next learning activity appropriate to that learner's progress. ITSs represented a significant advance from earlier efforts in the domain of programmed instruction including the teaching machines of B. F. Skinner. Content domains with recorded impact on learning included multi-column arithmetic for young children and LISP programming for college students.

4 Key Challenges

When the effort to effectively integrate learning analytics, big data, personalized learning, and smart technologies into education begins, as is quite likely, then the suggestion here is to take evaluation seriously (for a detailed elaboration, see Spector & Yuen, 2016). A few simple ideas to help one get started are presented here. While these ideas may seem simple and obvious, they have been overlooked for many years with regard to prior generations of educational technology innovations.

ITSs became prominent again in recent years with the development of cognitive tutors (Koedinger & Aleven, 2007). Cognitive tutors addressed more complex problem tasks than had been addressed by the previous generation of ITSs and they placed emphasis on dynamic formative feedback to learners. Cognitive tutors also began to represent more than a learner's progress in that domain including things such as interests and other knowledge.

A third case of progress with regard to smart technology applications in education involves advances in student modeling (Graf & Kinshuk, 2013). In this case, learning styles are explicitly recognized as relevant in addition to what the learner has already mastered. This area is using AI to address learners in a more holistic manner that takes into account more than previous performance in the ITSs (see also Spector & Anderson, 2000).

Other demonstration cases of successful smart technology applications in education can certainly be found. Our point is that none of these cases has yet to be embraced on a large scale, nor is there documented evidence of improving learning in significant ways beyond the research studies conducted in a variety of contexts. The potential for improved learning and transformed instruction surely exists, but the impact has yet to be fully realized.

5 Recommendations for Smart Technology in Education

Recalling NMC (2017) middle term key trends, there is the issue of growing emphasis on measuring learning. Given the additional emphasis in many countries on critical thinking and complex problem-solving skills, the issue of using smart technologies to provide dynamic formative feedback should be given high priority. An early example of the potential can be found in the Highly Integrated Model-based Assessment Technology and Tools (HIMATT) system (Pirnay-Dummer, Ifenthaler, & Spector, 2010).

Going forward, it is worth taking into account the lessons learned from prior educational research and those not learned. Adaptive and personalized learning should be well aligned with the lessons learned. This can be done by taking into account all that can be known about a particular learner to promote ongoing learning in a particular subject domain. Highly interactive and engaging learning activities and environments can be used to gain and maintain learning interest and promote motivation when learning to solve a complex problem becomes challenging. The third lesson learned from past research involves timely and informative feedback which we have already mentioned.

With regard to lessons not yet learned, careful and thoughtful attention should be paid to the training and ongoing support of teachers in the effective use and integration of new technologies. In addition, when introducing a smart technology into learning and instruction, it would be advisable not to claim that the technology will solve all problems. Rather, it would be advisable to engage teachers in identifying the problems to be addressed by the technology, how it might be used in the current or anticipated educational setting, and how its effectiveness can be determined. Finally, the strategy to be used when introducing a new technology should be to focus on the specific affordances of that technology and not simply try to replace a prior technology or methodology with a new one.

6 Concluding Remarks

What is evident from the discussion above is that powerful technologies continue to emerge that have a significant impact on learning and instruction. What is not clear is to what extent the technology can solve persistent problems in education. Intelligent tutoring systems have had limited success. The Internet has yet to revolutionize teaching and learning as promised and predicted. Significant barriers remain, including (a) ongoing support and professional development of teachers, (b) improving digital literacy of teachers, (c) clarifying the roles of technology in education, and (d) effective ways of integrating technology into learning.

Educational technologists have all too often become advocates of the newest technology and overestimated how that technology would impact and reform educational practice. However, what is important for learners is to become inquirers (i.e., have and explore questions), which involves admitting to being in a state of uncertainty or not knowing and to becoming engaged in a search for knowledge rather than learn facts and concepts. Perhaps we ought to place more confidence in properly trained, persistent, and dedicated teachers, designers, and administrators in order to meet the challenges and changes when introducing AI in education.

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J. Michael Spector is a Professor of Learning Technologies at the University of North Texas. He was previously a Professor of Educational Psychology and Instructional Technology in the Learning, Design, and Technology Program at the University of Georgia. Previously, he was a Professor of Instructional Systems at Florida State University. He served as the Chair of Instructional Design, Development and Evaluation at Syracuse University and as the Director of the Educational Information Science and Technology Research Program at the University of Bergen. He earned a Ph.D. in Philosophy from the University of Texas at Austin. His research focuses on intelligent support for instructional design, assessing learning in complex domains, and technology integration in education. Dr. Spector served on the International Board of Standards for Training, Performance and Instruction (*ibstpi*) as Executive Vice President; he is a Past President of the Association for Educational Communications and Technology (*AECT*). He is an editor of *Educational Technology Research & Development* and serves on numerous other editorial boards. He edited the third and fourth editions of the *Handbook of Research on Educational Communications and Technology*, as well as the *Encyclopedia of Educational Technology*, and has more than 150 publications to his credit.