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Evolution of Advanced Learning Technologies in the 21st Century

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Arthur C. Graesser

Evolution of Advanced Learning Technologies in the 21st Century

Developmental Editors: Bradley A. Henry and Hussam H. Kashou

The role of technology in education has mystified the contributors to Theory Into Practice (TIP) during its 50-year history. In the first issue of TIP, Guba (1962) was confident that “teaching machines are here to stay” and would help education, but raised various practical concerns, such as costs, programming resources, and acceptance by the education communities. Howell (1968) was confident that new technologies would change education, but not directly without educators understanding their potential and having a commitment to use them wisely. Caldwell (1980) emphasized the need to reconceptualize the use of computers in education by shifting the emphasis from mere information delivery and

testing systems to facilities that assist students in meaningful active learning, inquiry, and thought.

BY 1983, THE DRAMATIC CHANGES in digital computer capabilities had engendered sufficient uncertainty, controversy, and anxiety that there was the need for some serious reflection and planning among experts in education (Patterson, 1983; Tucker, 1983). According to Lesgold (1983), the first phase of the computer revolution had ended (namely, computers being a force in school) and the second phase had begun (namely, facing the challenge of deciding how they are to be used). The advent of personal computers, videodiscs, and other powerful computer tools could be construed as either a “promise or a threat” to teachers in classrooms (Lipsom & Fisher, 1983), making it important to have the teacher in the loop as the learning technologies were developed (Amarel, 1983). Roberts (1983)

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observed that the computer technologies were steadily penetrating offices and homes, whereas entry into the classroom was limited because of a substantial need to train teachers, staff, and education leaders on the capabilities of the new technologies.

There was substantial growth of new educational technologies in the 1990s because the economy was blossoming in the technology sector—the heyday of the *dot-com* era. Articles in *TIP* emphasized the need for educational reform to accommodate the new technologies. Bragaw (1992) lamented that teachers and administrators were too slow in making changes to the curriculum and pedagogy. Rigorous methods of teacher training and assessment were proposed, such as teacher portfolios, lesson plans, and videotapes of teaching (Baratz-Snowden, 1993; Ryan & Kuhs, 1993), but there was substantial uncertainty how this training would weave in new computer technologies. There were also worries that the new technologies would not reach the broad spectrum of populations with respect to race, ethnicity, class, gender, and culture (Damarin, 1998). By the year 2000, over half of the schools were connected to the Internet, but the schools encountered substantial problems finding ways to incorporate the Internet in learning activities (Johnson, Schwab, & Foa, 1999). This also was the case for other electronic media, such as CD-Roms, multimedia materials, and PowerPoint. During the last decade, the younger generation has fortunately found ways to learn how to use the new digital artifacts (Woolsey & Woolsey, 2008), often through experiences outside of school. At this point in history, the students in schools are more technologically proficient than the adult teachers. The major challenge currently lies in keeping students engaged in classroom environments when their standards for acceptable learning technologies are very high.

Three overarching conclusions can be made from this selective tour of previous *TIP* articles over its 50-year history. First, computer technologies are destined to penetrate educational practices at all levels. Second, new technologies are evolving at such a rapid pace that teachers, ad-

ministrators, and the public are having difficulties keeping up, so there is a need for new methods of teacher training and educational reform. Third, the students will be important partners in shaping the new learning environments because they are the digital natives with substantial expertise on technology. Interestingly, this expertise of the students is being acquired primarily from experiences outside of school with their family and friends.

The Optimists and the Pessimists

It is convenient to segregate the optimists and pessimists as nations and researchers struggle with new learning technologies. The optimists point to computers as empowering learners to achieve new levels of mastery, motivation, reasoning, inquiry, and self-regulated learning. There are many examples of this empowerment. Learners in the *Google generation* know how to access information within seconds on the Internet to find an answer to virtually any question they might have (Rus & Graesser, 2009); that is quite a difference from 50 years ago when a hunt through the books and journals in a library would take hours or days. Learners in the *computer simulation generation* spend hours manipulating the parameters of hypothetical worlds in an effort to understand complex systems (Funke, 2010), a capability entirely absent 50 years ago. Learners in the *game generation* are so absorbed in games, virtual reality, and mobile devices that they find it difficult to appreciate traditional formal education (Dede, 2009; Gee, 2003). Designers of educational technology are desperately trying to find ways to incorporate important, useful content and skills in the so called *serious games* (Ritterfeld, Cody, & Vorderer, 2009; Shaffer, 2006); this is a challenge when learners are skeptical of academic content invading their worlds of fun and entertainment. Learners in the *social media generation* communicate with dozens or hundreds of friends through Facebook, chatrooms, and instant messaging—and thousands through Blogs and tweets (National Research Council [NRC], 2011). These learners are no doubt learn-

ing more sophisticated paths of communication, collaboration, and social networking than was available 50 years ago. The optimists point to these landmark advances in digital technologies as radically influencing question generation, hypothetical reasoning, self-regulated learning, and social interaction—all being foundational knowledge and skills in the 21st century (NRC, 2011).

The pessimists have articulated many reasons to be skeptical of the new technologies in promoting learning. Educational historians have pointed out that advances in media such as radio and television have had little impact on the practice of formal education (Cuban, 2001). Educational researchers have argued that learning is not enhanced by learning environments that emphasize unguided discovery, inquiry, and constructivism compared with traditional pedagogies (Kirschner, Sweller, & Clark, 2006) and that learning may decrease for some forms of multimedia (e.g., animation) and game features (e.g., narratives) because they distract the learner from the primary academic material (Adams, Mayer, MacNamara, Koenig, & Wainess, 2012). The pessimists frequently remind everyone that technology does not directly cause improvements in learning, but rather it is the underlying pedagogical principles of learning that are responsible for any gains, a belief that is also endorsed by most of the optimists. However, the pessimists escalate the debate further by incisively identifying problematic pedagogical features of many of the new educational technologies.

The sensible compromise is to assume there is wisdom in the claims of both the optimists and pessimists. Quite clearly, it is essential to analyze the strengths and liabilities of any technology from the standpoint of empirical evidence in scientific investigations and a careful analysis of the learners' sociocultural ecology. A new technology is considered beneficial if it increases learning and motivation for important knowledge, strategies, and skills in the learner's sociocultural context. Motivation is extremely important when students have the freedom to control their learning experiences in a self-regulated manner.

Genres of Learning Technologies in the 21st Century

This section reflects on the different *genres* (categories) of learning environments with respect to learning and motivation in the 21st century. The emphasis will be on computer technologies that have been empirically evaluated and have survived for at least a few years in the fickle marketplace. Links will also be made to previous *TIP* articles that address learning technologies.

Conventional Computer-Based Training (CBT)

CBT (or what was once called computer assisted instruction) is the earliest genre of digital learning environment (O'Neil & Perez, 2003). Bitzer's (1973) forecast that CBT would be commonplace in the home and office in addition to schools was quite accurate. It is frequently implemented in formal education and the workforce because of its low cost and simple set of pedagogical principles. The essence of CBT lies in the learner studying material presented in a lesson with various media, getting tested with a multiple-choice format or other objective test that is immediately scored by the computer, getting quick feedback on the test performance, restudying the material if the performance is below threshold, and progressing to a new topic if performance exceeds a mastery threshold. The adaptive timely feedback is very different from classroom teaching where the teacher gives the same instruction to all students and gives individual feedback on tests or homework after many hours, days, or even weeks.

CBT is a mature technology that has been empirically tested for decades and has shown learning gains that equal or exceed classroom teaching in meta-analyses (Dodds & Fletcher, 2004; Dynarsky et al., 2007). However, CBT has three limitations that are widely acknowledged. First, the materials and pedagogical regime are not particularly engaging, so the student needs to be sufficiently motivated to complete the lessons. This limitation has been expressed in many *TIP* articles, as early as Caldwell (1980). Second,

CBT is much more appropriate for the learning of simple facts, rules, and rigid procedures (called *shallow learning*) than for the mastery of complex conceptualizations and mental models (called *deep learning*). The alignment of pedagogical practice to the depth of the learning materials is, of course, essential (Koedinger, Corbett, & Perfetti, 2012). Third, teachers need to be trained on how to weave in these computer technologies to the curriculum, but there is insufficient professional development to support this, which is a theme that has pervaded *TIP* articles (Damarin, 1998; Roberts, 1983; Tucker, 1983).

Intelligent Tutoring Systems (ITS)

These systems evolved in the 1980s to enhance computerized learning environments over and above CBT and get at deeper levels of mastery (Caldwell, 1980; Lesgold, 1983). An ITS is expected to improve learning for individual students by fine-grained tracking of knowledge and skills, detailed substantive feedback, and intelligently selected next steps and lessons (Graesser, Conley, & Olney, 2012). Researchers incorporate computational models in artificial intelligence and cognitive science in these ITS. The selection and sequence of hundreds of interactive events in a learning session is tailored to the abilities and performance of a particular student so nearly every tutorial interaction is unique. These systems show impressive learning gains (a half to a full letter grade; VanLehn, 2011) compared with classrooms and suitable control conditions, particularly for deeper levels of mastery. For example, the *Cognitive Tutors* (Ritter, Anderson, Koedinger, & Corbett, 2007) have been teaching mathematics in thousands of schools in the United States. ITS have also targeted ill-defined verbal subject matters, such as the *Intelligent Essay Assessor* (Landauer, Laham, & Foltz, 2003) and *e-Rater* (Attali & Burstein, 2006) that grade essays on science, history, and other topics as reliably as experts of English composition. *AutoTutor* (Graesser, D’Mello et al., 2012) helps students learn about science and technology topics by holding a conversation in

natural language. The impact of the ITS on learning is well documented, but they are expensive to build, which limits their market penetration in school systems that have limited infrastructures (Geiger, 1994; Johnson et al., 1999). However, the costs are decreasing substantially in recent years so this genre is growing.

Multimedia and Animation

A common belief is that material is comprehended and remembered better when it is delivered in multiple modes (verbal, pictorial), sensory modalities (auditory, visual), or media (computers, lectures) than when delivered in only a single mode, modality, or medium. Students live in a rich world of multimedia, animation, and film, so learning environments need to include these components to optimize engagement and motivation. Learners benefit from animations to the extent that they present a detailed visible picture of how a system changes over time. Meta-analyses of empirical studies (Mayer, 2009) show that these environments improve learning, but there are potential liabilities. For example, material presented in multiple modalities run the risk of interrupting the learner from a coherent learning experience, of imposing a “split attention” effect (the mind cannot concentrate on two things simultaneously), or of overloading the learner’s limited supply of cognitive resources (Sweller & Chandler, 1994). A nuanced cognitive theory and body of empirical research is necessary to sort out the conditions in which multimedia helps or hurts learning. The need for grounding technology in an adequate pedagogical theory has been emphasized by many *TIP* articles over the years (Cook, 1962; Lesgold, 1983; Lipson & Fisher, 1983; Ryan & Kuhs, 1993; Woolsey & Woolsey, 2008).

Conversational Agents

Both teachers and students often learn by observing others, as in the case of tutoring (Lesgold, 1983) or videotapes of experts demonstrating effective teaching practices (Baratz-Snowdon, 1993; Lipson & Fisher, 1983; Woolsey

Table 1
24 Most Relevant Articles on Technology (of the 55 Identified as Related to the Topic)

Author(s)	Title	Year	Volume (Issue)	Issue Theme
Guba, Egon G.	The issue: Teaching machines are here to stay	1962	1 (1)	Teaching machines and language laboratories
Frankel, Jack	Change in the developing world	1688	7 (4)	Educational technology
Johnson, Ted, & Otero, Hector	The school and technology	1688	7 (4)	Educational technology
Radvak, Betty Jean	The teacher and technology	1688	7 (4)	Educational technology
Berry, Stephen D., & Miller, Charles I.	Where do we go from here?	1688	7 (4)	Educational technology
Howell, Wayne K.	Technology and the human need	1688	7 (4)	Educational technology
Bitzer, Donald L.	Computer assisted education	1973	12 (3)	The new science of information in education
Cruikshank, D. R., & Telfer, Ross	Classroom games and simulations	1980	19 (1)	Special issue: Teaching methods: Designs for learning
Caldwell, Robert M.	Improving learning strategies with computer-based education	1980	19 (2)	Special issue: Teaching methods: Learning applications
Patterson, Janice	This issue	1983	22 (4)	Special issue: Microcomputers/ A revolution in learning
Lesgold, Alan M.	When can computers make a difference?	1983	22 (4)	Special Issue: Microcomputers/ A revolution in learning
Lipson, Joseph T, & Fisher, Kathleen M.	Technology and the classroom: Promise or threat?	1983	22 (4)	Special issue: Microcomputers/ A revolution in learning
Amarel, Marianne	Classrooms and computers as instructional settings	1983	22 (4)	Special issue: Microcomputers/ A revolution in learning
Roberts, Linda G.	The computer age comes to our nation's classrooms	1983	22 (4)	Special issue: Microcomputers/ A revolution in learning
Tucker, Marc	Computers in schools: A plan in time saves nine	1983	22 (4)	Special issue: Microcomputers/ A revolution in learning
Donald Bragaw	Society, technology, and science: Is there room for another imperative?	1992	31 (1)	Science–technology–society: opportunities
Ryan, Joseph, & Kuhs, Therese	Assessment of preservice teachers and the use of portfolios	1993	32 (2)	Assessing tomorrow's teachers
Baratz-Snowden, Joan	Assessment of teachers: A view from the national board for professional teaching standards	1993	32 (2)	Assessing tomorrow's teachers
Geiger, Keith	Rethinking American schools in the post-Cold War era: Introductory remarks from the NEA president	1994	33 (2)	Assessing tomorrow's teachers
Damarin, Suzanne K.	Technology and multicultural education: The question of convergence	1998	37 (1)	Technology and the culture of the classroom

(continued)

Table 1
(Continued)

Author(s)	Title	Year	Volume (Issue)	Issue Theme
Michael J. Johnson, Richard L. Schwab, & Foa, Lin	Technology as a change agent for the teaching process	1999	38 (1)	Redefining teacher quality
Woolsey, Kristina & Woolsey, Mathew	Child's play	2008	47 (2)	Digital literacies in the age of sight and sound
Haskell, Kathleen S., & Haskell, Thomas O.	What differences technology makes for a high school career center	2008	47 (3)	New media and education in the 21st century
Williams, Leslie A., Atkinson, Linda C., Cate, Jean M., & O'Hair, Mary J.	Mutual Support between learning community development and technology integration: Impact on school practice and student achievement	2008	47 (4)	Collaborative learning communities in schools
Avila, JuliAnna, & Moore, Michael	Critical literacy, digital literacies, and common core state standards: A workable union?	2012	51 (1)	Qualitative research in the 21st century

& Woolsey, 1998). The primary way that a person learned a trade or skill prior to the industrial revolution was an apprenticeship model that involved one-on-one conversations with a mentor, master, or tutor (Collins & Halverson, 2009). Available research on human tutoring supports the value of learning by tutoring and collaborative social interaction (Cohen, Kulik, & Kulik, 1982; Graesser, Conley et al., 2012; VanLehn, 2011).

Pedagogical agents have recently been developed to serve as substitutes for human experts, tutors, and peers. These pedagogical agents express themselves with speech, facial expression, gesture, posture, and/or other embodied actions (Biswas, Leelawong, Schwartz, Vye, & Teaching Agents Group, 2005; Graesser, Jeon, & Dufty, 2008). The students communicate with the agents through speech, keyboard, gesture, touch panel screen, or conventional input channels. The agents help students learn by either modeling good behavior and strategies or by interacting with the students in a manner that intelligently adapts to the students' contributions. Agents also have been developed that respond

to the emotions of the learner in addition to their cognitive states and that display emotions through facial expressions, gesture, and speech intonation (D'Mello & Graesser, 2012). Previous *TIP* articles have not addressed the role of the new agent technology, which is evolving at a rapid pace in diverse educational environments. Learning environments with pedagogical agents are now available on the Web at low costs to the users, so this new technology could have a revolutionary impact on education.

Serious Games With Interactive Microworlds

The links between emotions, motivation, and deep learning emerge in the design of serious games (Gee, 2003; Ritterfeld et al., 2009; Shaffer, 2006). Lesgold (1983) identified games as one venue for promoting learning that adapts to individual learners, but the value of games has not been on the primary radar of *TIP* articles over the decades. Educational games ideally are capable of turning work into play (Lepper & Henderlong, 2000; Woolsey & Woolsey,

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2008) by minimizing boredom, optimizing engagement/flow, presenting challenges that the learner can handle, giving students choices and a sense of control, delivering immediate feedback, preventing persistent frustration, and engineering delight and pleasant surprises in an exciting fantasy and narrative (Ritterfeld et al., 2009). Dede (2009) described systems with immersive multiuser virtual environments, avatars, simulations, multiparty collaborative communication, game features, and other motivating features that are explicitly designed to encourage deeper learning and to satisfy educational standards.

The more pessimistic researchers have speculated that game design may be inherently incompatible with pedagogy (Prensky, 2000) and there may be features (such as narrative) that detract from serious learning of important material by diverting cognitive resources to nongermane activities (Adams et al., 2012). The optimistic view is that there needs to be careful analysis of how the features of games are systematically aligned with the features of pedagogy and curriculum (Tobias & Fletcher, 2011). Empirical research has not evolved to the point of there being an adequate meta-analysis on the impact of games on learning.

Collaborative Problem Solving With Social Media

Students of the 21st century are well versed in a variety of communication technologies (NRC, 2011). Instant messaging, chat rooms, and Facebook are the selections of choice in 2012 for friends whereas blogs and tweets share news with the world. The new media are destined to support the learning communities that were discussed in the *TIP* article by Williams, Atkinson, Cate, and O'Hair (2009). The social communication media are a moving target at the time this article was written and assessments of these communication media on learning are sparse. Studies are emerging on computer-mediated communication during the process of collaborative learning and problem solving, but no systematic meta-analyses

have been conducted. This will be an important research frontier for the future.

Final Comments

To build on Lesgold's (1983) *TIP* article, it could be argued that society is entering a third phase of the technology revolution. Computer technologies obviously have had an impact on schools (phase 1). Teachers and educational leaders have been experiencing a frenetic process of making decisions on how to integrate technologies with instruction (phase 2), but much too slowly and, too often, not wisely. It is important to enter phase 3, which consists of a deep empirical assessment of the impact of new technologies on cognition, emotion, motivation, and social interaction.

Phase 3 will require radically different methodologies for empirical analysis. We live in a world where computers can collect hundreds, if not thousands, of data points per hour on single learners as they interact with the computer moment by moment. Cloud computing allows data to be collected overnight on hundreds or even thousands of learners. New quantitative models will be needed to guide the process of educational data mining (Baker & Yacef, 2009) and to align the data to educational standards (Avila & Moore, 2012). It is virtually impossible to predict how education will be influenced by technologies in the future, just as it is impossible to predict what the new technologies will be. There really are no futurists left standing in the midst of the computer revolution. There are *adaptivists*, but no futurists.

Note

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