Technology

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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 re-conceptualize 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) observed that the computer technologies were steadily penetrating our 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, administrators, 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 an important partner 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 these 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 (NRC, 2011). These learners are no doubt learning 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-related 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 point 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, CAI) 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 TIPS 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 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, Schwab, & Foa, 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 in order 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 "slit 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 TIPS 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 & 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, & Olney, 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, 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, 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 (20009) describes systems with immersive multiuser virtual environments (MUVEs), 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 non-germane 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 we are 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.

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