

A Roadmap for Education Technology

Organized by

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1 Overview

Over the last 40 years, educational technology has automated some of the more tedious tasks related to education, e.g., providing homework problems, delivering and sometimes grading test questions, and recording grades. Rarely has education technology been challenged to provide some of the more important needs in education and life-long learning, e.g., supporting learners to be fully active through inquiry, collaboration, discussion, and practice (Laurillard et al., 2008). Additionally, the tremendous advances in technology (e.g., the availability of mobile systems and social networks) have not yet been properly configured nor fully exploited for educational purposes, especially given their potential to provide seamless, ubiquitous, individualized and inclusive teaching.

To articulate these opportunities and to outline a path for supporting a potentially powerful educational infrastructure, a series of facilitated collaborative workshops were conducted in which leaders in several disciplines engaged in creative conversations that investigated the role of computation and technology in education, with wide coverage that extended from the learning of core ideas to learning from simulations and virtual worlds, as well as aspects of data management to support the teaching and learning processes. This project, Global Resources for Online Education (GROE), has been sponsored by the Computing Community Consortium (CCC) and its goal is to set a future vision for educational technology and to recommend a research agenda(s) for federal funding of that vision. The workshop participants are identifying educational needs, outlining perceived challenges, defining future impacts, and articulating a roadmap to achieve the results that address the identified challenges.

The first workshop of the GROE Project was held in Tempe Arizona from April 23-26, 2009 at Arizona State University. Twenty-seven participants came from a broad range of disciplines. Additional workshops for the GROE project are being convened both in the United States and in England, to focus on existing efforts as well as to enable technologies that should be fostered to advance education technology.

This report provides an overview of the discussions held during the first workshop. It lays out a roadmap for an integrated approach to computer science, cognitive science, and learning sciences research to address the high-level challenges faced in developing learning technologies that are relevant to current and future educational needs. This roadmap will be further embellished and refined as additional workshops and forums for the GROE Project are completed.

We recognize that educational technology impinges heavily on systemic processes and cultural effects and requires participation, dialog and cross-fertilization across a number of research disciplines including social and political science. For the purpose of this document, we restrict the recommendations made here to the fields of cognitive science, education, computer science and the learning sciences, with the assumption that there will be parallel efforts to identify and fund research in the other related areas.

2 Summary of Major Findings

(coming soon)

3 Motivation and Educational Requirements

The United States has a large accumulated investment in the educational apparatus and spends a great deal maintaining that investment. But researchers spend comparatively little effort to understand exactly how to improve the apparatus to assure that it serves teachers and learners better with respect to the goal of educating all people (youth as well as adults), at all levels (school, college, professional development), across all locations (home, work, institutions) and in all types of activities (work, recreational and hobby-related). Without such investment, it is impossible to learn how we might set directions that are both scalable and sustainable (King et al., 2009). This difficult challenge arises from an inherently complicated ecology. Learning and teaching are highly complex and time consuming activities, requiring significant effort. Currently, teachers decide what is taught, identify and acquire resources, and infer the intentions and beliefs of their learners (Ivanic and Tseng, 2005). They are responsible for many of the teaching activities, e.g., creating the learning opportunity, involving learners and providing intellectual and emotional support as well as feedback and evaluating learners. In the U.S. emphasis on standardized testing leads to a tendency to teach to the test and not to applying what is learnt to real-world problem solving nor on true conceptual understanding.

The use of information technology in education has been based on using existing technology, typically software developed for commerce or entertainment, e.g., text processing, slide preparation, graphics production and applications for producing standardized testing and grading of multiple choice questions. Such technology was never designed to solve deeper educational problems that deal with opportunities for exploration, problem solving, and learning with understanding (Bransford, et al., *How People Learn*). The more *opportunistic* approach to education technology takes existing technology and asks how it can make an impact on education (Laurillard et al., 2008). To authentically address the future of education requires viewing the educational ecology from the perspective of teachers, learners and other stakeholders. This *intentional* approach asks how we can invent technology that goes beyond current educational horizons and configures technology to support and expand educational innovation.

“Cool new technology” is not the proper starting point for the stakeholder-oriented solutions we should be seeking! Rather, the *intentional* view of educational technology starts from a stakeholder perspective and identifies required transformations for education (Laurillard, 2009), including those for all stakeholders (teachers, learners, parents, administrators, employers) and identifies how technology can be challenged to produce such transformations.

For example, education innovations require support for teachers, who are “struggling rather desperately now with maintaining the conventional methods their institutions run on, attempting also to use technology to transform the way they teach. Most don’t even try ” (Laurillard, 2009). We need to identify “what teachers need in order to do the tough job of helping learners understand difficult ideas and develop high-level skills. And then use this to challenge the technology to come up with something *better* than what is now envisioned” (Laurillard, 2009).

We also need to research which education innovations benefit learners. Students need support in the social aspects of learning and in using a variety of exploratory and inquiry activities. This can be accomplished through agents, simulations and artificial intelligence methods that model and systematically represent problem solving methods, graphics, animation, and visualization methods. Students can be supported to search for a wide variety of information, can connect to the real world, and can gather and analyze data, and communicate through a variety of social channels.

Similar thinking enables us to take into account all of the other stakeholders: administrators, parents and other interested individuals (e.g., business, industry, and government that needs to develop people with special skills).

The GROE workshops seek to identify what technological solutions show promise and are feasible for addressing complex learning and teaching problems both in the context of formal learning in school settings and informal learning that happens outside of the classrooms and brings together a number of stakeholders, in other words, society as a whole. Such thought experiments will help us identify and pursue the next big computing ideas that would begin to provide solutions to these very important but hard to solve educational problems. What is the future of education and how can we catalyze research investment and public support to create the educational future that we desire? We addressed two broad challenges:

- In what ways might computational technology be fully utilized in education to achieve the promise of open access to global resources and greatly enhanced and larger scale use of information technology in teaching and learning?
- What is the research agenda for federal funding that can make this happen?

The next section identifies some grand challenges in education to which technology might be applied and the following section looks at how technology might be coerced to satisfy some of those challenges.

4 Education Technology Grand Challenges

A society built on knowledge requires its members (students and workers) to rapidly acquire new skills, to engage in new learning approaches and to form new learning communities. For educators, this implies rapidly revising what is taught and how it is taught, based on evolving knowledge. To complicate this requirement, technology tools are evolving at amazing speeds, with significant updates happening every 2-5 years time frame. For example, social networks are immensely popular today among school-aged children (primarily within informal -- not formal -- situations) and were hardly available before 2007; the Internet is used extensively in schools today and yet was not widely available to schools before 2002. So how can educators predict and teach technology that don't exist today and will possibly dominate their students' lives? Trying to arrange rapid changes in education is nearly impossible.

Today's students will need different skills (e.g., teamwork, computer literacy, and presentation skills) and will engage in different experiences from those experienced two and three generations ago. They need to be prepared for the 21st century and to work with "hard" (e.g., the need to work across multiple domains) and so-called "soft" skills (e.g., teamwork, computer literacy, and presentation skills) (Shute et al, 2009). The rapid changes in education needed to keep up with the rapidly changing world and the globalization of commerce and industry present significant challenges for humans and technology to address and overcome.

In spite of the awareness and recognition of the 21st century challenges, today's classrooms often seem to resemble 19th and early 20th century classrooms, with teachers using old methods (e.g., lecturing to passive students and assigning independent and piecemeal homework assignments that focus on memorization of facts as opposed to understanding and application of concepts to realistic problems). Part of the problem is that development of qualified teachers takes an inordinate amount of time (King et al., 2009). It takes about 25 years from birth for an individual to receive a well-rounded education to become a proficient educator. Then it may take years of real experience before teachers figure out how to efficiently and effectively deliver this

information in classroom settings, while also keeping up with all of the changes that are continually happening. Therefore, effects of reforms across the learning spectrum cannot be seen in the consequences of a prepared educator -- that is, the consequences on *subsequent learners* -- for another 20 years. The conclusion seems to be that the cycle-time for reforms is on the order of 45 to 50 years. Very few challenges in research or social policy cover such a long time scale. But failure to consider such time-scales cripples efforts to understand the systemic characteristics of the challenge.

4.1 Assess student learning

The first grand challenge in education is assessment, which is critical to educational change. It is the most time-consuming and labor-intensive part of teaching, but because it is also highly political there has never been a large-scale development of tools to support teachers doing assessment, either formative or summative (Laurillard, 2009).

Given the increase in so-called soft skills required of 21st century citizens (e.g., communication, collaboration and problem solving), it is important that we develop good methods to assess students in these capabilities (Shute, et al., 2009). Furthermore, given the growing importance of lifelong learning we must find methods to measure those cognitive and non-cognitive factors that are likely to be predictive of learner success. As we envision seamless and ubiquitous learning in the context of lifelong learning, this vision can readily lead to seamless and ubiquitous assessment integrated with job performance support systems.

Of course, learners should also develop skills such as self-regulation or self-explanation. Methods for measuring these skills must be developed to know whether students have improved (Shute, et al., 2009). Therefore, the approach of building comprehensive models of learner competencies and attributes, and then developing assessment techniques to infer levels of those constructs is necessary in a shifting educational landscape. Assessing student competencies and attributes also supports future learning and teaching life long learning skills. It suggests the need to develop meta-cognitive strategies for learning.

This attractive vision of assessment has its primary goal to improve learning (e.g., Black & William, 1998; Shute, 2007).) Assessment should be used to gather evidence to inform instructional decisions, and to encourage learners to try to learn (Stiggins, 2002; 2006). This vision of educational assessment is exciting, powerful, and absolutely critical to supporting the kinds of learning outcomes and processes necessary for students to succeed in the 21st century. This type of assessment is referred to as “formative assessment,” which may be thought of as assessment *for* learning, in contrast to “summative assessment” (or assessment *of* learning).

Technology support of assessment is described in detail in Section 5.1.

4.2 Enhance the role of stakeholders

A second grand challenge in education is the role of stakeholders, e.g., teachers, students, parents, administrators and employers. Currently teachers are the sole provider of lessons and learning resources for many students. What will be the role of teachers when they are invited to “collaborate” with educational systems and work as a partner, each agent offering their best qualities, e.g., teachers have empathy for and intuitions about students; instructional systems have vast memories and can infer student knowledge. “Technology will eventually be embedded within all aspects of a professional teacher’s work, so the capability for a variety of technology skills will be an essential part of their training and professional development. Technology will continue to change rapidly, so teachers and institutions will need to continue to learn how best to

exploit what technology offers, and how learners are using it. Teachers will need specially developed learning design support tools, embodying educational requirements.” (Laurillard et al., 2009).

“We should also look at the future needs of the teaching professionals themselves. Teachers may not necessarily stay in the profession for life. The field may attract some professionals to move in and out for shorter periods of work in more of a ‘portfolio’ approach to careers.

Laurillard et al., 2008.

4.3 Support social learning

A third grand challenge in education is to support social learning and interactions. We can no longer accurately consider the individual as acting in isolation, especially as pertains to learning (Suthers et al., 2009). Social learning is pervasive and should be a component of all research that effectively addresses learning.

Social learning illuminates a bifurcation of learning theories: Cognitive theories focus on the individual, e.g., learning is a computational process in which humans process information in a manner similar to that of computers (receive and store, information) (Anderson, 1983). Social theories focus on the group and suggest that social interaction plays a fundamental role in the development of cognition (Vygotsky, 1978). Social interaction states that all fundamental cognitive activities take shape in a matrix of social history and from the products of socio-historical development (Luria, 1976). As members of a community, students slowly acquire skills and learn from experts; they move from being naïve to being skilled as they become more active and engaged in the community.

Now is the time to bring these two areas of learning theory together. The Internet is about connectivity. In the beginning it was about connectivity between people (Arpanet). The World Wide Web swept over that and searching became about information content. Now we have come full circle where we have both content and connections among people. The Internet is becoming again about connectivity (Suthers et al., 2009).

“Science advances whenever we can take something that was not visible and is now visible. This is now taking place with respect to social networks and processes.”

Kleinberg,

“The convergence of social and technological networks”

CACM

Social learning includes learning of individuals in communities; learning of communities themselves as they improve their functioning and accumulate knowledge capital; and learning of communities from each other.

The most effective uses of technology for children outside of school are multiplayer gaming environments and social networking (Suthers et al., 2009). Social computing is not just chat tools and threaded discussion and direct support for interaction. It includes designs that are used in contexts where conversations take place and that are potentially social learning designs.

4.4 Personalize feedback

A fourth grand challenge is to personalize education. We are rapidly learning more about how humans learn and how to teach them, but we already know a great deal that we have yet to apply as effectively as we might (King et al., 2009). For example, students learn in different ways and many students respond positively when material is personalized for them. Efforts to address learning challenges based on first principles have made some headway, but much remains to be done. A lack of solidarity among scholars and educators regarding many aspects of these challenges makes it difficult to achieve political agreement on how best to proceed.

Additionally education is currently based on undifferentiated and one-size fits all teaching. This simply does not work for our diverse population. Equity issues for people who are underrepresented in some disciplines (e.g., science) and for others who may learn differently demand new approaches. In some cases women (50%) are poorly served by methods that work well with men. Currently, minorities (33% of the U.S. population) and students with learning disabilities (~ 6.5%) (NCES, 2007; MassGov, 2006) are either not served in our schools or is poorly reached by traditional methods. These students often require additional staff or extra resources, which is something that schools are increasingly unable to provide due to budgetary constraints.

Many populations need personalized education. Some *minorities* and *women* have difficulty learning in traditional classrooms due in part to the lack of personalized help. Gender differences in academic performance do not appear to be biological (Beal, 1993). For example, basic mathematics skills can be trained and computational fluency can be enhanced with software-based interventions (Royer and Garofoli, 2005). Interventions that work (e.g., extra time on task, peer-tutoring) are difficult or impossible to sustain in classrooms without extra funding and resources. For example, students with *learning disabilities* often have complex multi-factor problems and this population has a large negative impact on society in terms of health and education costs and that behavior problems. Yet educational institutions are unable to provide potent cost-effective instruction for these individuals. Students unable to perform simple arithmetic calculations (dyscalcula) have a serious disability, since this failure persists into adulthood. It makes children in schools deeply unhappy, is detrimental to mental and physical health, and affects education and employment prospects (Laurellard et al., 2008). Dyscalcula is a serious problem for society: in 2000 26% of 30 year olds in England were at or below Entry Level 2. These students are severely under representation in science and mathematics.

The technology challenge in personalizing education is to understand an individual as might a human tutor, coach or peer, by seeing what each student is doing, and evaluating them in terms of finding learning opportunities for help and for collaboration. Technology can now monitor student activities step-by-step, understand what opportunities exist for improvement (relative to stakeholder goals), and plan and execute ways to support learners to take advantage of those learning opportunities (vanLehn et al., 2009). Monitoring includes the ability to take data (including sensor readings) and interpret (e.g., categorize) it without judging its “correctness” but merely understanding it in terms of progress toward end states.

Many personalized learning systems have been developed (e.g., Koedinger, vanLehn..) but most are concentrated in formal content domains (math, science, programming) and military tasks (e.g., equipment operation and troubleshooting; tactical decision making). Within these domains intelligent technology is quite successful at analyzing and responding to the accuracy of student actions, but technology is in the early stages of recognizing and responding productively to student intentions and to student affect (vanLehn et al., 2009). We need to move personalized

systems into new domains and to examine meta-cognitive and affective features (Biswas, et al., 2005; Schwartz, et al, 2009).

Technology supports students with disabilities

Technology helps by providing adaptive instruction (e.g. problem sequencing, helpful pedagogical agents, and meta-cognitive scaffolding) tuned specifically to these students. For example, one intervention might be animated learning companions that resemble students' gender and ethnicity (Hispanic or African America); another intervention adjusts the level of challenge, support and help at key moments of students' frustration; and another trains students in memory retrieval speed. These computer-based interventions appear to have the strongest potential for *broad dissemination* among minorities and women due to their general appeal, limited need for resources other than a browser and their ability to personalized tutoring.

Technology can provide students with learning disabilities instruction that is adapted to their needs and can enable them to catch up in a private and highly supportive way, working at the pace they need, and thereby bringing learners lost to education back into learning (Laurillard et al, 2008). Teaching strategies of the mainstream classroom could not, and do not, succeed for such learners, whereas specially designed educational systems can identify and remediate the same core deficit (Laurillard et al, 2008).

4.5 Diminish boundaries

A fifth grand challenge in education is to examine the many dimensions, boundaries and roles of the institution. Artificial boundaries have been set within educational institutions (Laurillard et al., 2008) including places of study (home, work, institutions), levels of education (school, college, university and professional development), personal ability (special and typical students) and types of learning (formal and informal learning). One goal of mobile technology and social networks is to provide seamless and ubiquitous learning across many of these boundaries. Given well-managed technology, education can better match the potential unity of an individual's experience across these boundaries.

One great challenge is to examine both the formal (in the classroom) and the informal (outside of the classroom). We need to integrate, for example, a student's computer studies in the classroom with her searches and computer work done at home. We also need to examine the need for custodial care of young people through education, even at a time when we may see less need for constrictive classrooms and daily routines (King et al., 2009). The current educational apparatus was created to facilitate formal learning. Learning, of course, takes place both within and outside that apparatus. The two things -- education and learning -- are not synonymous, and information technology plus other innovations increase opportunities for learning outside as well as inside the educational apparatus. When we talk about learning, we encompass learning that occurs within the educational apparatus as well as that which does not. We need to consider whether the impact of information technology on learning will be greater outside the educational apparatus than within.

Social inequality. A number of significant barriers need to be addressed and some of these barriers are both technical *and* social in nature (Laurillard et al., 2008). For example, education is beset by problems of inequalities of opportunity and outcome - with widening participation remaining a fundamental issue to be addressed by future governments. Many individuals "do not participate in any meaningful learning at all throughout their adult lives and many others have only sporadic and highly interrupted patterns of engagement. These inequalities are highly

dependent on an individual's age and stage of life, as well as patterned in terms of income, gender and social class" (Laurillard et al., 2008)

Technology addresses many boundaries in education. Boundary issues are addressed by technology in many ways. Boundaries in place of study are addressed by seamless and ubiquitous learning (see Section 5.1). Learners require easy access to learning opportunities and education that is both affordable and flexible in terms of time, place and pace (Laurillard et al., 2009). Levels of education (allowing students to engage in learning at their appropriate level) is addressed by intelligent environments (see Section 5.2). Personalized instruction for all students is addressed by modeling and assessment techniques (Section 5.3).

Technology addresses social inequality by providing access to educational content and learning opportunities that are relevant to a person's life-needs and situations (Laurillard et al., 2009). A further component is having access to social contacts and collaborative networks that support the learning process. "At basic level of ensuring equality of opportunity, platforms of access to learning will need to be low-cost, portable, durable and build upon the technologies which are already well-integrated into individuals' lives - such as mobile telephony, digital television and computer games. Similarly, modes of learning will need to follow activities which are already well-integrated into individuals' lives - such as playing and communicating"(Laurillard et al, 2008).

4.6 Develop alternative teaching modes

A sixth challenge in education is to develop alternative teaching modes. Today's students need to solve complex problems in innovative ways and to think clearly about systems (Shute et al., 2009). Systems thinking in today's world often means working across multiple domains, and, therefore, the need to learn, understand, and apply information that span multiple topics (e.g., math, science, and social studies) (Jasper work, How People Learn). As a consequence, additional resources are needed to further engage students to use collaborative tools to work with local and distal students and to provide supportive and flexible learning experiences. In addition to providing students the ability to handle more complex, realistic problems, such environments also have the potential to "develop students' communication skills and creative abilities as they become exposed to diverse cultures and viewpoints" (Shute et al, 2009).

Inquiry Reasoning. People need to develop inquiry reasoning and this need is more pressing than ever as citizenship in a high-technology world requires scientific reasoning and disciplined thinking. Inquiry reasoning includes the ability to ask new questions, to generate hypotheses and to gather evidence that either supports or refutes those hypotheses. People need to reason and solve messy problems without nearby authoritative help (answers supplied by instructors). Inquiry and collaborative learning strategies are ideal for helping students to articulate and reflect on their own knowledge and to transfer that learning to new contexts. The importance of active and authentic contexts for learning has been established (Greeno et al., 1996). In inquiry learning, students learn to plan and manage investigations and to analyze and communicate results (Woolf, 2008).

However, teaching with inquiry methods presents many challenges, especially in classrooms. Teachers have to monitor the progress of teams and individuals who articulate different hypotheses and pursue unique experiments. They have to intervene appropriately and encourage students to articulate questions, refine existing hypotheses, and gather evidence (Derry et al., 2000). Teaching with inquiry is time and labor intensive and often difficult to manage in larger groups, such as a classroom environment. However, small college settings have sponsored

excellent undergraduate inquiry projects (D'Avanzo and McNeal, 1997; Stillings et al., 1999), and a suite of new technology tools, such as simulation and guided discovery environments (van Joolingen, Wilensky, etc.) can provide support to both teachers and learners to conduct inquiry-based learning in classroom situations. The challenge is to develop these tools in a way that they can more easily be connected to the curricula and classroom teaching activities.

Collaborative learning. Knowledge has become complex (e.g., global data are processed by multidisciplinary teams in real-time 24 hours a day). Individuals can rarely single-handedly solve major problems. Teamwork is vital and students need to be taught skills to understand the processes by which teams of people generate, evaluate, and revise knowledge (Johnson and Johnson, 1989). Collaborative projects encourage students to work in teams to articulate and reflect on knowledge, engage in active learning, and envision how knowledge is shared and extended (Johnson and Johnson, 1994).

Collaboration has its own set of unique benefits and often results in higher achievement and greater productivity; more caring, supportive, and committed relationships; and greater psychological health, social competence, and self-esteem for students (Johnson and Johnson, 1989). Collaborative student discourse (i.e., reflective discussions among students about content) often results in learning that outperforms the ability of the best individuals in the group, produces knowledge that none of its members would have produced by themselves, and leads to the generation of new ideas (Fischer and Granoo, 1995; Johnson and Johnson, 2005; Smith et al., 2005).

Technology supports learning through collaboration by enabling exploratory learning, social interactions, ubiquitous learning and choice and adaptivity in learning. Resources are needed to provide supportive and flexible learning experiences and to fully engage students to use collaborative tools that work with local and distal students and. Such environments have the potential to “develop students’ communication skills and creative abilities as students become exposed to diverse cultures and viewpoints” (Shute et al, 2009).

Learning through discourse and social interactions. Dialogue and socially gathered and shared information is a powerful means of building individual conceptual understanding. Discourse provides an approach to constructivist learning in which students are active and engaged. It also enhances a teacher’s role as advisor and, when successful, supports structural and institutional changes moving classroom activities from teacher-centered didactic instruction to student-centered collaborative inquiry (Slavin, 1990 b; Stahl, 2003; Suthers et al., 1997). Social interactions support the Vygotskian approach of social constructivism and the Zone of Proximal development (the belief that students should be taught with material that is not too difficult (so they don’t become discourage) or too easy (so they don’t become bored).

Teaching students to discourse requires teaching communication skills (how to discuss alternative approaches, engage in reflection, jointly collect data, explore and construct knowledge, and reach consensus). Organization and management skills are needed for students to share as well as assume ownership of knowledge. Teaching such skills is time and labor intensive. Teachers need to know how and when to intervene appropriately (Derry et al., 2000).

4.7 Address policy challenges

The seventh and final grand challenge in education is the set of major and constructive changes in education policy that are required to address endemic educational problems. Education is the *perfect storm*. It fails us in multiple ways. Only 50% of the world population receive a

secondary education. In the U.S. 30% of enrolled students do not graduate from high school (Duncan, 2009). Many adults do not participate in learning. Others have interrupted patterns of engagement (Laurillard et al., 2008). Inequities in education are dependent upon a person's age, income, gender and social class (Laurillard et al., 2008). And yet, a knowledge society requires people to learn rapidly and to form new communities.

“Education is the civil rights issues for the 21st century . . . We cannot let another generation of children be deprived of their civil right to a quality education.”

Arne Duncan
U.S. Secretary of Education

Education should be a civil right for all people. Think of other civil rights issues: rights of women, African Americans, people with disabilities, anti-smokers. Civil rights issues take decades (often 40 years) to resolve. A useful example of a highly successful social movement that produced change on a society-wide scale is found in the rights of disabled people. The Americans with Disabilities Act was passed in 1990, but the movement necessary to create the ADA began years earlier, and provided the momentum to enforce the ADA's implementation. The change in the past 40 years has been dramatic. This success is largely because the issue became a matter of civil rights. A somewhat more difficult struggle has been to reduce use of tobacco. At the time of the 1964 Surgeon General's report approximately 2/3 of adult US males smoked. A sequence of scientific and health findings and corollary public policies have followed, aimed at suppression of smoking in particular. But the social movement went far beyond such efforts, and most importantly changed the image of smoking from “cool” to “uncool,” particularly by turning “second hand smoke” into a civil rights issue.

Will a time come when the ability to think critically or do algebra are civil rights, and citizenship bears the sign over the gate of Plato's Academy, "Let no one ignorant of geometry enter"? What would it take to make learning cool, and how can information technology help?

Stratification in the apparatus. Another issue is that education system in the US is stratified, and people at each stratum talk mostly to people in the same stratum. Researchers at one stratum talk among each other and develop recommendations aimed at people in other strata (e.g., teachers), but there are few guarantees that those recommendations are ever internalized or that they have much effect.

Social change and social movements: Given the enormity of the educational apparatus and the degree to which it is embedded in the society, it is naive to think that policy reforms as customarily understood will result in the needed changes. It makes more sense to think of these systemic, broadly-based changes as social movements. If the society is to embrace the scope and scale of needed changes, social movements must be launched and sustained over protracted periods of time.

These endemic challenges must be incorporated into any further efforts to improve learning. Without incorporation, we can never reconcile any vision of a learning society with the practical challenges of implementation. The nation will keep walking and will certainly end up somewhere. But we still will not know where we ought to go.

5 Technology Features

The grand challenges for education articulated above provide a background for the potential of new and emerging technologies; those educational requirements come close to suggesting solutions through learning technology. Many technologies already exists in the laboratory, but have not been combined in large scale or in optimal ways for education.

Table 1 provides a list of some grand challenges and technologies needed to satisfy them. To fully support the challenges (left), technology features provide resources that support many

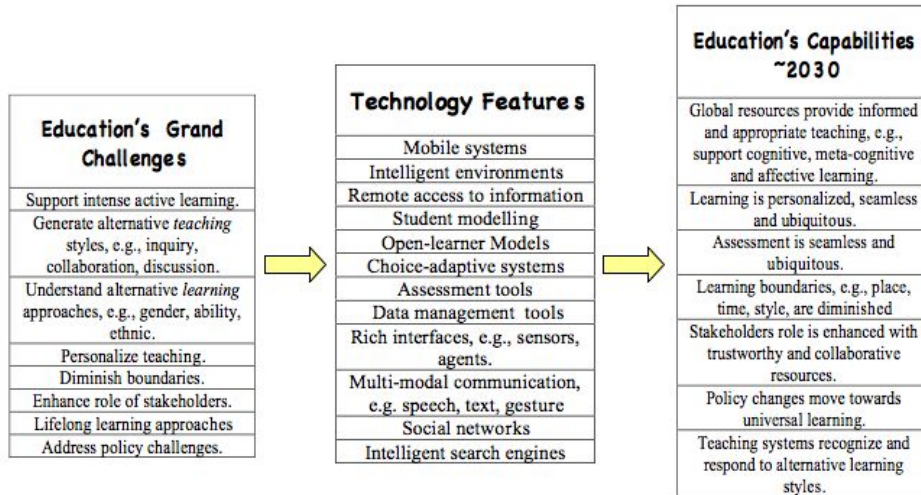


Table 1. Educational grand challenges and the technology features that would help satisfy each challenge to produce new capabilities by the year 2030.

teaching methods and learning styles. Each grand challenge requires a combination of technology features (middle). Several resulting capabilities (right) will be in place around the year 2030 if the technology is fully optimized for education. This section illustrates how new and emerging technology can be pressed into service to address education grand challenges. Some of the missing components and research to be addressed are listed for each technology. Once again, though we recognize the need to examine education from its social and political grounding, we have cast computation as one basis for education, in core ideas as well as simulations and data management.

5.1 Modeling students and assessing learning

Modeling students includes representing and measuring their capacities, including cognitive, metacognitive and affective capacities; assessing learning includes measuring changes in students; learning. Assessing can and should have important implications for instruction, positively influencing both the teaching and learning sides of the equation (Shute et al., 2009). Currently, assessments are too often used for purposes of grading, promotion, and placement, and not for learning. This needs to be fixed. On the other hand, assessment should: support, not undermine, the learning process for learners and teachers (as well as online agents); provide more formative than summative information (i.e., give useful feedback during the learning process instead of a single judgment at the end); and be responsive to what is known about how people learn, generally and developmentally.

Currently, assessment within educational software is typically handled by each individual educational system (Shute et al., 2009). To measure a specific construct (e.g., persistence, help-seeking) requires a substantial amount of effort to construct a model that is particular to the system in question. The construction of such a model—for a single construct for a single system—costs approximately one year’s time for a graduate student. Thus, the current approach does not scale to the increasing numbers of electronic learning environments.

Comprehensive student models of general learner characteristics need to be built and constructed so as to transfer across systems. Aside from reducing the costs of electronic learning objects that would have been created, this proposal also increases the number of such artifacts that are built since a broader set of content creators will be able to participate. In order for systems to maintain a model of the student, they must conduct some kind of embedded assessment relative to the descriptive terms of the metadata. For instance, if the student has just conducted a flawless negotiation, which descriptors are upgraded?

This should lead to valid and reliable inferences, both diagnostic and predictive. Assessment uses may be summative (e.g., for purposes of accountability and promotion) or formative (to support learning). However, we note that data from a given assessment can, in fact, be used for both formative and summative purposes through appropriate design and other analytical methods. Such a perspective aligns with viewing assessment as a dynamic agent in student learning over time.

5.2 Mobile technology

Mobile technology includes remote access to information through wireless devices (phones, laptops, printers, etc.) and supports users to access and receive information anyplace and anytime. This enables students to learn seamlessly while walking between buildings, moving from formal to informal spaces and while working with both known and unknown participants. Mobile technology provides access to search engines, documents, data and analysis independent of place, levels of education and personal ability. It supports ubiquitous learning exploit by providing remote access to information

Further research is needed before mobile technology is optimized for education. For example, as learners move between multiple environments – school, college, workplace, home, etc – information technology management across the related sectors is required on a massive scale (Laurillard et al., 2008). The challenge is to make this problem easier – for the technology to manage the integration and interoperability that is too complex for individual educational administrators to handle.

5.3 Social Interaction Tools

New technology is being developed and many Internet objects are available for shared social learning. Research on resources for online social learning should enable learning communities to flourish without requiring that participants or educators have technology skills. Major advances in scientific disciplines have often been accompanied by representational advances and shared instruments, in which representations mediate the daily work of scientific discourse (Suthers et al., 2009). Internet devices designed for use in the context of teaching are objects of conversation. For example, a graph that can be shared is an object for conversation. Tools provide venues for researchers to see social interactions, e.g., data mining, visualization tools, virtual “field” research tools.

Ecolab was an early example of a social interaction tutor that dynamically adapted its help and activities to a learner’s collaborative capability, ensuring that each learner was extended beyond what she could achieve alone (Luckin and du Boulay, 1999). The nature of the student’s activity determined the amount of help received from the tutor, dictated in part by the student’s presumed zone of proximal development.

Technology needs to be coerced to support student interaction distributed across space, time and media and with data in a variety of formats.

Future technology challenges include influencing learning in socio-technical systems by design (key areas). For example, we intend that technology enable the persistence of individual activity that leads to value for others, develop tools that enable teachers to support effective collaborative learning in class, develop integrations/mashups of devices/platforms that more effectively support distributed/social learning, discover innovative ways to untie computing resources from the desktop or laptop and help to refactor virtual “space” to be defined by task or topic (Suthers et al., 2009).

We look for technology to fill in the gap between detailed qualitative case accounts providing insight into situated accomplishments, and quantitative methods finding patterns in aggregate data yet distancing researcher from interactional processes by which participants appropriated the technology.

5.4 Intelligent environments

Intelligent environments include the use of artificial intelligence techniques (e.g., modeling, natural language understanding, machine learning, etc.) to develop systems that are knowledgeable about students and teaching methods and can provide flexible feedback to students. Such systems allow content to be altered to fit the personal needs and abilities of the learner.

Further research is needed for intelligent environments. For example, knowledge engineering or cognitive task analysis (CTA) is a recognized bottleneck in the development of knowledge intensive systems. Often the CTA process uncovers latent knowledge that the community was not aware of. This feeds back into an issue of trust between humans and computers. Authoring tools are desperately needed so that different segments of the community can repurpose educational systems to suit their particular needs and culture.

Intelligent environments are often researched in terms of the various sensor modalities, e.g., speech vs. text and briefly presented along with challenges. *Free-text and speech understanding* needs to become more reliable and accurate (vanLehn et al., 2009). This includes understanding

students' [typed](#)- and spoken-[input](#) turns during dialogue, either amongst themselves or with a computer. It also includes understanding essays, reports, long explanations, and other monologues that have long, substantive content. Both dialogue and monologue understanding have benefited from advances in statistical language processing.

Free-speech understanding is reliable now only in dialogues where the computer asks short-answer questions or other questions where only a few types of easily detected responses are expected. Improving continuous speech recognition is important for many applications, but the educational application has certain advantages that are currently not being seized. We need to look at actions taken in immersive environments that have nothing to do with text-verbal input. For instance, in some instructional applications, the computer doesn't need to recognize everything being said, but only the things that it can interpret as learning opportunities. Or, it may only need to detect who is talking, their affect (via prosody) and length and affect of the responses.

Interpret Student Responses. Even when a student's response has been successfully identified, there can be ambiguity about how it relates to the overall solution structure, and whether the action is correct or not (vanLehn et al., 2009). This in turn interferes with providing suitable feedback and recognizing learning opportunities. Sources of ambiguity about an apparently correct student action include the fact that students may respond correctly based on deep domain understanding or on superficial reasoning or they may respond correctly by guessing. Additionally a given action may be correct for more than one task subgoal, and it can be unclear which subgoal the student is working on. Alternatively an action may map correctly to one task subgoal, but may be incorrect for the task subgoal the student is currently working on.

Technology features that seem achievable in the short term include development of:

- Deep and shallow reasoning detectors.
- Mechanisms that detecting the nature of activity pauses (on-task thinking, on-task help-seeking, or off-task behaviors)
- Interpreters that reason about the intent of student turns in dialogue and group collaborations.
- Successful "guess" detectors (developed in math problem solving tutors) need to be extended to other domains.
- Tools that preserve ambiguous interpretations for as long as possible

Technology tools that are being developed use:

- [Activity-state](#) context to disambiguate a student's knowledge
- Population priors to guess interpretations about a student's knowledge or intent
- Data mining to determine new approaches, paths, and behaviors in problem solving activities

Many of these technology features have been developed in pilot research, but all need to be further developed to achieve greater accuracy and to be extended across domains.

Grounding the meta-data: A major, familiar technology challenge in intelligent environments is to insure that metadata descriptions mean the same thing when used with different system. One approach is to define central ontologies of learning objectives used to organize and index the systems. An alternative is the folksonomy approach where structure emerges from decentralized tagging. Both these approaches are in use and their relative merits are already being evaluated. Bringing the results of these analyses into the educational systems

research and recommending an educational systems architecture is an important challenge (time frame: current)

Several challenges revolve around community access to technology. Research is needed to determine and control ownership of educational systems (vanLehn et al., 2009). This needs to be dealt with in ways that motivate the community to collaborate and build on each other's work. Freedom of use must also be built into these systems, i.e., people should be able to choose to use or not use systems as it suits them. Communities need to be included in the design of superhighway infrastructure, social networking capabilities, and the systems allocations. As these systems will play a significant role in the education well-being of the community, testing and quality assurance is a very important consideration.

5.5 Data management and mining

Data mining includes methods for exploring data from educational settings and using those methods to better understand students and environments. Data from lifelong chronicles of student learning provides insight into how people learn and identifies effective pedagogy strategies. It provides knowledge about how to find clusters of children with similar problems, identifies success and failures in teaching strategies and generate a deeper understanding of learning. It sheds light on key questions in education and educational psychology.

School reform in the US depends of data management and mining. Under the American Recovery and Reinvestment Act, states must make assurances that they are building data systems to track student achievement and teacher effectiveness, in addition to adopting rigorous standards that prepare students for success in college and the workforce.

"Hopefully some day we can track kids from pre-school to high-school and from high school to college and college to career....
Hopefully we can track good kids to good teachers and good teachers to good colleges of education."

Arne Duncan
U..S Secretary of Education

Given a world where learners use a variety of electronic learning objects, and those objects are continuously assessing learner progress on a variety of measures, it is possible to assess each individual across a wide variety of activities (Shute et al., 2008). Assessment information needs to be made available to a broader variety of members of the educational establishment, to improve the odds that learners will succeed. For example, young learners could benefit from their parents being informed of learning deficiencies and providing additional help or motivation. Teachers would (probably) benefit from seeing a summary of areas of weakness of several students in the class above and beyond a report for each student; such a report would enable an immediate alteration of teaching methods. This highlights the importance of mechanisms that facilitate this communication of data in a way that is desired by and meaningful to stakeholders.

We need to communicate data by considering the social processes of learning outside of software; the assessment technologies need to enhance the learner's experience and support network, resulting in more effective, efficient, and enjoyable instruction (Shute et al., 2008).

Given a world where learners use a variety of electronic learning objects it is also possible to become drowned in details. This deluge of data requires new data mining, security and data base

techniques. Therefore, it is recommended that assessment designers think about who are the potential consumers of this knowledge, and determine how designers can distill the assessment content down to be of use to each stakeholder. If this is the responsibility of individual designers, a framework for orientation is needed for designers to develop assessment materials – a shared data dictionary that prevents duplication of efforts and streamlines nomenclature and categorization. Otherwise it will be extremely difficult to aggregate information across individual contributions. As described earlier, this envisioned taxonomy would first have to be established by corresponding research and then disseminated (and perhaps governed) by a body similar to other shared standards as coordinated by the IEEE or ISO.

5.6 Rich Interfaces

Rich interfaces involve new and exciting technologies for open-ended learning environments than combine a number of different learning paradigms and resources (Burlison et al., 2009). Students can complete quests in game environments (ref), work in problem solving environments guided by a tutor (ref), access the web (ref), and more generally make choices about different learning activities. A basic insight is that these choices can be extremely informative about student learning. Further, rich interfaces provide mechanisms for mining student choices in relatively open learning environments to determine whether students are showing (sub) optimal patterns of learning (refs).

Learners now have access to a variety of learning resources through connected networks of learning management and educational systems. The next generation of widely accessible ubiquitous learning environments must develop a new generation of rich interfaces that provide interoperability, and a seamless approach to bringing together learning content, personalized learning services, and the availability of a host of learning collaborators that span mentors, tutors, peers, and helpers (Burlison et al., 2009).

Technology now identifies opportunities to improve student affect (motivation, interest, emotions, self-efficacy), “21st century skills” (teamwork, leadership, critical thinking, communication skills, etc.), learning styles (one kid likes to explore, another likes to follow directions; one likes video and visuals, another likes text; curiosity, focus) (Burlison et al., 2009). Although these analyses feed directly into assessment (of the learner) and data-mining (for evaluation of the educational systems or treatment), rich interfaces focus on learning opportunities that trigger changes in the course of the interaction with learners. Learning opportunities also include excellence that needs to be reinforced, ingredients that will be used later in learning events (“just remember this, because we’re going to discuss it later”) and things that should be interesting to the student.

Rich interfaces include technologies to sense, analyze and recognize human action, whether cognitive meta-cognitive or affective. Some technologies include:

- Sensors: RFID, Speech Technologies, GPS, Smart Phone, Camera (self cam, external cam), longitudinal and comprehensive logging (MSR Vibe logger, socio-scopes).
- Virtual Agents: can be embodied and robotic; current low-cost and end-user deployable responsive environments can be deployed in classrooms and homes; agents can be presented as peers and offer engaging social support and advanced scaffolding.

Rich interfaces are included inside intelligent tutors, exploratory simulations, multi-user collaborative systems, and game environments. They are included inside social interactions that include multiple modalities, such as one on one intelligent tutors, virtual agents with multiple

roles (e.g., mentors, peers, learning companions, and teachable agents), and human to human interactions mediated through technology.

Rich interfaces are used within personalized interaction, that attends to motivation, self-efficacy, and affect using adaptive media, information, and user models. And finally they are used within Mixed reality, the nature of learner-system interactions ranging from purely physical to purely virtual environments, and those that include both.

The need and opportunity exists to test and explore diverse technology presentations and paradigms, to develop rich interfaces, including:

- Gaming: serious games, classroom game design as well as emerging paradigms for augmented reality (Mohr) and lifelong gaming (Burlison 2009) offer new opportunities to advance mixed reality systems and explore diverse rule-based paradigms.
- Simulation: provides opportunities for immersive understanding and adaptive exploration of diverse real world and constructed environments that afford a wide range of exploration opportunities, ranging from the scientific to the social and artistic.
- Intelligent Tutoring Systems: these systems are currently some of the most advanced rich interfaces and they will continue to be a driving force.
- Embodied, situated cognition and mind-body learning: rich interfaces and tangible media provide compelling opportunities to expand the important role of these learning modalities.
- Exploratory environment (sandbox): we are strong advocates of providing learners open exploratory environments that stimulate curiosity, exploration, and creativity; rich interfaces and participatory design strategies make important contributions in this domain.
- Holodeck for Formal/Informal Instructions: the paradigm of the Holodeck a fully adaptive rich interface environment is compelling and will continue to be advanced.
- Teacher and Mentors: rich interfaces and their diverse deployment scenarios offer learners and teachers new developmental opportunities to participate in diverse roles that will enhance both their learning and teaching abilities..
- Experiences, scenarios, projects: rich interfaces offer terrific and limitless opportunities for developing new and ubiquitous experiences for learning. Diverse scenarios, topics, social structures and engagements must be explored.

6 Future View

The previous two sections identified big computing ideas in education technology along with technology features that help address these challenges. A national initiative on education technology is needed with participants from industry, academia, and government laboratories and agencies. Several high-cost high-risk learning technology systems need to be developed that can be studied, with a structure based on desired outcomes and incentives for participation across many domains and many organizations. The National Science Foundation, U.S. Department of Education and National Institutes of Health are among several U.S. foundations that have an important role to play in both the technical and cultural aspects of this new field, as discussed in Section 7.

Once technologies are integrated into complex and ubiquitous information systems, they will begin to address the implications of cyberspace as a collaborative and cognitively supportive learning space. As we couple far more advanced computational technologies with far deeper knowledge about human cognition we expect to enable dramatically more effective constructivist and active instructional strategies. The impact of such a revolution will encompass not only new modes of learning and pedagogy, but also new organizational systems for education.

This section identifies possible capabilities in teaching and learning as a result of new and emerging technology. One goal is to achieve open access of global educational resources and the reuse, repurposing, and sharing of such resources. We look at both near term (2-5 years) and at the twenty-year time frame. Systems will harness the deluge of scientific and learning data flowing through them, monitor themselves (through machine learning) and raise new issues (e.g., dynamic student assessment, personalized feedback and lifelong learning). Again, we have cast computation as one basis for education, in core ideas as well as simulations and data management. We do not address other core bases for education, e.g., societal and political.

6.1 Assessment in the year 2030

The first future capability is assessment and support available for learners. Assessment will be seamless and ubiquitous in the year 2030; it will be consistent with learning (and not be based on the Teach/Stop/Test model). It will exist everywhere and everytime a student is learning and will feed back the results and implications of assessment into the learning system. Learning environments will prepare students for lifelong learning by focusing on meta-cognition and self regulated learning skills, not just domain content.

Rich interfaces will support learning is not be constrained to virtual desktops in students' classrooms, but rather will expand into learners' environments, effectively delivering ubiquitous instruction – any time and anywhere (Burlison et al., 2009). These interfaces will address all factors that influence learning, including not only domain-related traditional feedback, but also sleep hygiene, exercise and mental health, to name only a few.

We anticipate transformative advances in sensing devices, as summarized in Table 1, that will allow these interfaces to seamlessly capture user-relevant information and adapt to the user's needs to maximize learning outcomes and adapt to and interact with motivation and affect (Burlison et al., 2009). Sensing devices will take advantage of the full spectrum of physiological data in order to maximize system ability to appropriately tailor to individual users.

We anticipate that future interfaces will leverage a broad array of feedback techniques, including haptic, natural speech, novel interaction techniques and virtual simulation (Burlison et al., 2009). These interfaces will go beyond the traditional tutor model to include learning peers, i.e., holistic friends encouraging life-long learning through motivational tactics and curiosity promotion.

Systems that measure students' affect will identify eureka moments, or moments of intrinsic interest or frustration (Shute et. al., 2009). They will measure 21st century skills, e.g., good teamwork, students' communication skills and good peer dialogues.

Although stakeholders ultimately set policy and make decisions about which system to select, they often want to know how those selections will affect a student's future (Shute et. al., 2009). Thus, educational systems will make predictions and communicate to stakeholders about: (a) areas in which individuals have the proclivity to master, perhaps including career potential in relation to learner interests; (b) future performance in skill areas; (c) time to master a skill area or become an expert (d) topics that the student should find interesting, (e) given a particular topic, students who would work well together in a group. These predictions are driven by data-mining, recommender system logic, metric models of learning, etc.

Assessment information will be made available to a broader variety of members of the educational establishment. Assessment content will be distilled down to be of use to each stakeholder.

Table 1: Sample capabilities of rich interface elements in the year 2030

Rich Interface	Future Capability in the year 2030
Affective, emotional, motivational	Strong recognition of student, including sensing/expression; fluent expression and highly personalized
Embodied interaction	Mirroring students, Full body capture everywhere, including joint analysis
Learning companions	Virtual characters + robotic companions that seamlessly switch between virtual and physical settings
BCI	Continuous wearable, fMRI-like capability, also EEG/Infra Red
Physiological	In-body monitoring and transmission – oxygen, glucose and cortisol indicators, HR/ Breath
Augmented Reality	Seamless, natural, ubiquitous registration and resolution [Ref World board]
Haptic	High resolution, high power haptic capabilities, Enhanced Mobility, Supper Hero Capability

6.2 The role of stakeholders in the year 2030

A second educational change involves the role of stakeholders (teachers, students, parents, administrators and employers) who will effectively and consistently utilize technology and in some cases fully integrate technology into their teaching/learning in 2030. Education systems will consult regularly with these stakeholders, report about students' activities, emotion and meta-cognition and behavior. They will trust educational technology and use them as a daily activity (Shute et. al., 2009).

Currently, most interfaces focus on students in their early life stages, and do not sufficiently involve teachers in the design or instruction delivery process. Rich interfaces will remedy these limitations, by providing support for life-long learning and a wide range of tools for teachers, including the ability to tailor the instructional content and access to student assessment records (Burlson et al., 2009).

Teachers will take on multiples perspectives and roles. We expect teachers to continue to be of primary importance in school environment and to extend their significance to informal settings as well. Their influences will likely increase as their abilities to interact with students in broader and more diverse contexts increases (Burlson et al., 2009). We see teachers participating in administrative, participatory, and pedagogic roles. As administrators, rich interfaces will provide teachers more accurate forms of information about individual and group learning, motivation, social activity, and opportunities, enabling them to respond more effectively to a greater range of needs of the increasingly diverse learners with which they interact (Burlson et al., 2009). As participants, teachers will frequently engage side-by-side students, as members of project teams and at times as followers of student leaders. In their pedagogic roles, teachers will have more tailored and higher quality information to inform their actions and a greater range of actions will be afforded them. Teachers interacting with special needs children will have ready access and specific guidance from the latest and best strategies for their specific students, stemming from advances in educational psychology. These technologies will also empower teachers with new tools and targeted opportunities to directly apply these advanced theories, e.g. understanding

Dweck's message, that the mind is like a muscle and that even though the task may be frustrating, sticking with it may be a learning opportunity, and when to apply it.

Multiple perspectives and roles for students: we, likewise, expect students to engage in diverse participatory roles, as leaders, followers, public speakers, listeners, integrators, decision makers, supporters, contributors, etc (Shute et al., 2009). One particular role that is likely to increase is students' pedagogical role. As teachers, they will not only be solidifying and expanding their learning they will also be contributing to their peers and increasing their social skills and networks. These roles will span the formal and informal environments. We expect student roles to include enhanced creativity, curiosity, and intrinsic motivation (Burlison et al., 2009). We expect increased opportunities for engaging in and supporting creativity through personal constructionist project-based activities that apply Shneiderman's framework of using information technology to collect, relate, create, and donate.

Stakeholders will have a good understanding of the systems, what they do, and how they do it and will be confident that the systems have good privacy and security policies in place (Shute et al., 2009); stakeholders will engage technology in the educational process and exercise control over the use and evolution of systems.

Stakeholders further will trust that educational systems will fill their needs, fit within their culture and do what they are designed to do (Shute et al., 2009). Stakeholders will have the means to evaluate the pedigree, intent, and authenticity of systems and environments can evolve alongside their own needs and culture.

Stakeholders will negotiate with educational systems about the selection of instructional material or sequence of activities. They will be assisted to do this by clear interfaces that will contain content relevant to student pedagogical goals (what each student is learning, and what interests they have) and will be multimodal (providing graphic, symbolic and spoken feedback, in addition to text). These interfaces will track and analyze learner's competencies and behaviors. They will provide decision and analytic tools to support teachers in designing or exchanging learning activities (Laurillard et al., 2008). Systems will enable stakeholders to access models of students and predictions of learning. Stakeholders will interpret the system's current model/profile of the student, which exposes not only competencies but many other data as well.

Research will identify how much professional development stakeholders will need and what kinds of user interfaces are needed.

6.3 Social learning in the year 2030

A third educational change we expect to see is the prevalence of social learning. Learning communities of the future will be distributed across space, time, contexts, not defined by dichotomies (FTF/online, class/informed, etc.) (Suthers et al., 2009). We will leverage learning in the entire experiential ecology of the child as social context of the experience and make effective use of child, as an entire social network, e.g., teachers will be aware of all relevant weakness, social connections. Social ties will grow, interact, morph and dissolve dynamically (Suthers et al., 2009). Mobile networks will enable individuals to spend less time in front of "the computer" and continue to have ubiquitous computational support (Suthers et al., 2009).

We envision societal changes such that learning is no longer seen as isolated in and the business of schools alone. Sustaining value for learning in and of the community; learning will be

highly distributed and valued by the typical citizen. Enabling learning communities to sustain, build on and share knowledge. Knowledge organization tools, Solve the meta-data problem (whether formal, folksonomy...) to resolve the local/global tension: making what makes sense in one context make sense in another.

Social and motivational interactions will be enhanced: we expect rich interfaces to provide new opportunities for social and motivational interactions that facilitate learning (Burleson et al., 2009). Already we see emerging Intelligent Tutoring Systems with Affective Learning Companions that are beginning to become capable at sensing and responding appropriately to elements of learners' emotional and motivational states. These systems are leading to all learners having the opportunity for one-on-one personalized instruction. We see new opportunities emerging from multiple learning companions in many forms – as embodied, ambient, and embedded virtual agents; as co-located and distributed human peers and mentors; as community members, teachers, and parents, each enhanced by information from rich interfaces and diverse sources of guidance for providing actualizing social and motivational feedback opportunities and interactions.

We expect to see societal changes in the workplace. A person's career will be valued not only for what they earn, but also for how much they learn (Burt Woolf).

Personal space will arise naturally and effortlessly out of online activity (e.g., searching), persistence of object identity issues; networks of (social) agents will monitor information spaces and each other for relevant information and activity

6.4 Deep knowledge of students in the year 2030

A fourth educational change we expect is that educational technology will understand students' weaknesses and challenges (Shute et. al., 2009). They will understand the motivational style of the student (e.g., stars, competition, acknowledged by peers, get attention, perform, personal improvement).

Systems will customizing feedback and coaching techniques to student traits such as personality, learning style, motivation, and culture, and to student states such as affect, level of engagement, level of frustration, etc. A number of studies in the field of cognitive psychology have documented the benefits of different types of feedback techniques (e.g. immediate feedback vs. delayed feedback). Recently, data mining techniques are being used to study the effectiveness of different types of feedback and hinting techniques to different student characteristics. It is expected that there are several low-hanging fruits that can be exploited in the immediate (Shute et. al., 2009).

Calibrate students' self-monitoring: Given that systems will predict students' interest, competence, etc, they will support growth in competencies and self-efficacy judgments. For instance, they will ask learners to make predictions about their own performance, and then provide feedback and recommendations based on actual performance. Systems will interact with students as do human coaches, doing such things as facilitating communities of learning, including peer feedback.

Systems will insure that feedback is constructive (encourages students to learn) rather than discouraging (convinces students that they are "not good" at the activity). For instance the feedback will didactic vs. discovering corrective info by oneself. Systems will also be self-

improving; educational systems' policies on when/how to give advice will change as systems see whether students learn from the advice.

Informing the negotiation: Although there are certain well-accepted policies for selecting activities (e.g., keep students in their zone of proximal development; model-scaffold-fade), how can evidence from the learning sciences be brought to bear on the decision making? Would it only affect the predictions, and only via them would theory influence decision making? If so, how could the stakeholders find out the evidence or warrants behind a prediction?

Discovering implicit goals: It is possible that stakeholders, especially students, have goals that they are not aware of or which have been mis-described. In this case, their choices of system may exhibit a pattern that can be recognized and brought to the student's attention.

6.5 Diminished boundaries in the year 2030

A fifth education capability that should be available by 2030 is diminished educational boundaries. Tools and resources used in formal environments will become widely available and these tools will transition seamlessly between formal and informal environments (Burleson et al., 2009). Emerging examples of this phenomenon exist in the form of LEGO Mindstorms robotics interfaces that are used in formal and informal education in museums, classrooms, homes, and play. Likewise, the Scratch-programming environment (<http://scratch.mit.edu/>) offers tools that span formal and informal environments. The second manner in which we expect to see blurring of formal and informal learning environments is the seamless transition of learners and learners' abilities to transition, transfer, apply, and enhance their knowledge, experience, and discovery and imaginative inquiry across these environments.

We expect rich interfaces will support life long learning (longitudinal), and ubiquitous (embedded) experiences (Burleson et al., 2009). Learning will be longitudinal and lifelong as learning technology permeate throughout life experiences. Persistent interfaces will adapt to learners across life transitions and stages. In many ways they may come to know the learners better than the learners themselves. As tools they will enhance and facilitate each learner's life aspirations, reflections, and engagements.

We expect rich interfaces to lead to rich experiences that incorporate opportunities for learners to reflect on their own learning (Burleson et al., 2009). Likewise learning scientists will have new opportunities to analyze vast new data sets, collected from the rich interfaces, that contain elements of learning, affect, motivation, social interaction, and longitudinal, indeed life-long data and patterns of learning and engagement that will no doubt lead to new theory development with powerful impacts.

The longitudinal nature of rich interfaces provide a unique opportunity and tool, not only to better understand and facilitate learners attention to their engagements and reflective thinking, but also to ground and promote their ability to envision, plan, and pursue their desired futures (Burleson et al., 2009). These tools will literally provide direct exploration opportunities of diverse possible futures, consequences and benefits, and guide learners in the preparation and commitment to their plans for pursuing them. Rich interfaces can serve as self-actualizing technologies (Burleson 2005).

We expect to see rich virtual environments that include both human and virtual players, for instance in life-long games (Burleson'09, GALLAG); classrooms supplemented with specialized distributed virtual and physical simulations that foster curiosity and instruction through inquiry

based learning (moher'08); and robots that are increasingly socially expressive aimed at fostering learning (Personal Robots, MIT Media Lab). We believe these interfaces will be integrated throughout most aspects of learners' lives.

6.6 Alternative Learning Modes in the Year 2030

A sixth education capability that should be available by 2030 is seamless and ubiquitous learning; seamless refers to the removal of the false boundaries between learning and assessment that characterize the current Teach/Stop/Test model and ubiquitous refers to the constant nature and need to feed back the results and implications of assessment into learning, anywhere anytime.

Educational systems will elicit student actions and provide student feedback. Current learning objects consist largely of passive objects, e.g., videos. Systems will make informed recommendations at the end of an activity (e.g., what to do next: If a student shows an interest in X, and many people who like X also find Y interesting, then it will suggest Y).

Systems will match learners with other learners and/or mentors taking into account learner models and interests. This is in support of feedback and coaching provided by peers and mentors.

Automatics coaches will seek and present just-in-time references that take into account the learner's current task context, prior knowledge and mastery and preferences. This will remove the need for constant teaching and assessing from the teacher, creating tools that are easy to incorporate in the daily lesson plan, and which include actionable information.

By the year 2030, educational systems will detect students who game the system (e.g., push hint buttons until the answer is provided); bad gaming vs. good gaming. They will find opportunities to provide interventions even when they don't understand the user's ultimate intentions during the activity, and there is no "correct" path as in ill-defined domains (diagnosis, art, law).

Systems will classify the differences between a student's and the "correct" path in terms of predicted eventual outcomes (e.g., serious misconceptions vs. minor mistakes vs. missed opportunity for interesting sidetrack. Systems will be aware of each student's pre-requisite and follow-on activities. This is the map of the content area. They will also be aware of each student's meta-cognitive and affective capacities. Based on existing linguistic ability systems will understand student input (text, speech, gestures). Also, if educational systems notice learning opportunities that they cannot handle (e.g., the student is weak on a certain pre-requisite), they report that out to an agent so that it can suggest making that student weakness a priority.

6.7 Political changes in education technology in the year 2030

The last capability discussed is the societal changes that should be available in the year 2030. We expect global education based on customized teaching will be effective in the year 2030. As we transfer to global (on-line) education for everyone, the cost of education will drop by orders of magnitude and many more people will be educated at much reduced cost per person.

7 Educational Technology Research Initiative

In order to achieve the capabilities listed above by 2030, major research opportunities need to be addressed and sponsored by federal agencies. The suggested advances can only be accomplished through intense, concerted long-term efforts championed by federal agencies, led by committed researchers and involving breakthroughs in computational science, cognitive

psychology, and the science of learning and education. The intention is to expand computer research (facilities for experimental hardware, software and networks), encourage large-scale deployment, and assure real educational impacts.

This section provides suggestions and rationale for increased government funding to solve the education challenge, to identify big ideas that are not being pursued, and to target computational models, reasoning, experimentation and implementation of mobile and ubiquitous pedagogical software.

(Coming soon)

8 Conclusions

Lifelong learning facilities that transcend traditional educational institutions (K-12 and university) and begin to impact aspects of continuing education and professional development is a major new direction that greatly expands the role of rich interfaces and learning environments (refs). Content, delivery, personalization, and choice adaptivity in the future will support seamless, ubiquitous access to lifelong learning facilities at home, at work, in schools and universities (Burlison et al., 2009). This implies the development of new ways of organizing learning delivery that go beyond course and program centric models to flexible and adaptive learner-centered, learner-controlled models of distributed lifelong learning

9 References

References (incomplete)

- Arroyo, I., Cooper, D., Burlison, W., Woolf, B. Park, Muldner, K., Christopherson, R. (2009) Emotion Sensors go to School. Proceedings of 14th International Conference on Artificial Intelligence in Education.
- Baker, R. S. J. d., Corbett, A. T., Roll, I., Koedinger, K. R. (2008) Developing a generalizable detector of when students game the system. *User Modeling and User-Adapted Interaction*, 18, 3, 287-314.
- Beal, C. R. (1993) *Boys and girls: the development of gender roles*. McGraw-Hill.
- Beck, J. E., & Sison, J. (2006). Using knowledge tracing in a noisy environment to measure student reading proficiencies. *International Journal of Artificial Intelligence in Education*, 16, 129-143.
- Beck, J.E. (2006). Using learning decomposition to analyze student fluency development. *Proceedings of the Workshop on Educational Data Mining at the 8th International Conference on Intelligent Tutoring Systems* (pp. 21-28). Jhongli, Taiwan.
- Black, P., & Wiliam, D. (1998b). Inside the black box: Raising standards through classroom assessment. *Phi Delta Kappan*, 80(2), 139-148.
- Breazeal, C., Gray, J., and Berlin, M. (2009). An embodied cognition approach to mindreading skills for socially intelligent robots. *International Journal of Robotics Research*. To appear.
- Brna, P., Self, J., Bull, S., & Pain, H. (1999). Negotiated collaborative assessment through collaborative student modeling. *Proceedings of the workshop Open, Interactive, and other Overt Approaches to Learner Modelling at AIED99*. Le Mans, France, pp. 35-44.

- Bull, S., & Pain, H. (1995). Did I say what I think I said, and do you agree with me?: Inspecting and questioning the student model, *Proceedings of World Conference on Artificial Intelligence in Education (AACE)*, Charlottesville, VA, pp. 501-508.
- Bunt, A., Conati, C. and Muldner, K. 2004. Scaffolding self-explanation to improve learning in exploratory learning environments. In *Proceedings of the Seventh International Conference on Intelligent Tutoring Systems (ITS'04)*, (Maceo, Brazil), pages 656-667.
- Burleson, W. Developing creativity, motivation, and self-actualization with learning systems. *International Journal of Man-Machine Studies* 63(4-5): 436-451 (2005)
- Burleson, W., Biswas, G., Muldner, K., Baylor, A. (2009) Rich Interfaces -20 year Horizon, Available soon on <http://www.cra.org/ccc/groe.php>.
- Coburn, C. E. & Talbert, J. E. (2006). Conceptions of evidence-based practice in school districts: Mapping the terrain. *American Journal of Education*, 112(4), 469-495.
- Conati, C., Gertner, A. and VanLehn, K. 2002. Using Bayesian Networks to Manage Uncertainty in Student Modeling. *Journal of User Modeling and User-Adapted Interaction*, 12(4), pages 371-417.
- Diana Laurillard, Magdalini Kolokitha, Dr Harvey Mellar, Dr Neil Selwyn Professor Richard Noss (2008) Learning through life: The role of technology.
- Dimitrova, V. (2003). StyLE-OLM: Interactive open learner modelling. *International Journal of Artificial Intelligence in Education* 13(1), 35-78.
- Hartley, D. & Mitrovic, A. (2002) Supporting Learning by opening the student model. In *Proceedings of ITS 2002*. pp. 453-462.
- Honig, M. I. & Coburn, C. E. (2008). Evidence-based decision making in school district central offices: Toward a research agenda. *Educational Policy*, 22(4), 578-608.
- Ivanic, R. and Tseng, M. L. (2005). Understanding the relationships between learning and teaching: an analysis of the contribution of applied linguistics. London, NRDC.
- Kapoor, A., & Horvitz, E. (2007). Principles of lifelong learning for predictive user modeling. In *Proceedings of the Eleventh Conference on User Modeling (UM 2007)*, 37-46.
- Kay, J. (1998). A Scrutable User Modelling Shell for User-Adapted Interaction. Ph.D. Thesis, Basser. Department of Computer Science, University of Sydney, Sydney, Australia.
- Kay, J. (2008). Lifelong learner modeling for lifelong personalized pervasive learning. *IEEE Trans on Learning Technologies*, 1(4), 215-228.
- Keylor, E. and Burleson, W. (2008) Experience Scapes; Work In Progress Paper, CHI 2008
- King, J., Kelly, H., Sabelli, N., (2009) Learning Technology Policy, Available soon on <http://www.cra.org/ccc/groe.php>
- Lahey, B., W. Burleson, and D. Birchfield, "Designing Tangible Interfaces for Embodied and Mediated Learning", Proceedings of SIGGRAPH Sandbox Symposium, (2008).
- Leighton, J. P., & Gierl, M. J. (Eds.) (2007). *Cognitive diagnostic assessment for education: Theory and practices*. Cambridge University Press.
- Mass Gov (2006) Enrollment Data, Massachusetts Department of Elementary and Secondary Education, <http://www.doe.mass.edu/InfoServices/reports/enroll/?yr=sped0607>
- Messick, S. (1994). The interplay of evidence and consequences in the validation of performance assessments. *Educational Researcher*, 23, 13-23.
- Mislevy, R. J. (1994). Evidence and inference in educational assessment, *Psychometrika*, 12, 341-369.
- Mislevy, R. J., Steinberg, L. S., & Almond, R. A. (2003). On the structure of educational assessments. *Measurement: Interdisciplinary Research and Perspectives*, 1, 3-67.
- Mislevy, R. J., Steinberg, L. S., & Almond, R. G. (2003). On the structure of educational assessment. *Measurement: Interdisciplinary Research and Perspective*, 1(1), 3-62.
- Moher, T. 2006. Embedded Phenomena: Supporting Science Learning with Classroom-sized Distributed Simulations. In Proceedings of CHI 2006 (Montreal, Canada, April 2006), 691--700.

- Mostow, J., & Aist, G. (1997). The sounds of silence: Towards automated evaluation of student learning in a reading tutor that listens. *Proceedings of the Fourteenth National Conference on Artificial Intelligence (AAAI-97)* (pp. 355-361). Providence, RI.
- NCES, National Center for Educational Statistics, IES, Status and Trends in the Education of Racial and Ethnic Minorities,
http://nces.ed.gov/pubs2007/minoritytrends/tables/table_1a.asp, also
<http://nces.ed.gov/fastfacts/display.asp?id=64>
- Olguin D, Waber, B., Kim, T., Mohan, A., Ara, K., and Pentland. A. Sensible Organizations: Technology and Methodology for Automatically Measuring Organizational Behavior. To appear in *IEEE Transactions on Systems, Man, and Cybernetics-Part B: Cybernetics*, Vol. 39. No. 1, February 2009.
- Pellegrino, J. W., Chudowsky, N., & Glaser, R. (2001). *Knowing what students know: The science and design of educational assessment*. Washington, DC: National Academy Press.
- Royer, J. M., & Garofoli, L. (2005). Cognitive contributions to sex differences in math performance. In A. M., Gallagher & J. C. Kaufman (Eds.), *Gender differences in mathematics*. Cambridge University Press. (pp. 99-120).
- Shute, V. J. (2007). Tensions, trends, tools, and technologies: Time for an educational sea change. In C. A. Dwyer (Ed.), *The future of assessment: Shaping teaching and learning* (pp. 139-187). New York, NY: Lawrence Erlbaum Associates, Taylor & Francis Group.
- Shute, V. J. (2007). Tensions, trends, tools, and technologies: Time for an educational sea change. In C. A. Dwyer (Ed.), *The future of assessment: Shaping teaching and learning* (pp. 139-187). New York, NY: Lawrence Erlbaum Associates, Taylor & Francis Group.
- Shute, V. J. (2008). Focus on formative feedback. *Review of Educational Research*, 78(1), 153-189.
- Shute, V. J., Ventura, M., Bauer, M. I., & Zapata-Rivera, D. (2009). Melding the power of serious games and embedded assessment to monitor and foster learning: Flow and grow. In U. Ritterfeld, M. J. Cody, & P. Vorderer (Eds.), *The Social Science of Serious Games: Theories and Applications*. Philadelphia, PA: Routledge/LEA.
- Shute, V. J., Ventura, M., Bauer, M. I., & Zapata-Rivera, D. (in press). Melding the power of serious games and embedded assessment to monitor and foster learning: Flow and grow. In U. Ritterfeld, M. J. Cody, & P. Vorderer (Eds.), *The Social Science of Serious Games: Theories and Applications*. Philadelphia, PA: Routledge/LEA.
- Shute, V., Baker, R., Kuntz, D., Levy, R., Zapata, Diego, (2009) Assessing and Enhancing learning, Available soon on <http://www.cra.org/ccc/groe.php>
- Snow, R. E. (1994). Abilities in academic tasks. In R. J. Sternberg & R. K. Wagner (Eds.), *Mind in context: Interactionist perspectives on human intelligence* (pp. 3-37). New York: Cambridge University Press.
- Stiggins, R. (2006). Assessment for learning: A key to motivation and achievement. *Edge: The Latest Information for the Education Practitioner*, 2(2), 1-19.
- Stiggins, R. J. (2002). Assessment crisis: The absence of assessment for learning, *Phi Delta Kappan Professional Journal*, 83(10), pp. 758-765.
- Suthers, D., Derry S., Schlager, M., (2009) Social Learning, Available soon on <http://www.cra.org/ccc/groe.php>
- VanLehn, K., Corbett, A., Ramachandran, S., Jensen, C., Underwood, J., Intelligent Virtual Environments, Available soon on <http://www.cra.org/ccc/groe.php>
- Vygotsky, 1978
- White, B. Y. 1993. ThinkerTools: Causal models, conceptual change and science education. *Cognition and Instruction*, 10(1), pages 1-100.
- Zapata-Rivera, D. & Greer, J. (2004) Inspectable Bayesian student modeling servers in multi-agent tutoring systems, *International Journal of Human-Computer Studies*, 61(4), 535-563.