

# **A Roadmap for Education Technology**

## **Release 2**

**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 databases of homework problems and grading and recording grades. Rarely has education technology been challenged to provide for learning that is life-long and life-wide, supporting learners who are 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 outline a path for developing potentially powerful educational tools and infrastructures, 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 process was part of Global Resources for Online Education (GROE), a project sponsored by NSF and the Computing Community Consortium (CCC).<sup>1</sup> 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.

Preliminary discussions were led by Paul Cohen, of the University of Arizona, during the Fall Symposium of the Association for the Advancement of Artificial Intelligence, November 7-9, 2009.<sup>2</sup> 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. A second forum was convened in Brighton, England, where twenty participants (many from the European computer science community) contributed additional comments, ideas and recommendations to the conversation. These participatory programs helped us focus on existing efforts and to shape a 30 year vision for research to enable technologies that should be fostered in the context of education and learning.

This report provides an overview of the discussions held during these first two programs of the GROE project. It lays out a roadmap for an integrated approach to computer science, cognitive science, and learning sciences research that addresses 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 through additional workshops and forums.

We recognize that educational 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 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.

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<sup>1</sup> The Computing Community Consortium is funded by the National Science Foundation through the Computing Research Association to mobilize the computing research community to formulate important questions facing the field and develop strategies for pursuing them.

<sup>2</sup> See [https://garuda.cs.arizona.edu/iicp/Fall\\_Symposium](https://garuda.cs.arizona.edu/iicp/Fall_Symposium) and <http://iicp.cs.arizona.edu/submissions/>

## 2 Summary of major findings

This Roadmap describes new ways of organizing and delivering instruction and suggests methods to move education towards adaptive learner-centered and learner-controlled distributed lifelong learning. Using an *intentional* approach, we ask how to challenge technology to support the needs of education innovation. We also describe a research agenda for federal funding that can make this happen within seven key areas:

- *Assessing student learning.* A compelling vision of assessment should have as its primary goal to improve learning. Through education technology we will move beyond the “Teach / Stop / and Test” model. Assessment will be everywhere and every time a student learns. It will be seamless and ubiquitous and consistent with learning. We recommend federal funding focused on: (1) Understanding the full complement of characteristics brought to bear in learning - What are learning competencies? How do they relate and how do we acquire evidence about them? (2) Fusion of assessment and learning - What are new sources of assessment? How do they flow to, from and with learning, and how can we tear down conceptual and practical barriers between assessment and learning? (3) Rendering assessments useful to all parties - Who makes what decisions? What information do they need, how does assessment provide evidence for those decisions, and how to best communicate the complicated results of assessment to each party?
- *Personalizing instruction.* Learning environments will personalize instruction to harmonize with student *traits* (e.g., personality, learning style, motivation and culture) as well as student *states* (e.g., affect, level of engagement and level of frustration). For example, they will understand students’ weaknesses and challenges as well as their motivational style (e.g., is a star, wants competition, needs peer acknowledgement, seeks personal improvement). One technology challenge is to understand an individual as might a human tutor. We recommend federal funding that focuses on: (1) Implementing advanced learning models that represent what learners know, can do, when and how knowledge was learned and what pedagogy worked best for each learner. (2) Developing machine learning and data mining techniques, including algorithms that are particularly adapted to educational data - How do we manage vast amounts of data, effectively store, make available and analyze data for different purposes and stakeholders? (3) Developing simulations and representations that explain themselves to learners-- How do we address the communicative interaction and use multimedia to switch modalities as appropriate?
- *Supporting social learning.* We can no longer accurately consider individual learners as acting in isolation. Social learning is pervasive and should be a component of all research that effectively addresses learning. Active students learn continuously; technology will sustain that learning in a way that is highly distributed and valued by typical citizens. We recommend federal funding that focuses on: (1) Supporting learning communities to sustain, build on and share knowledge - How do communities interact and share knowledge resources? (2) Addressing infrastructure (API, management) and application level (representations) issues - How can we achieve more than just technical interoperability and also support semantic interoperability? What integrations/mashups of devices/platforms would more effectively support social learning distributed across time, space and media? (3) Treating the social group as a cognitive unit, but not to the exclusion of the individual – What analyses are needed to relate the two.
- *Diminishing educational boundaries.* We re-examine the many artificial and non-productive boundaries that have been established within educational institutions, including *place of study* (home, work, institutions), education *level* (school, college, university and professional

development), personal *ability* (special and typical students) and *type of learning* (formal and informal). Education technology will help cross many of these boundaries. For example, mobile technology and social networks provide seamless and ubiquitous learning across place of study and intelligent environments address the level of education (by enabling each student to engage in learning at her appropriate level). We recommend federal funding that focuses on: (1) Increasing opportunities for learning outside as well as inside the educational apparatus- When does learning occur? How should learning outside of the norm (e.g., at home and informally) be supported? (2) Developing tools and resources for learning that are available across society; (3) Supporting students to transition, transfer, apply, and enhance their knowledge, experience, and discovery and imaginative inquiry across boundaries.

- *Developing alternative learning modes.* 21<sup>st</sup> century students need to solve complex problems in innovative ways and to think clearly about vast amounts of knowledge. This means working across domains, collaborating with others and engaging in inquiry reasoning. These needs are more pressing than ever as citizenship in a high-technology world requires scientific reasoning and disciplined thinking. Teamwork is vital. We recommend federal funding that focuses on: (1) Developing resources to support collaborative inquiry— What is the process by which teams generate, evaluate, and revise knowledge? Which tools support learning of more complex, realistic problems? Which tools match learners with other learners and/or mentors taking into account learner interests? (2) Developing students' communication skills and creative abilities as they become exposed to diverse cultures and viewpoints; (3) Developing resources to support exploratory learning, social interactions, ubiquitous learning and choice in learning.
- *Enhancing the role of stakeholders.* Education stakeholders (teachers, students, parents, administrators and employers) will effectively and consistently utilize technology as part of instruction and in some cases fully integrate it into their teaching/learning. Stakeholders will trust educational technology to do what it claims to do and be assured that students have absolute privacy. We expect teachers to continue to be of primary importance in school environments. We recommend federal funding that focuses on (1) Extending a teacher's significance to informal settings as well as formal ones and increases their interactions with students in broader and more diverse contexts; (2) Developing more tailored and higher quality information to teachers to inform their actions. (3) Addressing the historical imbalance between children and teachers - Which activities and environments make teachers' experiences as engaging and motivational and productive as childrens' experiences?

In setting the context for this report, we recognize that the realm of education is vast, and that the realm of learning is even larger. The participants in this project are not representative of the broad interests in education and learning, and are not even representative of all the interests in the area of technology in education and learning. The ideas developed in the GROE project are illustrative of the kinds of promising initiatives that might be undertaken. Success in achieving the broad objectives of improved learning will depend on many communities, including teachers, students, parents, and educational leaders, in addition to researchers and technologists. The specific ambition of the GROE project is to push the frontier of thinking, to speculate about what is possible, and then turn to the issues of prioritization and implementation. This draft document does not provide the priorities or a plan for implementation. Rather, it provides the motivation for the effort, a set of grand challenges to be considered, and suggestions of what technological advancement might offer in meeting those challenges.

### 3 Motivation for the work

The United States has a large accumulated investment in the existing educational apparatus and spends a great deal of money 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 apply what is learnt to real-world problem solving nor on true conceptual understanding.

The information technology used in education has been based on existing technology, typically with 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*). This 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 configure it 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 study which education innovations benefit which learners. Students need support in the social aspects of learning and in using a variety of exploratory and inquiry tools. This can be accomplished through agents, simulations and artificial intelligence methods that model and systematically represent instructional methods, scaffold learners and support student exploration. Students should be supported to search for a wide variety of information, connect to the real world, gather and analyze data, and communicate through a variety of social channels.

Similar thinking enables us to take into account all other stakeholders, e.g., administrators, parents, and other interested individuals in business, industry, nonprofit organizations and government agencies who use technology to develop new and more specialized skills in the workforce.

The GROE workshops seek to identify technological solutions that 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. This project brings together a broad range of stakeholders, reflecting a wide spectrum of constituent experts, who are making an effort to identify the needs society as a whole. The resulting thought experiments help identify the next big ideas that might provide solutions to important but hard-to-solve problems regarding the future of education, and that shed light on how research investments and public support can be catalyzed to create a better educational future. Two broad challenges characterize this goal:

- 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 exemplary grand challenges in education to which technology might be applied. The section after examines how technology might be coerced to satisfy some of those challenges.

#### **4 Grand challenges: Engaging the magnitude of the problem**

A society built on knowledge requires its members to acquire new skills quickly, to engage new learning approaches enthusiastically and to form new learning communities that work well. For educators, this requires rapid revision in what is taught and how it is taught to take advantage of evolving knowledge where technology changes every 2-5 years. As an example, the Internet was not broadly available in schools as late as 2002, but is now widely used in the classroom. More recently, social network technologies have become immensely popular among today's school-aged children, yet they hardly existed in 2007. How can educators embrace technologies that barely exist today, but that in a short time will change their students' lives?

Today's students need so called "soft" skills (e.g., teamwork, computer literacy, and presentation skills) and to engage in experiences that are different from those of two or three generations ago. The 21<sup>st</sup> century workforce needs both "hard" skills across multiple content domains, as well as soft skills across a wide array of interpersonal, behavioral, and social domains (Shute et al, 2009). Yet, many of today's classrooms look like 19<sup>th</sup> and early 20<sup>th</sup> century classrooms. Teachers use old methods (e.g., lecturing to passive students, assigning homework tasks focused on memorization of facts) that do not require the understanding and application of concepts to realistic problems. Change is slow. Development of qualified teachers takes much longer than most people realize (King et al., 2009). It takes about 25 years from birth for an individual to receive a sufficiently well-rounded education to become a proficient educator. Years of additional experience are required before teachers figure out how to work consistently and effectively in classroom settings while keeping up with continual changes in accepted best practices. The effect of their teaching cannot be seen in *subsequent learners* for another 20 years. The total cycle time for learning improvement is on the order of 45 to 50 years. Very few

challenges in research or social policy cover such a long time scale. But failure to consider such time-scales cripples our efforts to understand the systemic characteristics of the challenge.

#### **4.1 Assessing student learning**

The first grand challenge in education is assessment, which is also 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).

A compelling vision of assessment should have as its primary goal to improve learning (e.g., Black & Wiliam, 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 21<sup>st</sup> century. This type of assessment maybe referred to as “formative assessment,” or assessment *for* learning, in contrast to “summative assessment” (or assessment *of* learning).

Given the increase in so-called soft skills required of 21<sup>st</sup> century citizens (e.g., communication, collaboration and problem solving), it is important that we develop good methods to assess students in these formative 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. Seamless refers to the removal of the false boundaries between learning and assessment that characterize the current Teach /Stop /and Test model of assessment and ubiquitous refers to the constant nature and need to feed back the results and implications of assessment into learning, anywhere and anytime.

Learners should also develop the skills and practice of self-regulation or self-explanation. Methods for measuring these skills must be developed to know whether students have improved (Shute, et al., 2009). Therefore, in a shifting educational landscape, it is necessary to establish approaches to building comprehensive models of learner competencies and attributes, and then developing assessment techniques to infer levels of those constructs. Assessing student competencies and attributes also supports future learning and the teaching of lifelong learning skills, thus suggesting the need to develop meta-cognitive strategies for learning.

Technology support of assessment is described in detail in Section 6.1.

#### **4.2 Personalizing feedback**

A second 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, we know that students learn in different ways and that many students respond positively when material is personalized for them. Yet efforts to address learning challenges based on first principles have made little headway. 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. Many populations need personalized education. 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. 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 are poorly reached by traditional methods. These students often require additional staff or extra resources, something that schools are increasingly unable to provide due to budgetary constraints. Students with *learning disabilities* often have complex multi-factor problems. This population has a large negative impact on society in terms of health and education costs and behavior problems. Yet educational institutions are unable to provide potent cost-effective instruction for these individuals.

The technology challenge in personalizing education is for information technology to be implemented to reason about a student as might a human tutor, by observing each student's activities and evaluating their learning and finding opportunities for help and 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 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 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* due to their general appeal, limited need for resources other than a browser and their ability to personalized tutoring.

Technology can provide students with instruction that is adapted to their needs and enables 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 can not, and do not, succeed for all learners, whereas specially designed educational systems can identify and remediate core student problems (Laurillard et al, 2008).

Developing personalized feedback through technology is described in detail in Section 6.2.

### 4.3 Supporting 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.

Technology support of social learning is described in detail in Section 6.3.

### 4.4 Diminishing boundaries

A fourth 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; the impact of technology on learning might be greater outside the educational apparatus than within it.

Some 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)

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 5.4). Personalized instruction for all students is addressed by modeling and assessment techniques (Section 5.1).

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).

Technology in support of diminished boundaries is described in detail in Section 6.4.

#### **4.5 Developing alternative teaching modes**

A fifth challenge in education is development of 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 often means working across multiple domains, and, therefore, students need to learn, understand, and apply information that spans multiple topics (e.g., math, science, and social studies) (Jasper work, How People Learn). As a consequence, additional technology resources are needed to further engage students in collaborative activities, in working with local and distal students, and in asking good questions. In addition to providing students the ability to handle more complex, realistic problems, we need rich environments that 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.* Inquiry reasoning is more pressing than ever because citizens in a high-technology world need to employ scientific reasoning and to ask new questions, to generate hypotheses and to gather evidence that either supports or refutes those hypotheses. In inquiry learning, students learn to plan and manage investigations and to analyze and communicate their results (Woolf, 2009). People need to use disciplined thinking to solve messy problems without nearby authoritative help (answers supplied by instructors). Inquiry and collaborative learning strategies are ideal for helping students to work within active and authentic contexts to reflect on their own knowledge and to transfer that learning into new contexts (Greeno et al., 1996).

However, teaching inquiry reasoning presents many challenges, especially in classrooms. Teachers have to monitor the progress of teams and individuals who articulate different hypotheses and pursue unique experiments. Teachers need 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. 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 integrated with 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; it 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 collaboration learning 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 work with local and distal students. 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 (a theory that says that instruction should not be so difficult that students are discouraged nor too easy so that students are bored).

Teaching students about 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 to assume ownership of knowledge. Teaching such skills, e.g., knowing how and when to intervene appropriately, is time and labor intensive (Derry et al., 2000).

Technology support of alternative learning modes is described in detail in Section 6.5.

#### **4.6 Enhancing the role of stakeholders**

A sixth 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.

Technology support for the role of stakeholders is described in detail in Section 6.6.

#### **4.7 Addressing policy challenges**

The seventh and final grand challenge focuses on major and constructive changes in education policy that are required to address endemic educational problems. A *knowledge society* requires people to learn rapidly and to quickly form new learning communities. Yet the existing education infrastructure is a *perfect storm*; it fails us in multiple ways. Only 50% of the world’s population receives 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 and 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).

“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 a 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.

Technology support for political changes is described in detail in Section 6.7.

### **5 What technology might offer over the next 20 years**

The grand challenges for education articulated above provide a backdrop 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 educational grand challenges and technologies needed to satisfy them. To fully support the challenges (left), technology features are needed to support a variety of teaching methods and learning styles. Each grand challenge requires a combination of

technology features (middle). Several resulting educational capabilities (right) will be in place around the year 2030, if the technology can be fully optimized for education.

We have selected six information technologies that show great promise for educational innovation, specifically user modeling, mobile technology, social networking tools, intelligent environments, data management and rich interfaces. This section illustrates how each of these technologies can be pressed into service to address educational grand challenges and some of the research needed to enhance 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 User modeling

The first information technology that holds great promise for education is user modeling or the ability to identify and represent student capacities for learning. This involves identifying knowledge skills (e.g., addition, subtraction), a student's knowledge about learning (e.g., meta-cognitive knowledge) and affective characteristics (student traits and states). Assessing learning includes measurement of changes in students' learning (Shute et al., 2009).

Comprehensive student models of general learner characteristics need to be constructed so as to transfer across systems. Aside from reducing the costs of electronic learning objects that would have been created, this idea also increases the number of such artifacts that are built since a broader set of content creators will be able to participate. Furthermore, 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?

We need approaches that lead to valid and reliable inferences, both diagnostic and predictive. We must look at assessment uses as both "summative" (e.g., for purposes of accountability and promotion) as well as "formative" (to support learning). Indeed, through appropriate design and other analytical methods, data from a given assessment can, in fact, be used for both formative and summative purposes. Such a perspective concurs with the view that assessment is a dynamic agent in student learning over time.

Currently, assessments are too often used for purposes of grading, promotion, and placement, and not for learning. This needs to be fixed. Rather, assessment should support, not undermine, the learning process for learners and teachers (as well as online agents) by providing more formative than summative information (i.e., give useful feedback during the learning process *about* the learning process, instead of a single judgment at the end). In short, assessment should be more 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.

## 5.2 Mobile tools

The second set of technologies that hold great promise for education are mobile tools or remote access to information through wireless devices (phones, laptops, printers, etc.) and supports users to access and receive information anytime and anywhere. 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 networking tools

The third set of technologies that hold great promise for education are social networking tools. Social learning is pervasive and should be a component of all research that effectively addresses learning. Active students learn continuously; technology will sustain that learning in ways that are highly distributed and collaborative. For example, we intend that tools will 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, enable the persistence of individual activity that leads to value for others, and help students to refactor virtual “space” to be defined by task or topic (Suthers et al., 2009).

Technology needs to be coerced to support student interaction distributed across space, time and media and with data in a variety of formats. Research on resources for online social learning should enable learning communities to flourish without requiring that participants or educators have technology skills. For example, new technology is being developed and many Internet objects are available for shared social learning. 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. 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).

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.

Future technology challenges include influencing learning in socio-technical systems by design (key areas). 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

The fourth set of technologies that hold great promise for education are intelligent environments, or system that integrate artificial intelligence techniques (e.g., modeling, natural language understanding, machine learning, etc.) to provide knowledge about students and teaching methods (Woolf, 2009). Such systems provide flexible and adaptive feedback to students and support content to be altered to fit the personal needs and abilities of each 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.

*Interpreting 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**

The fifth information technology that holds great promise for education is data management and mining, or methods for exploring data from educational settings and using that data 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**

The sixth and final set of technologies that holds great promise for education are rich interfaces that involve new and exciting technologies for open-ended learning environments that combine a number of different learning paradigms and resources (Burleson 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 (Burleson et al., 2009).

Technology now identifies opportunities to improve student affect (motivation, interest, emotions, self-efficacy), “21<sup>st</sup> 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) (Burleson 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 A Future View: Education in the year 2030**

The previous two sections identified big ideas in education technology along with technology features that help address these challenges. A national initiative on education technology is needed with participants from education, industry, academia, and government laboratories and agencies. Several high-risk/high-return learning technology systems should be developed that can be studied in depth, 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 emerging capabilities in education as a result of new 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. Future 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). We describe seven educational capabilities that we expect to see in the year 2030, including assessment, social learning, diminished boundaries, alternative learning modes, enhanced role of stakeholders and political changes. Then we discuss application beyond traditional boundaries, specifically health care.

### **6.1 Assessment in the year 2030**

The first educational changes we expect to see will be in assessments that 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 21<sup>st</sup> 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**

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

## 6.2 Deep knowledge of students in the year 2030

A second educational change we expect will be systems that have deep understanding of students. Systems will understand students' weaknesses and challenges and will understand the motivational style of students (e.g., stars, competition, acknowledged by peers, get attention, perform, personal improvement) (Shute et. al., 2009). They will customize 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).

*Calibrating 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.

### **6.3 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 (Burlinson et al., 2009). Already we see emerging intelligent tutoring systems with affective learning companions that are capable of sensing and responding appropriately to elements of learners' emotional and motivational states (Graesser et al., Lester et al., Arroyo et al. 2009, Burlinson and Picard, 2007). 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 Diminished boundaries in the year 2030**

A fourth education capability that should be available by 2030 is diminished educational boundaries. Tools and resources used in formal settings will become widely available and these tools will transition seamlessly between formal and informal environments (Burlison 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 in the seamless transition of learners and learners' abilities to transition, transfer, apply, and enhance their knowledge, experience, and discovery and imaginative inquiry across formal and informal learning situations.

We expect rich interfaces will support life long learning (longitudinal), and ubiquitous (embedded) experiences (Burlison 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 (Burlison 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 (Burlison 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 (Burlison 2005).

We expect to see rich virtual environments that include both human and virtual players, for instance in life-long games (Burlison'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.

## **6.5 Alternative Learning Modes in the Year 2030**

A fifth education capability that should be available by 2030 is seamless and ubiquitous learning. Educational systems will elicit student actions and provide individualized feedback. Current learning objects consist largely of passive objects, e.g., videos. Intelligent systems will make informed recommendations at the end of a student's 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. Automatic 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) and identify 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.

## **6.6 The role of stakeholders in the year 2030**

A sixth 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 (Burlison et al., 2009).

Teachers will take on multiple 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 (Burlison 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 (Burlison 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.

## **6.7 Political changes in education technology in the year 2030**

The seventh and 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.

## **6.8 Applications beyond traditional boundaries: The case of health care**

The foregoing discussion suggests that these innovations will affect primarily the domain of traditional education, but that takes too narrow a view. It is becoming widely recognized that other major problems facing the society require a fundamental shift in learning. A good example is health care. It has been known for some decades that lifestyle choices have a dramatic effect on long-term health status. Campaigns to reduce the incidence of smoking provide evidence that the message is understood at the policy level, and when mitigation efforts are implemented aggressively, behavioral changes follow and desired health effects are achieved. The recent surge in obesity offers another example where behavioral modification might be needed to curb a looming public health disaster.

The rise of Internet-based communication, especially using the World Wide Web, has enabled a dramatic change in the flow of information between researchers, health care providers, patients and the population at large. This first was noticed in the shift in information asymmetry between health care providers and patients, as patients gained access to information about their conditions that previously was available only to providers. This, in turn, has changed the relationship between providers and patients. It is now possible to enlist patients in their own health care decisions and treatments more effectively than before. Patients suffering from particular conditions can join in chat groups or other forms of on-line discussion to compare notes and learn from each other. These changes suggest that the technologies discussed above could improve learning about health dramatically, with possibly revolutionary consequences for the nation's health care system. This is but one of many applications of these technologies that go beyond the traditional educational boundaries.

## **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. Establishment and execution of such a program requires careful study and consideration. There are many possible options for pursuing such a goal, and even with significant funding choices will have to be made among the options.

(Coming soon a list of recommendations to funding agencies)

## **8 Conclusion**

We expect major changes in education as a result of evolving education technology education technology and learning environments. Specifically, lifelong learning facilities will transcend traditional educational institutions and begin to impact aspects of continuing education and professional development. Content, delivery, personalization, and adaptivity of instructional systems will support seamless, ubiquitous access to lifelong learning facilities at home, at work,

in schools and universities. Changes in education will deliver new ways of organizing learning delivery that go beyond course and program centric models and include flexible and adaptive learner-centered, learner-controlled models of distributed lifelong learning.

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