

SETTING A COMPUTER SCIENCE

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RESEARCH AGENDA FOR

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EDUCATIONAL TECHNOLOGY

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**F**rom the earliest days of computing, experts have predicted that information technology held the potential to make major transformations in how people learn. Over the years, although the path into the schoolroom for computer technology has been tortuous at best, this belief has persisted, buttressed by research that hints of the powerful potential—hints that have triggered a surge of political interest. Indeed, over the last few years schools have scrambled to install computers, and the Federal Communications Commission recently announced rules intended to ensure that all classrooms are connected to the Internet by the year 2000.

Underpinning this growing demand for educational use of computer technology is a phenomenal and ongoing technological change. In the not-too-distant future, many students will sit at personal computers equipped with gigahertz processor chips, hooked into data communication networks with transmission speeds of millions of bits per second. These and other technologies—memory, display and the like—are improving at an extraordinary rate. And the end is not in sight.

But, powerful as that social demand is and impressive as those technological capabilities are, we are just beginning to understand how to connect them seamlessly with the education process and with the actual needs of the students and the institutions responsible for their education. Clearly, a major research effort is needed to close that gap.

On Sept. 30 – Oct. 2, 1995, the Computing Research Association and the Georgia Institute of Technology convened a three-day workshop in Washington, DC, to bring computing research and educational research experts together to develop a research agenda.

The workshop was funded by the National Science Foundation. We would like to express our deep appreciation to the NSF program staff for their support and concern with these important issues. The authors of this report have tried to capture the content and spirit of the discussions at the workshop. However, the ideas and suggestions contained in this report are those of the authors and workshop participants. This report does not reflect NSF policy or the views of any particular participant.

We would like to thank all of the participants and session leaders for their hard work and valuable contributions (see Appendix A). It is not easy for researchers to engage in intense deliberation with experts in other, quite diverse fields and, in such a short time, begin the process of creating the multidisciplinary research agenda presented in this report. We hope this report will serve as a first step in triggering a new wave of research combining the fields of educational technology and computing research.

Thanks to the reviewers of the various sections of this report (see Appendix B). The resultant document has been improved greatly by their comments. The views expressed here do not necessarily reflect those of the reviewers.

We wish to thank Chris Dede for organizing his students at George Mason University and for helping us in the workshop sessions. We thank the students (see Appendix C) for their efforts in dealing with the odds and ends in each working group.

We would also like to thank Joan Bass of CRA for her assistance in producing this report.

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# Research in the Union of Computer Science and Education

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## 1. MEETING THE TECHNOLOGICAL NEEDS OF EDUCATION

### 1.1 THE PROMISE AND THE PROBLEMS

During the last several decades, since the invention of the digital computer, many researchers have believed computer technology holds great promise for education. The National Science Foundation (NSF) and the Defense Department (DOD) began supporting research on the feasibility of the instructional use of computers in the 1960s. This and successive research over the ensuing 30 years have repeatedly proven that computers can be powerful educational tools. Information technology (IT), when properly used, can improve learning, motivate students and help them gain higher-level cognitive skills critical to lifelong learning.

Yet despite instructional computing's proven success, it has not yet been adopted in any meaningful way into K-12 education.

This delay in adoption is particularly striking when compared with rates of technological adoption by other institutions, both private and government. Two probable causes for the delay are: 1) financial constraints and 2) the significant changes that must occur within both the institution and the technology itself if instructional computing is to become a significant and meaningful part of education's learning environment.

Costly investments in hardware, software development and staff retraining generally are required to bring technology into any organization, and the nation's educational system is a very large organization. Furthermore, for the past several years school budgets have been under severe constraints, providing administrators little flexibility to accommodate such cost demands. Additionally, previous research has often been done with expensive, state-of-the-art technology. Although the cost/performance ratio for most computer technology has been improving rapidly (doubling about every two years), it can still take several years for these applications coming out of the laboratory to become affordable. Thus, computing researchers are, in essence, working with time machines, exploring applications that will become cost effective only in the medium-term future. Educators' expectations for the short term may have been uninformed by these realities and, thus, in all likelihood went unfulfilled.

The second, and perhaps even more difficult, problem is that successfully adopting technology in a deep way means adapting both institutions and the technology in a deep way. This observation is not new; significant organizational adaption has accompanied nearly every major application of computer technology. Nor is this observation an indictment of the inertia of the educational establishment.

Not much technology that is compatible with the educational and institutional goals of any given educational system exists. Substantial research on learning processes and on problems in the computing field is needed to meet that design goal.

It is time for such a major research initiative in education technology, particularly one that is broadly based and that focuses on the use of communications and computer technology.

The convergence of digital technology with its rapidly changing communications infrastructure and growing political and societal demands for effective, relevant and affordable education is creating an ideal opportunity for a fundamental transformation of education.

IT is clearly transforming the U.S. economy and the nature of work. In most professions, skills in using new information media are becoming a premium, and those skills inevitably require mastery of IT. Technology is also changing society's demands on education. Economists are warning that in a globally competitive information economy, one of the few natural advantages a nation has is an educated, skilled work force. More broadly, in the face of rapid change, the most important skill to learn is learning itself—how to learn again and how to learn more.

As mentioned earlier, in terms of cost/performance, basic IT is improving at an enormous rate. In some cases, the rate of improvement is as much as 50% per year. Ten years from now a processor in a modestly priced desktop computer will be almost as powerful as today's supercomputer. Random access memory (RAM) will be measured in gigabytes (billions), and bulk memory—the equivalent of disk storage—will be measured in terabytes (trillions). CD-ROMs or their successors will contain hundreds of times the amount of information they hold today. Terminals will feature high-definition, flat-panel, color displays and reliable voice input and output. Communications technology will improve at an equally impressive rate, although how fast it will become broadly deployed is debatable.

In the last few years these trends and responses to the concerns they have elicited have become encapsulated in a government initiative for a new National (now Global) Information Infrastructure. The NII—which seeks to combine a variety of policies and laws ranging from research funding to standards to rewriting the telecommunications laws—is intended to speed the deployment of a ubiquitous, broadband digital communications network. Its emphasis is on applying the NII to social applications, including—most notably for this report—education.

On Sept. 30 – Oct. 2, 1995, the Computing Research Association, the American Educational Research Association and the Georgia Institute of Technology hosted a workshop in Washington, DC, aimed at defining a computing research agenda for education. This report presents the results of the workshop, which brought together leaders in computing and educational technology to develop an expanded and long-range computing research agenda. The agenda includes fundamental investigations in computer science and engineering directed at solving problems posed by new educational applications. This report is intended to be the start of a long and productive dialogue between the computing research community and those concerned with bringing technology to bear on the problems of education.

Fully realizing the potential future benefits of IT for education (and avoiding some of its pitfalls) will require substantial R&D. If IT is to inform and transform educational practice over the next five to 10 years:



- Teachers and students will have to have classroom tools for easily accessing and using resources available on the NII.
- Schools, workplaces and other centers of learning will have to organize their institutions and organizational processes around network and computer-based learning.
- Teachers will have to learn techniques and develop new skills for guiding student learning on the NII.
- Designers will have to develop new technologies and methods to serve the growing demand for lifelong learning.
- Authors will have to have sophisticated authoring tools to develop educational applications that take advantage of powerful new multimedia and distributed computing technologies.

## **2. THE VISION OF TECHNOLOGY AND EDUCATION**

To develop a research agenda for educational technology, workshop participants wanted to start with a vision of the role technology will likely play in the future educational environment. Such a vision needs to address several questions. For example, what will society ask of education in the future? How will institutions that provide those services be organized? What skills and tools will individuals bring to their learning experiences? What sort of technological infrastructure will education use?

These questions are actually issues too large and complex to be fully explored in a workshop. Developing conclusive and detailed answers in such circumstances is impossible. Nevertheless, attendees felt it important to develop a brief, general vision based on what they do know, a vision that encapsulates future educational goals and the potential of technology to help meet those goals.

Computers and communications services already have become fundamental tools for creating, storing, processing, distributing, organizing and presenting information in most economic sectors and in most social environments. Inevitably, they must also become central to the processes of learning. If these assumptions are correct, advances in computer science and engineering research will be critical in meeting the future needs of education. The greatest progress, however, will result from the integrated efforts of computer scientists, education researchers, curriculum developers and the wide range of stakeholders and participants in the education system. Only through this collaborative effort will we learn how to successfully adapt new IT to support and develop learning activities.

The vision and research agenda presented in this report focuses on research that merges an understanding of technology with an understanding of the needs and methods of education.

## **3. NEW MODELS OF LEARNING**

After years of research, educators are beginning to create a model of learning radically different from the dominant model of the last century. Effective learning is not a passive activity; it is not something just “delivered” to the student, as is assumed in the traditional lecture mode. Learning requires that students think, work with ideas and be actively engaged in their subject materials and the materials’ processes—e.g., students need to participate in activities that motivate learning and give them a

chance to build their own understanding. In order for this new learning model to be used, it will have to fit into the institutional constraints and demands of the U.S. educational system.

The new model is characterized by:

- *Authentic activities.* Activities similar to ones students will eventually participate in or encounter in the working world beyond school. Authentic activities engage and motivate students and encourage deep learning—i.e., the development of analytical and cognitive skills—that can be transferred to new contexts. Technology can provide tools to help students manage and learn from such activities.
- *Metacognitive learning.* Learning where students are actually learning how to learn and can identify when they have not learned critical skills.
- *Collaborative learning or reciprocal teaching.* Learning where students use one another as teachers, reviewers and critics. Technology can support online, structured collaborative forums for student engagement, forums unrestricted in time and place.
- *Apprenticeship learning.* Learning where students are supported while learning by actively using their new knowledge. Technology can provide online models, coaches and immediate feedback and help.

## 4. INFORMATION TECHNOLOGY AND SOCIETY

Broadband digital networks are becoming the critical pipeline for information processing and communication. This trend is causing significant changes in society's demands on schools, students and teachers.

For example, organizations, including schools, will become more distributed and have less need for constant physical presence. The classroom and physical laboratory will cease to be the sole locus for learning. Whether this trend will, ultimately, mean the total disappearance of the school as a physical location remains to be seen. It is clear, however, that a significant amount of learning will take place at a distance, supported by high-bandwidth interactive communications and educational software.

The technological infrastructure that is evolving has a very heterogeneous character, both in terms of capability and availability. Unlike telephony, for which it was a public policy goal that every residence have affordable access to a phone, not everyone will have access to or be able to afford all the services available on the network. This heterogeneity is likely to persist indefinitely. Yet if IT is to have a significant impact on education, advanced services must be widely and easily accessible. Thus, local technology centers—including libraries, schools and community centers—will likely serve as important access points for higher-level information services.

Lastly, computer networks do more than just provide access to information and computing resources and create connections among people. They can help organize and channel complex flows of information among groups. Scholars and researchers already are developing powerful new ways to use computer communications to make geographically dispersed collaboration easier. The networks will have an equally powerful impact on collaborative educational activities.

## **5. RESEARCH AGENDA FOR EDUCATION AND TECHNOLOGY**

This report's research agenda for computer science and engineering is organized around the needs of the educational system rather than around traditional technological subfields. Consideration has been given to four critical components of the system: organizations, teachers, students and authors.

For the purposes of this report, organizations are workplaces, schools and a variety of other kinds of organizations (e.g., community organizations, social organizations), all needing mechanisms for facilitating and managing the needs of their learners.

With the successful adoption of IT networks, the role of teacher will shift from directing individual students in self-contained classrooms to responsively distributing teaching and expertise. Some teachers will have expertise in development, disciplinary specialties and/or learning resources. They will serve as coaches and guides in distributed environments, showing students how to find and use current, relevant and reliable information.

The goals and attributes of their students will also change. As adults become lifelong learners in response to the changing social/global milieu, they will be more focused and more interested in integrating learning with their work activity. Although children will still undertake 12 or more years of education before entering the work force, the educational system's new goal will be to prepare students for knowledge work, requiring a focus on developing learning skills rather than disembodied facts.

It will be difficult for authors of educational technologies to keep up with the pace of change and produce tutorials or simulations for fixed domains. Instead, they will need to transfer content knowledge bases from tutorials to simulations and create frameworks that can be used across domain areas.

Current technology cannot fulfill the needs of organizations, teachers, students and authors. Designing technology that can meet these needs will require research. And the research that will prove most fruitful in addressing their needs will be that research resulting from the union of computer science and education. Although there is certainly benefit for educational technology from research in education and research in computer science, the most challenging issues require the synergy of technology exploration with a deep awareness and appreciation for the complexities of human learning.

## **6. RESEARCH AREAS AND ISSUES**

During the workshop, a set of umbrella issues kept arising that needs to be addressed throughout the research agenda described herein. These issues include:

- The need to develop new methods of research and design, including a close connection among researchers, designers and developers and the people and contexts in which the technology will be used. Involving educators on design teams is fundamental. Rapid prototyping and frequent cycles of testing and redesign in educational settings are also very important.
- The need for new assessment methods to handle the complexity of fundamental changes in educational systems: changes in location (from schoolroom to workplace and home), in social needs and expectations (from an industrial to a knowledge-based economy) and in student roles (from consumers of transmitted information to producers of knowledge).

- Equity issues, which are at the very core of any design and development activity in education, require attention to access and educational outcomes for diverse populations.
- Scaling issues, which must be addressed from the outset if we hope to meet the challenges inherent to changing the entire national education system.
- The critical need to sustain a comprehensive, systems-level research perspective that includes teachers and how they are educated, how educational systems evolve and are organized and how students differ by background and developmental level. Without this perspective, only systems and techniques with overly narrow applicability will be developed.

## **6.1 ORGANIZATIONS**

Virtual space allows for much more flexible organizational structures than physical space does, but as an extension to physical space physicality is still an important part of who we are and how organizations function. Thus, an important research priority is the exploration of how learning organizations across a wide spectrum—schools, workplaces, museums, homes and so on—exist in virtual space.

For example, what is the nature of “virtual space?” What does it mean to have a virtual space? How is it communicated? How do we manage and evaluate activity in it? How do we relate physical objects, space and activities to virtual objects, space and activities? How do we link to it? And how do we relate public, group and private space in virtual space?

What tools are needed for supporting existing social and organizational structures or developing new organizational structures that are effective for learning in virtual space?

Much NII-related research has dealt with information repositories, digital libraries, and associated tools and intelligent agents for organizing and retrieving information. Additional priority should be given to the study of the processes by which humans work with information to generate new information to create knowledge, the valued commodity of an information society. For instance, attention should be paid to intellectual property rights and economic compensation for contributions to knowledge bases; representing and organizing information collected over time; organizing knowledge bases for various uses, including multiple representations of information; and developing aids for assisting technological fluency and media literacy.

## **6.2 TEACHERS**

Teachers serve as guides to information resources, mentors of learning activity, assessors of student understanding, and managers and coordinators of distributed learning activities. Research is needed to help teachers fulfill these roles and adapt to change. Clearly, a wide range of new tools and resources is needed, such as resource location and coordination tools, assessment tools, libraries of educational materials and customizing mechanisms for adapting materials to individual students’ goals and developmental levels.

Virtual communities for professional development and socialization can also help teachers successfully make the transition. So can collections of technological transitional tools.

## **6.3 STUDENTS**

A key role for research is to inform educators what and how to teach students, whatever their stage in life or needs. Curricular research on media literacy and fluency can help educators

prepare students to contribute to a society where the main communication media is digital. Learning technologies need to be developed that can support the depth and breadth of student needs, from hand-held wireless devices for mobile learners to set-top boxes for learners in the home. New forms of evaluation for technology are needed that allow for evaluating software for usability and usefulness across a range of users. And new design methods to address users who are not familiar with the domain or their task and new interface designs and styles for users who will frequently be at the steepest part of the learning curve (and whose needs, therefore, will change dramatically and quickly) are needed.

## **6.4 AUTHORS**

New technologies create new media and new genres within those media. Little is known about the future genres of educational technology, especially in a highly networked world with access to enormous computational power. The cost of developing content must be reduced. Also needed are:

- Catalogs and taxonomies of general cognitive and social activities that students perform in tasks and an understanding of how technology can best facilitate these activities. We need models and guidelines for the genres of educational technology.
- Catalogs and taxonomies of tasks and task scenarios for use by authors, techniques for modifying and reusing application software for use in learning contexts, and representations for content knowledge that allow reuse in a range of educational applications (e.g., tutors, simulations and games).
- Tools to facilitate content-knowledge acquisition; and shareable libraries of tools, components, content knowledge and design guides or examples for developers.
- Tools and frameworks that make it easier to use the same or similar software across a range of hardware technologies, from hand-held devices to set-top boxes, thereby making development more economical.
- Research to support evaluation and assessment under the conditions of the new educational paradigm, including techniques and tools for gathering and analyzing data on software, ways to extend traditional “usability” metrics to “learnability,” and application components and tools that allow for gathering and analyzing student performance and learning data.

## **7. FUTURE OF COMPUTER SCIENCE IN EDUCATION**

Many of the research issues raised in this report, such as creating models for new teaching practices and defining new teacher education curricula, are already being addressed through educational research. Education researchers are well aware of the dramatic changes that technologies are bringing to traditional educational systems. These efforts should be encouraged and supported. Many of the other research issues mentioned above lie in the realm of traditional computer science research or are on the boundary where the two research fields converge.

For the vision described herein to be supported and guided, effort must be made to increase the number of researchers who integrate education and computer science. The breadth and depth of research identified in this report cannot be undertaken by the relatively small community of researchers currently working within the intersection of education and computer science.

## B.1 Designing for Learners

*Group Leaders: Elliot Soloway and Mark Guzdial*

### 1. VISION

Designing technology for learners is completely different than designing for professionals or experts. Learners do not necessarily know what they want to do with the technology, nor do they know how to use it. For a learner to successfully use technology, the interaction must be supportive and empowering. For the learner to actually learn with the technology, the interaction must also encourage reflection and stimulate motivation.

These are high standards for a piece of software or a computerized device to meet. What makes these standards even more challenging is that very little knowledge exists in the design community on how to achieve them.

Four research questions are key to successful designing for learners:

1. How do we characterize learners and their activities? Research in human-computer interface design specifies how to characterize professionals and what critical variables should be considered in design choices. Characterizing learners requires identifying learners' current levels of knowledge and motivation. It also requires considering how these levels will change as they learn through the activities they undertake.
2. What are the genres of technology to be designed, and how do we design them? It took hundreds of years for today's genres of books to evolve. The advanced technology we are working with today is very new. To make the most effective use of it into the foreseeable future, we will have to carefully determine technology trajectories and what learners' needs are, then consider the ways to design technologies that best support those needs.
3. What are the architectures and implementation strategies for technology designed for learners? A good designer in the physical world knows about the construction and manufacturing practices that will be used to bring his or her design to realization. These practices serve both as constraints and as enablers of possibilities. A technology designer must similarly consider how his designs will be realized in order to determine the limitations and capabilities of the media and genres.
4. How will designers evaluate the effectiveness of their designs? Human-computer interaction research has shown us how even the briefest and lowest-cost evaluation efforts can result in significantly more effective designs. Evaluating technology for learners can be of similar benefit, but only after we determine how to evaluate technology for learners. We may need to create new evaluative measures. For example, ease of use can sometimes be the enemy of effectiveness when technology is designed to be used as a learning support.

## 2. DESIGN EXAMPLES

To make the issue of designing for learners more concrete, the Designing for Learners working group spent time in small groups doing design for learners. No designs were completed in the short time available, so no evaluation was attempted (i.e., no response to research question number four in the previous section could be made). However, the designs provided a context in which the working group could practicably consider the first three research questions.

Three of the design discussions are summarized below: design of a physical learning space, design of an online museum exhibit and design of a programming language for learners.

### 2.1 DESIGN OF A PHYSICAL LEARNING SPACE

*Characterizing learners and their activities.* Group members spent little time on the question of how to characterize learners and their activities in a physical learning space. Instead, they were more interested in the broader question—as it pertains to different kinds of learners and learning activities—of what should replace traditional physical classrooms given today’s advanced technologies?

*Genres of technology.* Group members identified metaphors that served as examples of comfortable and successful learning environments—sports arenas, theaters, informal banjo lessons and even sitting on a parent’s or grandparent’s knee. These metaphors challenge traditional models of learning spaces, but all answered the group’s design goals of enabling learning participants to see one another, to be intimate and to be comfortable with the physical space.

Group members also sought to develop metaphors that would allow the integration of hardware and software into this envisioned physical space. The metaphor they found most valuable was the “24 Hour Classroom.”

Educators in general, and university educators in particular, have long been criticized for not being productive nor accessible enough. The theme of a 24-Hour Classroom emphasizes the constant availability of learning opportunities made possible by technology. The teacher can be available whenever she or he has the opportunity to visit synchronous or asynchronous collaborative spaces, while other educational opportunities (e.g., discussion with fellow students or making use of multimedia resources, or diverse learning aids and guides) can be availed upon whenever the student has the time and inclination to do so. The 24-Hour Classroom is particularly attractive when considering the needs of adults engaged in lifelong learning.

*Architectures and implementation strategies.* The greatest research challenge posed by the 24-Hour-Classroom metaphor is determining how to achieve an integration of the real (physical) and virtual classrooms. What mechanisms are needed to realize this goal? Students are likely to continue gathering in traditional classrooms and lecture halls, and even adult learners will perform their work and do their learning in physical spaces. Integrating physical and virtual spaces will probably involve a number of different activities combined in many different ways, such as recording physical space activity for availability in the virtual space, providing means for participants in a virtual space to interact with a classroom in physical space and developing activities that can easily cross the physical/virtual classroom border.



## 2.2 DESIGN OF AN ONLINE MUSEUM EXHIBIT

*Characterizing learners and their activities.* Group members focused on identifying characteristics of the kinds of activities online museum exhibit learners/visitors would find most useful or attractive. For example, learners must be able to control the exhibit, which would involve either downloading materials to the client computer or limiting access to enable rapid response time. The exhibit must have a “quick grab, slow release”—it should be immediately attractive and attention-getting, but also be intriguing enough that it engages the learner’s attention for a while. And, because there is usually a social component to visiting museums, technologies that afford social interactions (e.g., agendas, guides and multiple-user dimension (MUD) object-oriented (MOO)-like environments) should be used, in addition to single-person access.

*Genres of technology.* Group members established several design goals, which, in turn, determined the forms of technology they desired. The optimal exhibit design should enable very broad access. The online exhibit, like in-person museum exhibits, would seek to hook the learner affectively, by encouraging his or her sense of wonder and desire to explore further. The online exhibit, however, should offer the additional benefit of opportunities for deep learning.

*Architectures and implementation strategies.* A variety of research issues would have to be addressed before museum exhibits that enable these desired learner activities and meet these intended design goals could be built. New authoring tools that would provide the structure and support to create the desired content depth would have to be developed. Presently, most authoring tools aim at “handbill depth,” i.e., a relatively brief overview of a subject. Researchers would have to determine how to best make use of the virtual nature of an online exhibit (to maximize the impact of the learner’s museum visit), perhaps linking formal educational resources that provide detailed and authoritative information with informal ones that might be more motivating, captivating and accessible to the learner.

## 2.3 DESIGN OF A PROGRAMMING LANGUAGE FOR LEARNERS

*Characterizing learners and their activities.* Because programming as an activity for learners has a long history—from efforts to have students construct interesting artifacts by programming (e.g., Boxer, Emile) to using programming as a medium for learning higher-order thinking skills (e.g., Logo)—group members began the discussion by asking why they might want learners to use a programming language at all. It was concluded that a programming language can change the way the programmer thinks by introducing new constructs, structures and perspectives that can provide important leverage on problem-solving; enable users to construct new objects, thus facilitating their becoming producers as well as consumers of computational media; provide users some power over an increasingly computational world (i.e., without the skill and knowledge of programming, users’ activities are limited to what others enable them to do); and serve as a medium for defining meaning for computational objects and for sharing that meaning.

*Genres of technology.* Next, group members asked themselves what was wrong with current programming languages. They used Logo as an example to critique. They realized that syntax is not the most critical aspect of a language. In Logo’s case in particular, the “turtle” as a computational object is far more important than the syntax. In general, the problems with current programming languages for learners are more cultural and social than compu-



tational. For example, most programming languages do not offer a coherent set of associated activities, do not have genres (thus, it is difficult to know what pieces of a program are shared with others of a similar program type), ignore cultural and application contexts and do not promote a social agenda.

A critical goal for a programming language for learners is that it have an epistemology: a theme or set of embedded ideas for how all the pieces of the language fit together and are used in solving computational problems. Several important ideas that designers need to remain cognizant of when designing a programming language for learners include:

- Different languages are used in a given domain of programming because epistemologies in the languages themselves differ, i.e., the domain does not drive the choice of an epistemology.
- A strong relationship between natural language and programming languages exists, especially with regard to epistemology.
- There are typologies of languages—for example, scripting languages versus C/C++-like languages versus LISP-like languages. Each type of language has its own epistemology, and indeed, it is the shared epistemology that defines the type.
- The development of one general language for learners may not be the most profitable research direction to pursue. Single programmers often draw upon a range of epistemologies at different times for different projects.

*Architectures and implementation strategies.* Programming languages for learners should be used to support lifelong learning and enable users to express and use computational ideas throughout. They should expand the learners' perspective and change their thinking. At the same time, the programming language should not be limited to applications for learning, which would make them too circumscribed to allow for the broad range of explorations that a learner could engage in.

### **3. RESEARCH AREAS AND ISSUES**

#### **3.1 HOW DO WE CHARACTERIZE LEARNERS AND THEIR ACTIVITIES?**

As mentioned earlier, developing an in-depth understanding of learners' unique needs and interests at the cognitive, organizational and sociocultural levels is the first step toward designing meaningful and productive technologies for learning. We must determine the learning-skills and content goals that students need to pursue. Then we should take advantage of students' interests and intrinsic motivation(s) to ensure the design of technologies that best help students meet various curricula objectives and, concurrently, best make achieving those goals an engaging process. We need to assess how content or learning-skills goals can promote deep and rich learning, i.e., learning how to learn. The learning-skills goals should be defined in conjunction with goals of the corresponding content areas, using standards established by the National Council of Teachers in Mathematics and other education standards groups as exemplary guidelines. Development of a design model that places the learner at the center and situates the learning process within the larger educational context is key to this process and will result in the identification of design features that make significant contributions to students' learning.

### **3.1.1 CHARACTERIZING USERS AS LEARNERS**

Current models of human-computer interaction place the user at the center of the software design process by defining tasks undertaken by the software, the tools provided to cope with the task and the interfaces to those tools. They are designed for professionals, i.e., users who know the domain, are motivated and are a homogeneous population possessing the same goal—to increase their success.

Learners introduce a different kind of user with distinctive features. They usually do not know the domain, often are not motivated and, as a group, encompass very diverse populations. Models of learner-centered design need to take into account these user features and move beyond “ease of use” goals to a model geared toward “ease of adaptability.” Designers should also take into consideration the implications of research on gender differences that points out the different interests that male and female users have that lead them to begin and continue their interactions with technology.

This design focus on ease of adaptability becomes particularly relevant in the case of young learners. Technologies for learning must serve the needs of learners of all ages in numerous content areas. Yet, currently, very little is known about interface design for young children as learners. Questions such as “What interface design and features help young children interact with a piece of software and facilitate their learning process?” and “What structures and representations of software facilitate the entrance of learners into a content area?” need to be explored.

A further aspect to be considered in learner-centered design is the concept of lifelong learning. Currently, the concept of learners is usually limited to school populations. Yet learning is not just for students in the classroom. Professionals, too, are—or should be—constantly learning. How can systems be designed so that they can be useful to learners over their lifetimes?

### **3.1.2 MEETING THE NEEDS OF THE BROADER AUDIENCE**

Learners are found both in formal educational settings (such as classrooms and schools) and in informal learning places (such as museums and after-school organizations). Learner-centered design research needs to determine what the needs of learners in such different learning places are—how they are distinctive and where they overlap. Research also needs to be concerned with the larger organizational structure these educational settings are part of because the integration of technology within this pedagogical and administrative structure is critical to technology’s successful adoption and use.

The new roles that will be required of teachers within the computer-based learning environment also require further investigation. For example, how can the use of technology facilitate and support teachers’ interactions with and coaching of students in the learning process? Within this context, research also needs to address the needs of teachers as learners and resolve such issues as identifying the features of technology that create a learning environment that facilitates teachers’ development of pedagogical and content knowledge, and determining what models of learner-centered design result in the conjunct development of software for students and teachers.

### **3.1.3 DEVELOPING A NEW DESIGN PROCESS**

Developing models of human-computer interaction that place learners at the center requires a new design process that acknowledges that learners are a “moving target,” i.e., people are learning even as they interact with software, and thus, their interactions change over time. Key challenges to the development of this new design process include: determining the design cycle when the design task is to characterize users in terms of distributions and rates of change rather than static descriptions, identifying which models of the design cycle take into account that software is being used by learners at different stages, and determining how to evaluate software that fits a dynamic model of learner development.

Developing operational models of software design that delineate the stepping stones in the iterative design process are essential to establishing this new design process. Also needed are process models of students’ thinking and learning that will, ultimately, provide guidance in defining landmarks in software achievement. In fact, because students’ interactions with interface features change over time, the software design process cannot be considered separately from students’ learning processes. Thus, it is crucial to identify system features that should stay stable and those that can eventually fade or disappear, with the fading away providing learners greater degrees of freedom and addressing the diversity in their thinking and approaches. It will also be necessary to define features of software modules that facilitate connections to other pieces of software and that allow the learner to design products or temporary states of it and export it to other software.

## **3.2 GENRES OF TECHNOLOGY AND HOW TO DESIGN THEM**

There are a wide variety of potential genres for interactive computational media. It is useful to think of these potential genres as having both functional and supportive roles, with functional roles enabling students to undertake activities that create opportunities for learning (e.g., creating a Web site, designing a video game, or writing a paper or book) and supportive roles facilitating students’ learning or enabling them to succeed at functions at which they might otherwise fail. We all know that experience, no matter how compelling, is not the same as learning; activity without reflection does not lead to learning. Thus, the supportive roles must be present in all educational technology genres and deeply intertwined with the functional roles.

### **3.2.1 FUNCTIONAL ROLES**

Technology’s functional roles can build upon a student’s interests or intrinsic motivations to create new opportunities for learning. Many activities students may find to be exciting and intriguing might not be possible or accessible without a computer. Yet it is not currently known how systems can provide advanced functionality at a level or in a manner that students find approachable. Perhaps this challenge can be met by designing appropriate representations and metaphor-based interfaces and by somehow encouraging interconnections between students’ existing knowledge and the challenges they find in these various new settings.

Some of the functional role issues or iterations that commonly appear across a variety of genres should be explored. Specifically, designers need to develop powerful and approachable computational objects, such as the Logo turtle, and identify epistemologies that allow programming languages to be easily mapped to a variety of problem domains.

For students to learn through other tasks, such as scientific computing and visualizations, other research issues need to be explored. Specifically, how can educational technology be designed to:

- Enable students to create and manipulate models or systems with a variety of variables and parameters that interrelate in complex ways?
- Allow students to manipulate the metarepresentational level of a program to choose among various representations or views of a system?
- Provide students access to real data, interactions with experts in the field and virtual-space field trips to distant places?

### **3.2.2 SUPPORTIVE ROLES**

All users need functionality, yet in a research program to support learners, the crux of new program system success will reside in the support the system offers. Learners need special support services to facilitate their successful use of and learning in genres of computational media that are new to them. Such support services should include, but not be limited to, cognitive apprenticeship, goal-based scenarios and collaboration. Additionally, single supportive roles (e.g., collaboration) can be combined with a number of functional roles (e.g., writing, model-building) to create several genres of computational media for learners (e.g., collaborative writing environments, interactive model-building for work groups). Thus, research in supportive roles will broadly support development of existing and new genres of computational media for learners.

One type of supportive role is enabling and facilitating collaboration as a mechanism for making it easier to succeed (e.g., groups can often do things that individuals cannot) and easier to learn (e.g., learning can be facilitated by articulation, such as explaining to others what you are doing). Much work and learning, if not most, is accomplished in the context of social activity. New software systems will offer access not only to extensive development of educational material, but to varied and far-flung interactions between people. Users will have the ability to connect with friends, colleagues and experts who previously would have been inaccessible or reachable only by phone or mail.

Research is needed on how users will interact with each other, how they will socialize in the new network communities, how different access protocols will exist across communities and how users will switch from community to community.

Research issues involved in using collaboration as part of the supportive role of a genre include:

- How computers and networks can be used to support multiuser collaboration.
- How they can be designed to support community access, community involvement and parent-principal-superintendent interactions.
- How they can be extended broadly, such as across age groups and geographically dispersed communities.
- How technologies can be designed to assist students using knowledge from remote databases.

- How they can be designed to support teaching and learning across the network.

Another important supportive role is accessing and using diverse sources and resource materials across wide-area networks. Research issues in making these sources broadly useful as supportive roles include:

- How to organize diverse sources and resource material.
- Constructing an epistemology and subject-matter ontologies, and designing a method for indexing through these ontologies that accommodates varying user abilities to create and use these ontologies.
- Designing frameworks for organizing multiple knowledge constructs.

Another broad supportive role is scaffolding, which is an educational term for the kind of support provided to facilitate student success at an activity. Typically, it involves modeling a process (sometimes simplified at first) for a learner, coaching the learner through that activity and then providing opportunities for the student to articulate what has been learned—by teaching others, writing instructions and/or responding to prompts. Key in the concept of scaffolding is that support can be “faded,” or reduced, so that the student can learn to succeed without it. Yet very little is presently known about how to provide scaffolding in software.

Supportive-role research challenges related to scaffolding include:

- Identifying appropriate restricting activities for beginners.
- Creating mechanisms for fading scaffolding and determining how fading gets controlled. Does the system or the student choose when to fade the scaffolding? What kinds of safeguards should be used?
- Designing systems that provide scaffolding through the use of transfer, i.e., allowing students to make transfer between a simpler analogy to a more complex one as a form of fading.
- Designing systems that do not add peripheral complexity and that maximize empowerment over time.
- Designing systems that scaffold by altering the interface modalities, i.e., first presenting kinesthetic, then iconic and, later, symbolic knowledge.
- Creating tools for students that are easier to use than existing tools but which do not eliminate the essence of the material.
- Creating systems that support students in receiving a gestalt about knowledge rather than step-by-step regurgitation of material.
- Developing systems that engage the learner for increasingly longer periods of time and, thus, facilitate development of learners’ attention spans.
- Developing generalized methods for providing scaffolding, thereby reducing scaffolding’s design costs.

It may be necessary to design models of users and domains found in various learning environments in order to offer learners in each domain customized support. Such support can

be open-ended, nonintrusive and can reside within authentic and community learning situations. It can be built within a community of practice, such as the medical field, and can actively engage the learner. It might use planning or plan-recognition research strategies to recognize how learning is phased and how to guide it. Advanced model-based systems could involve parameters and variables that the user can change so that he or she can access the internal model and change it. Recent technological breakthroughs allow us to dissect the domain and control knowledge, to represent the user's knowledge and goals and to represent and structure pedagogical knowledge.

Research issues fall into three categories: 1) modeling the domain, 2) the student model and 3) tutoring strategies.

*Modeling the Domain.* In modeling the domain, the following issues must be addressed:

- What are the appropriate topics, skills and misconceptions to be addressed within a domain?
- What topics will be presented?
- What are the precursory or co-requisite topics, and how can knowledge of them be represented?
- How and when should new problems be generated?
- How and when should hints, examples and simulations be provided?

*Modeling the Student.* In modeling the student, issues that must be addressed include:

- How to represent student knowledge so that coherent analysis of the problem-solving process can be achieved.
- How to provide error analysis and identify common mistakes.
- How to represent student misconceptions.
- How to design useful feedback appropriate to the student's activity or misconceptions.

*Modeling Tutoring Strategies.* In modeling tutoring strategies, the following issues must be explored:

- How and when to adjust the level of difficulty of problems and skill restrictors, as is done with scaffolding, but with the advantages of a model.
- How and when to move on to new topics based on teacher-supplied algorithms.
- How to identify a student's strengths and weaknesses, and how and when to use this knowledge.
- How to provide—at the correct times—feedback, challenge, confirmation, response and motivators to the student.

### **3.3 ARCHITECTURES AND IMPLEMENTATION STRATEGIES FOR TECHNOLOGY DESIGNED FOR LEARNERS**

A great limitation to the wide-scale use of new genres of interactive computational media is the inherent difficulty in creating educational software. The issue of implementation is impor-

tant to the designer because, as mentioned earlier, the available tools for realization of a design both constrains the design process and highlights possibilities. Tools for learning environments (as opposed to tools simply for authoring educational software) will need to be similar to current educational authoring tools, except that they will also need to address the unique needs of learners at several levels, including the organizational and social/cultural levels. Specifically, they will need to fit into the educational system, be applicable to designing for learners, meet the needs of teachers as learners and address the diversity of genres of software, e.g., goal-based scenarios, multiuser construction kits and computer-supported collaborative learning. Tools must be developed to support the complexity and interplay among levels, which is what makes deep learning and exploration of content possible. Developing techniques for simplifying the generation of such learning systems will accelerate their deployment and use.

Using technology to advance education will require designer attention to the interplay between local (i.e., pertaining to the individual student, subject domain and classroom) and systemic (i.e., pertaining to the broad range of students, all subject domains and entire schools or school systems) educational factors. In some sense, all learning is local; students construct knowledge in response to the problem at hand, their personal sense-making ability and the social and technological supports available. Yet if software design addresses only these local factors, the result is often systemic failure: software that is fragmentary, poorly supported and easily marginalized. For software to contribute broadly to educational improvement, the research community must begin to address factors that will enable local successes to plug into larger agendas, scale up to widespread audiences and evolve to meet new challenges. Addressing these presently unknown factors will involve attending to implementation strategies and, more broadly, software architectures throughout the design process.

Software architecture serves as a framework for fitting together components and identifying how different pieces of software (in this case, a learning system) interact with one another. Providing good architectures can make development and implementation easier, including the creation and use of tools for building learning environments.

The need for architecture arises from the inherent complexity of learning processes. Layers of support are needed for educational activity structures: for using particular notations, models, simulations and representations; for gathering and organizing information resources; for constructing and expressing ideas and skills; for communicating with peers, teachers and the world; and for instructional processes such as assessment and tutoring.

Broadly speaking, these support layers can be conceived of as types of support within learning software. Within these layers, a software architecture for learning systems requires modular objects that provide commonly useful facilities, such as notebooks, graphs, tables and calculators, and markup and annotation. Decades of research have taught us much about how an individual layer or object can be designed to enhance learning. Now designs need to be scaled up to suites of layers and objects that offer solutions to learners' overall needs. Three critical challenges to achieving broadly applicable learning-software architectures are: 1) decreasing the cost and increasing the reuse of needed educational layers and objects; 2) supporting flexible integration and customization of layers and objects regardless of the source and; 3) enabling decentralized authoring and publication of interactive, dynamic educational objects.



Emerging component-based, distributed-object architectures offer the potential to overcome these challenges and produce top-quality educational software that can gracefully scale up, spread out and advance forward. Unlike prior “application island” architecture, components could allow educators to reuse graphs, tables and other objects rather than recoding each required capability. Components could transform educational software architecture development into a process of composing rather than coding. In composing an activity, educators could draw together, regardless of vendor, best-of-class objects and layers and organize their own layout, scripts and instructional presentation. Distributed objects could realize the promise of the Internet and multimedia by making fully interactive, dynamic, collaborative artifacts available to every student regardless of location or platform.

Emerging industry standards of component software may provide a substrate for educational architecture, raising the level of the playing field. However, industry solutions will be aimed at business needs and not at learning processes. To achieve the potential of educational technology, researchers should consider and use the best solutions industry has to offer, then address these industry agendas and techniques in new and dynamic ways to the specific needs of education.

Important research questions for facilitating the growth of educational software architectures include:

- What additional standards are needed to support educationally relevant features, such as linked multiple representations, publishable student portfolios, collaborative work and interactive instructional aides?
- What sorts of design frameworks, both conceptual and technological, are required to enable educators to smoothly integrate diverse layers and objects to fully meet the needs of their students?
- What models for implementation, distribution and support will enable the rapid growth of a distributed, educational technology community that can meet the challenges of scale, diversity and rapid change?
- How can the kinds of support roles described in the previous section apply to component architectures?
- Where does intelligence (about the domain, the learner and pedagogy) fit into a component-based architecture? Is it a pluggable component, or is it part of the framework into which components fit?

### **3.4 EVALUATING THE EFFECTIVENESS OF THE DESIGN**

Assessment and evaluation of educational technology materials requires the design, development and implementation of new assessment paradigms. Older frameworks that focus mainly on software attributes—such as standard software evaluation forms described in the Office of Technology Assessment’s 1988 report *Power On!: New Tools for Teaching and Learning* (pages 232-235)—allow for descriptions of software but not for descriptions of the software’s impact on learners and educators. For design for learners to be successful, assessment must be an integral part of the design and development cycle. Such integration can be effectuated through a variety of mechanisms, including:

- Formative evaluation, including an ethnomethodological component (studying technology’s impact on and interactions with the educational environment’s organizational and cultural levels).



- The integration of assessment tools into the software system itself, whereby assessment becomes an ongoing part of software use.
- Tools and methodologies that consider the wide variety of potential impacts of learning software on students, including changing what students learn as well as how it is learned.

New assessment paradigms need to address the impact of software on all stakeholders (from the learner, to the educator, to the larger administration, to the educational process at the broadest level) and then clearly articulate criteria for its success, both in the short term and in the long term.

Such levels of assessment allow evaluation of small changes in the short term and larger impact effects over time, including how applications change the discourse within and among the disciplines. Long-term analysis provides researchers the opportunity to address the scalability and sustainability of an application. What works well in small settings is not always viable in terms of cost, production or use in large settings.

Obviously, the criteria for success must address the effectiveness of the software's use as well as its level of integration into the learning environment. We must be able to identify software that students hate, software that teachers cannot and will not use and software that teaches things that are not worth the students' time. The success criteria must also provide for determination of software motivational impact as well as user evaluation of the quality and integrity of the learning experience. Hard questions must be asked about the usability and usefulness of the application, with special emphasis on deep change as opposed to decorative embellishments.

These new assessment categories demand the establishment of assessment protocols that partner the use of quantitative studies to ethnographically based qualitative research. New techniques for capturing and analyzing rich data, including information about learners' and educators' motivations for software use, should be encouraged. Current techniques will be inadequate to judge the breadth and depth of learners' expression in new media. An important research direction will be to enhance current techniques and develop new techniques to judge the full extent of material in future learners' portfolios.

The education community needs to define metrics and techniques, whether observational, analytic or heuristic, for assessing individual learning and group learning and for how knowledge gained fits into the larger social context. Currently, some of the most clearly defined metrics are for individual performance—time to learn a task, time to complete a project and so on. These metrics are important, but new ones need to be developed. Defining new metrics will necessitate research in the following areas:

### **3.4.1 INDIVIDUAL METRICS**

*Learning.* How much time does it take to learn a topic or skill, and just what is learned? Not all behaviors are indicative of learning, and tests are not the only, nor always the best, way to evaluate learning.

*Student satisfaction.* Validation extension is needed to determine how students feel about software (i.e., we need programs, similar to questionnaires, embedded in the software that allow students to record how they feel about the software).

*Quality of performance.* What constitutes strong performance for individuals? For teams? For communities?

*Productivity.* Did the software facilitate a tremendous breadth of ingenuity and creativity?

*Usability.* Are students intimidated, fatigued, bored or otherwise put off by the software?

### **3.4.2 GROUP METRICS**

We need to specify metrics to analyze the effect of educational technology on a group or community, the activity it generated or made possible, the production from this activity, and the ingenuity and creativity it facilitated.

## B.2 Supporting Teachers in Changing Roles

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*Group Leader: Jan Hawkins*

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### 1. VISION

In light of current understanding about the conditions necessary for effective and sustained learning, the new educational outcomes demanded by our evolving society and the new technologies that can support these educational goals, the roles of teachers will change substantially in coming years.

The world is changing. Education, charged with the function of preparing people to participate in, enjoy and even direct changes in the world, must change as well.

Technology is a significant factor in our changing world. Media now infuse our lives and inform the ways in which we encounter and appreciate ideas, information and knowledge. There is an increasing use of technological tools in the fields of science, mathematics and engineering. More and more workplaces are using new interactive media. Workers must continually re-examine and upgrade their knowledge and skills.

These social and technological changes now intersect with new understandings of education, including the restructuring of curriculum, pedagogy and assessment. Yet this knowledge still needs to be integrated into the curriculum, pedagogical methods need to be further refined and implemented, and more effective methods of assessing learning and education need to be created.

Curriculum and assessment are already being reconceptualized, with new emphasis being placed on project-, problem- and case-based approaches to the development of understanding. These reconceptualizations are enjoying broad support, yet exist in somewhat uneasy tension with struggles to define common knowledge, or discipline-based standards, that can be nationally shared.

Teachers need to thoroughly understand these new definitions and range of practices regarding core knowledge, effective curriculum and flexible coordination of resources. They soon will be responsible for orchestrating a much wider array of experiences for students than those that now exist.

Education will become substantially more distributed across multiple persons and resources. Concurrently, teaching will shift from emphasizing individuals fully responsible for their students' learning in self-contained classrooms to the distribution of teaching/expertise across teachers, disciplinary experts and content resources. Professional competency will still be judged primarily by the strength of teachers' command of foundational content, but increasingly more emphasis will be placed on their skill in facilitating and coordinating learning experiences for individuals and groups of students. The diversity and depth of expertise required to support learning for the new multiplicity of students leads to a teaching model that can comfortably and thoroughly draw on distributed resources.

Developing robust ways to compose and coordinate such distributed teaching will be an essential feature of professional educational training. Teachers will be expected to understand—in-depth and across the spectrum of developmental levels—the needs of their individual students, to support these diverse students in meaningful sustained inquiry and to coordinate the resources (expert persons and material resources) necessary to their pursuits. To accomplish this kind of education, teachers will need substantial support as they shift from their traditional teaching roles to their new ones.

Providing this support will require the development of new educational infrastructure for distributing expertise and resources (including the new roles for teachers, students and “outsiders”). Technology can provide new tools for meeting this challenge.

As the society beyond the school walls increasingly uses telecommunications, innovative cognitive tools and other technologies, education can then also use these same technologies to integrate learning much more broadly with these outside resources and practices. The roles of teacher and student can be re-examined and redistributed. Students can use for their learning many of the same new technologies that scientists, mathematicians, engineers and other adults are using in their work. Adults previously outside the educational system will be able to become involved in education in ways that mutually benefit students and themselves. And education can become a collaborative partner with the rest of society.

## **2. UMBRELLA ISSUES**

In defining a research and design/research agenda for a combined effort of NSF’s Education and Human Resources Directorate and Computer and Information Science and Engineering Directorate, certain issues thread through all parts of the territory that must be explored.

### **2.1 INNOVATIVE METHODS**

Two aspects of research and design innovation need to be encouraged:

- Designing new research methods to encourage close connection among design/development activity and the people and contexts where the technologies will be used. As mentioned earlier, the use of rapid prototyping and frequent cycles of testing and redesign in education settings is one way to facilitate this connection. Involvement of educators/ users on design teams is fundamental.
- Developing new methods for analyzing and understanding education innovations. The fundamental changes envisioned in this report require many variables in a school to shift simultaneously: the curriculum, teacher and student roles, assessment, professional development, administration, technologies, infrastructures and so on. Current research methods emphasizing ANOVA (analysis of variance) approaches cannot adequately meet the complexity of the task.

### **2.2 EQUITY**

Equity of access is a necessary but not sufficient condition for true equity in educational technology. Close attention must also be paid to equity of educational outcomes for diverse populations. Such equity concerns lie at the very core of the design process; current design practices, as well as outcomes, are themselves a reflection of present inequities in the educational system.

- *Scale up.* Attention to the problems of scaling any innovation is needed from the outset. Although most kinds of research projects are circumscribed in scope in order to accomplish the fine design, analyses and refinements that lead to understanding, consideration of the issues of broader use (should the design prove successful) is also essential.
- *Comprehensive perspective that spans the entire range of education.* Education reform requires interconnected changes throughout a complex system, a sobering reality for any research program. The overall research agenda should span K-12, undergraduate education and schools of education (because how teachers are themselves educated is critical to how they teach).
- *Sensitivity to developmental level.* Different cognitive and social features are important to learning at different developmental levels. The design of new environments and tools for teaching and learning, and thus the research agenda, must be sensitive to this range of developmental needs.

### **3. RESEARCH AGENDA FOR NEW EDUCATIONAL AND PROFESSIONAL CONTEXTS**

A research agenda on the changing roles for teachers must define and coordinate research in a broad territory. Two overall issues are especially important. First, the goals for and practice of teaching are changing, and we need to understand more about these changes in classrooms and in professional development contexts. Second, these changes can be facilitated and supported by the design and incorporation of exemplary technologies.

There are three research foci for learning more about teaching and learning in the anticipated distributed conditions: 1) the nature of changed practice in classrooms and schools; 2) new models of professional development that result in changed practice; and 3) new models of social support for the new practice, including how to best organize resources, communities and expertise.

#### **3.1 THE NATURE OF NEW CLASSROOM PRACTICE**

##### **3.1.1 STUDIES OF CLASSROOM PRACTICE**

To design for more effective teaching, we need to know more about the new learning situations currently being created in schools and teachers' new roles in those situations. Thus, a central (but often overlooked) research issue in educational technology is what is known about the changing roles of teachers and students, and how can this best be used as a basis for the design of usable technologies?

This is a question that must be explored at several levels. At the highest level, descriptive studies must be conducted of the political, social, demographic and economic issues contributing to change in the classroom to better understand the context for which new technologies will be designed. At a much finer level of detail, there is also a need for descriptive and observational studies of how instructional practice has actually changed in schools that embody these new approaches. Note that in asking this latter question the emphasis is on change in enacted practice rather than changes in pedagogical theory.

Hopefully, some normative theories of what constitutes exemplary instructional practice in the technology-enriched classroom can be developed from these studies. (What is the job description for a learning coach, team facilitator or knowledge broker?) Further, the studies

should help illuminate those aspects of their new roles that teachers and students find difficult, thereby suggesting a direction for the development of new support tools.

A second, related research question pertains more specifically to the relationship of technology to change in instructional practice: In what ways have computer and network technologies changed classroom practice? Were these anticipated or unanticipated effects of the introduction of technology? Conversely, how do new technologies become appropriated into local practice (i.e., how does use of a technology vary across situations of use)? Studies of this sort should provide guidelines for the design of more flexible and readily adapted applications in the future.

Further research issues include:

- How are learning environments reflecting new learning approaches integrated into the classroom context?
- What changes in teaching practice are required for teachers to effectively and aggressively use learning environments that foster students as active learners, such as interactive inquiry-based environments?
- How can classroom activities reinforce and complement the new learning approaches reflected in interactive learning environments?

### **3.1.2 DESIGN RESEARCH ON TECHNOLOGY FOR NEW CLASSROOM PRACTICE**

The new roles teachers must assume to successfully manage productive learning environments place new and complex demands on them. Teachers are now being asked to be monitors, facilitators and/or coordinators of their students, who are working independently or in small collaborative groups on different projects. How can teachers adequately understand and effectively monitor and support the work of these students—each actively engaged in interactions with different resources, perhaps each exploring a different topic, each using a different approach and each working at a different pace? Technology-based tools and environments can provide essential support.

Research questions to be addressed include the following issues:

- First, how can technology be used to produce the diversity of expertise and experiences required to support progressively more student-directed learning? Telecommunications resources such as electronic mail, electronic bulletin boards and the World Wide Web can provide students with a wealth of information and advice. How can these resources best be used to provide students with meaningful learning experiences? What sort of structure, if any, needs to be imposed on telecommunications resources to increase their effectiveness as learning tools? What kinds of learning opportunities and experiences can be provided by other technologies, such as simulations or multimedia environments?
- Second, how can technology be designed to assume or redistribute some of the responsibilities for helping guide or structure students' work? How can computers be designed to function as coaches? How can technology be designed to structure students' work on complex problems, providing them useful feedback and comment on their work? How can technology be designed for use as an information resource? When teacher support is designed into technologies, how are the responsibilities for guidance and facilitation coordinated between the teacher and the new technology? What technological supports can

help teachers provide direction for students' work, e.g., how can technology be designed to facilitate the performance of teachers as information brokers?

- Third, how can technology be used to facilitate teachers' understanding and evaluation of students' work? What kind of work environments for students can be created that leave a trace of their growing, changing understanding? What should the contents of these records be and what media best communicates this information? How can records of student interactions and work products be summarized in a way that makes them manageable for teachers to monitor? What tools can be provided for students so they can communicate their achievements in project work to teachers, e.g., technological support for portfolios? How and when should these records be made available to other interested parties, e.g., parents, school system personnel, researchers and so on? What kind of assessments can be supported by computers? How can technology be used to assess higher-order thinking skills? What are some effective strategies for implementing assessments of computer-based collaborative learning?

- Fourth, how can technology be designed so that teachers can adapt and extend the new designs for their own classrooms, e.g., how can learning environments be designed to be extensible and customizable by teachers? Can learning environments provide a supporting structure (e.g., basic inquiry tools) while allowing teachers to extend the content of a system?

- Fifth, how can technologies be designed to enable teachers to effectively integrate innovations into the learning environment? For example, how can curriculum planning tools augment an interactive learning environment to assist teachers in considering how to weave such a learning environment into their curriculum rather than treating it as a stand-alone unit? How can technology be used to provide examples (e.g., video cases) of other teachers' use of the technology to serve as models? What kinds of support materials can enable teachers to adopt a learning-environment teaching approach—e.g., a focus on inquiry and explanations—in other activities in their curriculum?

In summary, tools and environments are needed to support teachers in new practices. In particular, technology-based tools should be explored to help with the new features of teachers' roles highlighted in this report. These technology-based tools can help teachers to facilitate the learning of their diverse students in complex classrooms where students independently and simultaneously pursue multiple strands of inquiry; support in-depth assessment of understanding; help teachers to coordinate distributed teaching and learning; and help teachers adapt to and integrate new technological innovations into the learning environment.

One final note: Students can lead teachers toward new practices by their expectations, questions and work. To encourage this, tools developed for students should coordinate well with tools developed for teachers. Student tools are considered elsewhere in this report. We encourage an agenda that coordinates the technology-enhanced environments for students with those designed for teachers.

### **3.1.3 NEW MODELS OF PROFESSIONAL DEVELOPMENT**

The rapid technological changes in and refinement of tools for communication and collaboration and the continuing emergence of new and more powerful environments for student learning make imperative the development of substantially reconceived models for the professional development of teachers. Without such new models, the potential of



emerging educational technologies is likely to fall far short of achieving the vision of education that is needed for the 21st century. There are three areas of R&D that need to be examined in order to achieve such new models: 1) research on exemplary models of professional development that include all elements of a teacher's growth (pre-service and in-service development and the larger school and community context in which that development takes place); 2) research on technological support for professional development; and 3) research on how the teaching profession's adoption of such new models can be facilitated and supported.

### **3.1.4 RESEARCH ON EXEMPLARY MODELS FOR PROFESSIONAL DEVELOPMENT**

Traditionally, in-service training experiences for teachers are short and circumscribed; schools of education are, as of yet, still little altered by changed ideas, practices and tools. Telecommunications and visual media can provide an impetus and serve as a strong support for teachers' professional growth by creating the circumstances of sustained trial, observation, coaching and reflection that characterize effective professional development. Their resource potential should be fully exploited.

Long-term and large- and small-scale projects and studies should be supported. For example, large-scale projects can create comprehensive programs for teacher development built upon new collaborations of practitioners, educational researchers, local community members, workers in local and remote businesses, undergraduate students, schools of education, developers of educational technology and national research centers. Such collaborative relationships could serve as demonstration sites for new technologies that support teachers' professional development and provide a testbed for examining research questions about the nature of collaborative interactions and synergies among its components.

Longer-term studies are needed to understand how to break the cycle of teachers teaching the way they were taught, undoubtedly the most powerful source of ideas about teaching. Other studies should analyze successful (and unsuccessful) implementations of technology in education and explore how teachers' beliefs were impacted. To what extent did teacher practice change? What was technology's impact on student achievement? What were the variables that impacted success? What tools are needed to help structure collaborative discourses in such new professional communities? What sub-models of the larger paradigm could be useful to other communities as they seek to restructure themselves?

Smaller-scale research studies are needed to examine new models of professional development. What are the best designs? How can existing and emerging tools affect the kind of professional support that can be provided? In what ways can teachers reflect on and assess their own practice within the professional education community? What are new ways for teachers to contribute to the knowledge of the professional community? How can a redistributed role for teachers, which draws on multiple sources of information and supports many levels of interactions, be implemented? What are the key conditions for the success of the new teaching models?

### **3.1.5 DESIGN RESEARCH ON TECHNOLOGICAL SUPPORT FOR PROFESSIONAL DEVELOPMENT**

Technology makes possible new strategies of professional development for teachers and greatly extends the range of ways to reach teachers at remote sites. Current successful approaches include the use of video to construct case studies of exemplary teaching



practice or to allow teachers to discuss examples of their practice with other teachers. Research questions concerning the use of technology to help teachers learn new practice approaches (both pre-service and in-service), reflect on their practice and communicate with their colleagues include:

- How can libraries of video cases be made available to teachers?
- What type of context of use is most effective for teachers to use the case library?
- What type of case content is important: Examples of students? Student work? Teacher-student interactions? Teacher reflections? Others?
- How can technology support the use of cases in pre-service teacher development programs?
- How can video-case technology support in-service teachers as they experiment with new curricula, technology or teaching approaches?
- How can video be used to allow in-service teachers to reflect on their own practice?
- How can technologies such as interactive video, videoconferencing and satellite broadcasting be used for teachers' ongoing professional development?
- How can technology be used to enable teachers to communicate with their colleagues so that they can learn from each others' experience?
- How does technological support for communication with peers facilitate adoption of an innovation?
- What types of materials (e.g., examples of student work, video of classes, activities and commentary) and social context foster productive sharing of ideas?

Current models for teachers' professional development are well-formed by constructivist theories of learning and social theories for collaboration. However, they are considerably less grounded in practical or theoretical examination of the impact of technology on student learning. Layering new technologies on top of existing goals for student learning is an inadequate response to technology's potential contribution to education. In their professional development, teachers need to be examining and posing appropriate new goals for student learning and determining effective pedagogies to reach those goals. This has far-reaching implications for curricular change and, ultimately, in determining how more distributed teaching and learning environments can be implemented.

Any model of teacher professional development must also address crucial issues in the assessment of student learning. As described earlier, computer-based learning technologies raise new questions of how teachers understand their students' work in a technology-rich environment. How can technology support teachers learning new approaches to evaluating student work and sharing these ideas? How, for example, might teachers use software tools to assess higher-order thinking skills? What tools can be developed to help students assess their own higher-order thinking skills? How do such assessment tools relate to both the pedagogies and the goals for student learning?

New models of teachers' professional development will need to possess the capacity to sustain changes, to modify and adapt changes and to continue to evolve as technology changes. Critical research questions to be examined include investigating how teachers

appropriate new technology-enhanced learning environments, determining the variables that impact success and sustain continued change, determining the infrastructures that support teachers in their ongoing and evolving roles as users of technology, determining what and how technological tools support those changed roles and determining what kinds of tools are needed to encourage sustained reflection upon practice.

### **3.1.6 SUPPORT FOR THE TRANSITION**

New models for teachers' professional development must address the critical transition issues today's teachers face as they work toward fulfilling their new roles. Similarly, in considering new teacher-support technology designs, it may be necessary to shift our focus, homing in on the state of transition education is now experiencing. Thus, a new research and design strategy that considers and creates classes of "transitional tools" to help teachers move from traditional to new practices may be more useful than our current strategy, which overlooks this transitional stage and focuses solely on the final advanced environments and how to implement them.

How can we design software that will help teachers fulfill their new roles, design new curricula and productively integrate the usage of new tools into their practice? How can technology itself be used to improve the effectiveness and fluidity of the change process within schools and the larger communities within which they are embedded?

### **3.1.7 NEW MODELS OF SOCIAL SUPPORT FOR CHANGED PRACTICE**

In addition to specific studies about innovative practice and new models for professional development and professional community, our research agenda should explore models for effectively distributing learning. For teaching and learning to successfully be more broadly distributed, including the integration of resources and outside communities in robust ways, we need to know more about how such complex systems might work. There are many alternative ways of organizing these new relationships; promising models should be explored and analyzed.

New technologies (e.g., e-mail, the Web and videoconferencing) offer unprecedented opportunities for bringing the outside and "real" world into the classroom, thereby satisfying demands for increased authenticity or relevancy of in-school experiences and strengthening schools' connections to their local communities as well as exponentially enhancing the learning environment.

New approaches to learning and instruction are needed that reflect this view of the situated classroom as well as research on how technology can support this connection and make it a productive one. Research issues include:

- How can technology bring outside expertise into the classroom, i.e., how can technologies be designed to enable students to communicate with tele-mentors?
- How can technology connect students and teachers, in school and at home, to the nation's cultural resources now housed in libraries and museums?
- How can students work on authentic projects outside the classroom and, thus, contribute to their communities?

- How can families be involved more directly in the schooling process, e.g., communicate with teachers, access school information from home and so on?
- How can technology foster connections between schools and the research community?

Another issue of social support concerns connecting teachers with their colleagues. Environments need to be created that support a vibrant, sustained professional exchange among teachers that transcends the traditional school boundaries. Technology-based designs need to be conceived that allow this historically highly isolated profession to evolve a new collegial infrastructure that will serve as the basis for continuing reflection and renewal. This new professional infrastructure might enable the teaching profession to reach beyond the traditional delivery-model of change by providing it its own ongoing capacity to consider, debate and distribute effective innovations as they arise. Again, well-designed technological supports will be key.

## B. 3 Integrating Learning and Working

*Group Leader: Chris Dede*

### 1. INTRODUCTION

Wisdom is not a product of schooling, but of the lifelong attempt to acquire it.

—*Albert Einstein*

The best work is done by individuals and organizations that are continuously learning. U.S. prosperity in a competitive global marketplace requires that new employees rapidly assume their job responsibilities and that all employees continually increase their knowledge to effectively meet ever-changing career and workplace challenges. The following problems illustrate that in America this full integration of learning with working is not yet occurring:

- Students often have trouble choosing an appropriate career and selecting occupational education that adequately prepares them for their first job.
- Graduates of traditional schooling frequently are not well-prepared for their initial workplace roles. At times, what instruction they receive that could help them prepare is boring or irrelevant.
- Many jobs are so mindless and stultifying that people have little incentive to work or to learn.
- The pace of current social change is so fast that the concepts, practices and skills most people use to perform their jobs become obsolete within three to 10 years. As the number of firms that are downsizing continues to proliferate, many people working in supposedly secure lifetime jobs are finding themselves unemployed—and unemployable because what they know is no longer marketable. Although employers and employees alike realize that workers must continuously upgrade their skills, many employees feel pressured not to take time off for training or schooling. Further, workers who participate in occupation-related learning experiences are frequently not remunerated for improving their skill base.
- When people change careers, for whatever reason, they often find that what they learned in school was designed only to prepare for them for their first career.
- For a variety of reasons, employers have trouble with or are reluctant to institutionalize what employees have learned about improving suboptimal operational processes, so dysfunctional organizational practices go unchecked.

The U.S. system of education rests on several assumptions and practices that contribute to these vocational problems, including:

- Schooling is isolated from workplace settings and, as preparation for a career, is almost always completed before work begins.

- Schooling provides only general skills abstractly related to solving problems arising at work. It fails to anchor these skills in concrete, practical applications. Instructors often lack direct and/or current knowledge of workplace settings.
- Continuing education is, primarily, conceived of and structured as part-time schooling: it, too, occurs in environments physically isolated from the work world; involves teachers serving as conduits of decontextualized knowledge; fails to provide practical illustrations; and rests upon a “just in case” mentality, i.e., the material is taught just in case it might be needed rather than “just in time” for it to be essential to accomplishing a task.
- On-the-job training in specific, employer-dependent skills is usually not coordinated with the more general concepts students have learned in their career preparatory education.

These separations of schooling and working undercut the continuous occupational learning our citizens need to succeed in and contribute to America’s emerging knowledge-based economy.

Conceptualizing working and learning as fundamentally related, with learning an integral component of work, would help address many of the problems that now undercut America’s prosperity and threaten workers’ efficacy and motivation.

Pursuing this reconceptualization a step further, work is the carrying out of actions to accomplish something of value for another person or oneself. Clearly, such actions are not limited to the workplace. Individual learning is the acquisition of new capacities for thought and action, which are embodied as one’s knowledge, habits, practices and mind-sets. Clearly, organizations that encourage learning acquire new institutional capacities embodied through shifts in practices, roles, policies, procedures, communications and information systems, discourse and institutional culture.

Thus, learning and working are closely intertwined; carrying out actions can produce new capabilities, and acquiring these capacities can make possible new kinds of actions. Such a reconceptualization facilitates implementing new types of occupationally related educational experiences. In classroom settings, learning through “authentic” activities—i.e., activities similar to those actually encountered in workplace situations—shows how the capabilities being mastered can be of value to others and creates a motivating sense of empowerment.

Sophisticated learning technologies based on high-performance computing and communications can enhance such experiences by providing more powerful pedagogical approaches and by enabling access to education any place, any time.

## **2. THEMES RELATING WORKING AND LEARNING**

Breakdowns in accomplishing tasks are one way of interrelating learning and working. The work of organizations is riddled with breakdowns—disruptions, interruptions, dead ends, projects never completed, missed communications, unforeseen circumstances, obstacles, impasses, external events and even unexpected opportunities. Coping with such breakdowns is essential, for otherwise no work would be accomplished. If a problem or crisis arises, workers must undertake to fix it; after solving the problem, they may stop to reflect whether they could restructure any process so as to avoid that breakdown again. When this reflection occurs, individual workers learn from the breakdown and, if the work process is restructured, so does the organization or institution.

This model of coping with breakdowns can be characterized roughly as an action-breakdown-repair model; the worker or learner acts from existing knowledge without deeper thought until some impasse is reached. The person then stops to reflect on the problem, chooses some new actions that eventually enable him or her to overcome the breakdown and resumes, once again, less reflective behavior. Such an approach to working and learning differs significantly from pre-planning (which assumes that everything can be known in advance and then acted on without breakdowns) and from postmortem analysis (in which people reflect to see how they can avoid recurring breakdowns through restructuring a process).

Typically, career-related instruction is a form of preplanning and does not teach students how to cope with breakdowns while working or how to conduct meaningful postmortem analyses. Pedagogy oriented around students and workers learning by surmounting breakdowns would be more realistic.

The concept that much of the work-related knowledge we acquire is in response to breakdowns has far-reaching consequences and research implications. What are basic skills in a world where most job-related knowledge is learned on demand in response to breakdowns? For example, calculus is seen as a basic skill for engineers, but calculus does not appear relevant to most young engineers because it does not help them with basic engineering problems. Only after someone shows them that an important, seemingly intractable problem can be solved by calculus will they be motivated to really learn calculus and incorporate it into their mental repertoire of workplace tools. Further, as part of such an experience, they may also develop an appreciation of calculus from a purely philosophic perspective, seeing it as more than just a tool.

Much work-related learning transcends responding to breakdowns and results in making breakthroughs or achieving self-fulfillment. For example, even when standard operating procedures are adequate for existing business practices, thinking “outside the box” can lead to new, more effective ways of accomplishing a task or achieving an innovative goal. Work also provides a forum wherein individuals learn about their own goals, beliefs and values. Integrating learning with working provides ways of shaping one’s self-image and developing an identity within an even larger social context.

Integrating learning and work involves several stages of instruction. First, novices in a subject or skill will engage in problem-solving to prepare them for work (learning for doing). Then workers will access embedded learning tools that help them accomplish tasks and overcome breakdowns (learning through doing). Finally, workers will participate in learning situations that enable strategic reflection about what they have mastered in their workplace experiences, i.e., how they overcame breakdowns and how their organization might restructure its processes to prevent breakdowns (learning from doing).

Insights gained in each stage can be used to inform instruction in the others. From a pedagogical perspective, learning for doing is the best understood of these stages; learning from doing the least. Each of the three types of learning experiences can be enhanced through the use of instructional technologies.

### **3. EDUCATIONAL TECHNOLOGIES AIDING LEARNING FROM BREAKDOWNS**

Information technologies that facilitate learning can be divided into six categories: 1) computer-based training/computer-assisted instruction; 2) intelligent tutoring and coaching systems; 3)

multimedia/hypermedia; 4) computer-supported collaborative learning, i.e., educational “groupware”; 5) models and simulations, including virtual reality; and 6) computer-based tools as learning enablers (e.g., computer-aided design, intelligent agents for carrying out tasks, Webcrawlers for searching the Internet, visualization tools, electronic performance support systems and so on).

Each of these categories is characterized by distinct assumptions about design and pedagogy and requires different technological capabilities for implementation.

Structured learning-by-doing environments, such as simulations, are effective in helping students master breakdowns because the user encounters authentic, work-related problems in a structured context and with appropriate levels of guidance. Incorporating computer-based tools as learning enhancers (e.g., search engines for databases and decision support systems) aids the student in mastering challenges encountered. Similar tools can also support learning through doing in real workplace settings; multimedia and hypermedia resources can provide background information, advice and training useful in surmounting the problems learners/workers confront. If intelligent coaching is included, some student mistakes can be diagnosed and remediated without the intervention of a human instructor. Other types of mistakes can be addressed by peer assessment through the use of collaboration-enhancing technologies.

Multiuser virtual environments (e.g., MUDs and MOOs, and distributed simulations) are also a promising technology for learning from breakdowns because each participant can alter the shared environment, thereby producing unanticipated breakdowns for others and inducing their cooperation to overcome these challenges. Embedding computer-supported collaborative learning tools enhances this collective problem-solving. Computer-based training systems that teach the basic concepts and skills of a work domain can help novice learners obtain the background they need for contributing to shared problem-solving in these simulated workplace environments. Research suggests that such instruction is best accomplished at those times when the knowledge is needed to solve a particular problem. In the workplace, such tools can also facilitate reflective learning from doing, thereby helping organizations reduce breakdowns by modifying their processes.

Some instructional technologies also enable integrating the workplace and the classroom, incorporating the strengths of each. For example, researchers in computer-supported collaborative learning are studying tele-apprenticeships and tele-mentoring, which provide students the opportunity to interact intellectually and emotionally with geographically remote workers whose careers they would like to emulate. Also, hand-held wireless devices with appropriate software allow the creation in field settings of “classrooms with electronic walls,” i.e., physically separated learners located in various parts of a workplace inhabiting a virtual classroom, through which they share their observations and receive guidance from the instructor.

A wide range of occupation-related simulations that incorporate these types of instructional technologies are now being constructed by educational researchers (see the section on exemplary illustrations and online resources later in this report). To effectively integrate learning and working, all instructional systems that help workers cope with breakdowns or aid students in learning how to respond to breakdowns should have the following generic characteristics:

- The instructional system presents learners with authentic, work-related challenges and tasks.
- The vocabulary, tools, functions and practices supported by the instructional system mirror what students will encounter in the working environment but are tailored to help learners understand their relevance and master their capabilities.



- The pedagogy used emphasizes learning from breakdowns, accomplishing typical tasks, mastering how to learn and fostering lifelong learning.
- The instructional system aids learners in several kinds of reflection: immediate, to deal with the problem and to organize a solution; postmortem, to see if the problem is recurring and can be avoided by restructuring work processes; and metacognitive, to reflect on one's own thought processes and motivation.
- The instructional system includes interactions among workers because they are the source of many breakdowns. Although the instructional system may have some built-in aid and guidance, learners find most of the help they need through their interactions outside the educational application—i.e., with teachers, peers, other types of experts and archival resources—just as they would in the workplace. Some tools help through cross-domain searching and case-based reasoning, locating similar problems that have been solved elsewhere and reporting on their solutions.
- The instructional system simultaneously supports an individual's solo performances and cooperative work he or she does as a member of multiple groups, thus enabling immediate dispersement of collective knowledge, learning synergies and other enhancements of collective knowledge.

To build instructional systems with these capabilities, a variety of technical challenges must be overcome.

#### **4. TECHNICAL CHALLENGES UNDERLYING THE INTEGRATION OF LEARNING AND WORK**

Work-related learning is not unique in its technical challenges. Many other types of education involve learning for doing, learning through doing and learning from doing. However, integrating work and learning is unusual in that:

- The range of learner knowledge and skills (or range of user attributes) is very broad, from naive precollege students through adults with extensive employment experience.
- The spectrum of content and skills that could potentially be mastered is quite diverse because various employers have different needs.
- Work-related education must be integrated across a variety of physical settings (classrooms, workplaces and homes) and should be available on a just-in-time, on-demand basis.
- Workers' time is quite valuable (i.e., it is the most costly aspect of on-the-job training), so workplace education must be very efficient.
- Assessing the result of such educational interventions is very complex and challenging because the goals of work-related learning are to enhance individual performance and make organizations more productive.

These user characteristics and design constraints make integrating learning and work one of the most difficult applications of IT to education.

New technical capabilities necessary to actualize the pedagogical principles described earlier are listed below. New capabilities specifically tied to integrating learning through doing and learning from doing into workplace settings as well as linking workplaces to classrooms, must be devel-



oped. Generic technical challenges underlying learning-for-doing applications in classrooms must also be solved in order to fully integrate learning and working. However, because they are included elsewhere in this report, they are not presented below.

#### **4.1 CUSTOMIZATION**

Performance enhancement tools of all types should unobtrusively adapt their capabilities and interfaces to individual users, who range from expert workers to novice students.

End users should be able to modify the interfaces and capabilities of these tools to support their individual styles of working and learning.

#### **4.2 KNOWLEDGE ACCESS**

Learners and workers need customizable agents and filters to readily obtain the information they require.

Information systems should represent knowledge in a way that allows users with different goals to easily extract the specific data pertinent to their purposes. For example, the same information in an organizational database might be used by managers for decision making, by trainers for constructing case-based learning experiences and by students to see examples of excellent or flawed performance.

#### **4.3 ASSESSMENT**

Workplace tools should contain embedded assessment systems that diagnose patterns of sub-optimal user performance for future remediation of user performance. Related tools should enable self-evaluation by workers that reveals the degree to which they have mastered various higher-order thinking skills.

On the organizational level, tools and information systems should incorporate diagnostic mechanisms that analyze work flow and collaboration patterns, both for identifying suboptimal institutional processes and for abstracting generalizable principles and practices.

New methods for analyzing and understanding learning innovations are also needed. When multiple variables in the educational situation change simultaneously (e.g., in intern programs), current research methods emphasizing analysis of variance are inadequate for full comprehension of the situation.

#### **4.4 KNOWLEDGE SHARING**

Individual knowledge bases need to be interlinked in a way that enables facile sharing of ideas among collaborative team members. For example, technology design and development teams should be closely interlinked to the people and organizations in which their products and services will be used.

Workplace information that is potentially useful for learning should automatically be routed to classroom educators and trainers. For example, as embedded assessment systems collect examples of successful and unsuccessful resolutions to work-related breakdowns, these examples should be sent to educators for case-based indexing. Similarly, models of operational processes that organizations develop should also be used to create simulated workplaces for educational purposes.

As diagnostic systems collect information about individual worker capabilities to solve various types of problems, this data should be used to develop cascading networks for accessing

expertise, enabling learners or workers to easily locate people who have the knowledge needed to resolve a breakdown.

Clearly, as workers increasingly become authors of knowledge and redesigners of institutional practices, the distribution of organizational authority and responsibility will also have to shift. Technologies that facilitate such restructuring of roles and information flows are vital to the development of a knowledge-based workplace.

#### **4.5 LINKING CLASSROOMS AND WORKPLACES**

Hand-held wireless devices should be redesigned to enable field-based experiences in which learners are physically distributed across a work site yet linked together by shared data, collaborative discussion and pedagogical guidance.

Videoconferencing systems should incorporate collaboration tools (e.g., shared design spaces) that facilitate a wide variety of interpersonal educational activities, such as tele-apprenticeships and tele-mentoring.

#### **4.6 AUTHORIZING LEARNING TOOLS AND ENVIRONMENTS**

Authoring systems that enable educators without advanced programming skills to create the types of learning tools and environments discussed above must be designed. Fundamental research in computer science and cognitive science is needed to achieve realization of these types of technical capabilities.

### **5. COMPUTER SCIENCE RESEARCH ISSUES IN INTEGRATING LEARNING AND WORKING**

The following types of computer science research would aid in overcoming the technical challenges described in the previous section.

#### **5.1 CUSTOMIZATION**

Customization could assist through the development of:

- Layered architectures for tools that gracefully upgrade from working (adept use) to learning (novice use).
- Adaptive interfaces that assess user style and prior knowledge through cognitive modeling.
- Shells that wrap easy-to-use interfaces and exploration support systems around workplace application tools.
- Modifiable interfaces that present users with a broad menu of options for customization.

#### **5.2 KNOWLEDGE ACCESS**

We need to create systems that provide:

- Modeling and representation of complex/multiple media, including annotations, relationships and interactions.
- Ontologies for knowledge representations, optimized for various types of workplace information.
- Knowledge representations that employ multiple sensory channels (sight, sound and touch) and use multidimensional coding strategies.

- Advanced query languages that tolerate inaccurate or imprecise requests, support constructive dialogues to reformulate requests, anticipate requests by prefetching information that matches the activity patterns of the user, support a continuum of access interfaces from querying through browsing and enable content-based queries on multimedia information.
- Agents or “mediator” facilities that dialogue with the user to constrain searches, filter out information and present the information in a manner customized to the user’s learning style.
- Cognitive modeling for retrieving information based on assumptions about the user’s broad goals and plans.

### **5.3 ASSESSMENT**

We need to develop assessment tools that contain or provide:

- Cognitive modeling for assessing user performance and diagnosing suboptimal strategies based on assumptions about the user’s broad goals and plans.
- Mechanisms for assessing individual contributions (credit and blame) in a group environment.
- Representations for modeling organizational learning, including distributed cognition and social interaction issues.
- Organizational modeling and representations that capture work flow patterns and assess group task performance.
- Mechanisms for abstracting generalizable principles from specific individual tool use as well as collective work flow and collaboration (e.g., charting relational infrastructures that complement physical and communications infrastructures).

### **5.4 KNOWLEDGE SHARING**

Knowledge sharing can be facilitated and enhanced by developing:

- Knowledge representations and templates that facilitate sharing information through structured dialogues.
- Mechanisms for reusing knowledge by reconfiguring the data based on the differential purposes of various user populations.
- Enhancement systems that monitor user interactions across an organization and suggest potentially valuable lateral communications.
- Automated indexing to facilitate case-based reasoning.

### **5.5 LINKING CLASSROOMS AND WORKPLACES**

To effectively link classrooms and workplaces, we need to develop:

- Inexpensive wireless network connections with support for a wide range of bandwidths.
- Video source coding matched to the impairments of wireless channels and highly compressive coding schemes.
- New voice and gesture input modalities.
- Bounded delays for media streams.

- Multimedia knowledge representations for collaborative work spaces.

## **5.6 AUTHORING LEARNING TOOLS AND ENVIRONMENTS**

We need to develop authoring tools supporting differential pedagogies that bridge from general education to domain-specific training and architectures that support team learning in simulated environments.

## B. 4 Facilitating Use of The Network: Classroom Use

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*Group Leader: Louis Gomez*

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### 1. INTRODUCTION

“Networked classrooms” is an evocative term. For some people the term means building rooms that provide high-fidelity video and audio connections from one space to another. For others, it means a place where teachers and learners are surfing the Net in search of pearls of wisdom. Still others envision networked classrooms as the portal to a vast array of interpersonal interactions, like those that occur in MUDs—but now in the service of teaching and learning. The networked classroom could be, and in all likelihood will be, all of these. The key focus of this report is not that of determining which of these visions is “correct.” Rather, this report focuses on isolating the set of research issues that will allow the networked classroom to flower into productive instantiations.

There are three critically important themes that must shape and inform development of the networked classroom of the future. First, the research community must recognize that classrooms are, first and foremost, social structures and that networked media will change these social structures. Second, new networked media and the architectures that support them need to be informed by social structures and social goals. Third, both architecture and applications must have evaluative mechanisms that allow them to evolve in effective and meaningful ways.

Social interaction as used herein encompasses most aspects of networked communication widely touted in the popular press, and many others yet to be conceived. Widespread school networking will not merely change the ways learners get information or surf the Net; it will fundamentally reshape the way people engage in interpersonal communication for learning purposes. Thus, the challenging opportunity is to adopt the perspective that social interaction is the means to understanding classrooms and classroom work. Seen in this light, even the simple finding of information can be viewed as the connection of students to distant communities and ways of knowing. Our goal here is to support learning as social interaction in all of its forms through a research agenda that will shape the creation of an enhanced network infrastructure. For example, while we want to support the expanded notion of a teacher as a mentor or guide, we must make a concerted effort to engineer learning spaces in ways that do not constrain developers and educators to one particular set of teaching and learning roles. This perspective is important because today, and into the foreseeable future, no single theoretical tradition that has all the answers to building robust and effective learning environments exists.

Similarly, the purpose of networks in classrooms is not to merely amplify what already exists, and key research questions must not be constrained to how to make the same classroom activities occur faster, become less expensive or take place over longer distances. Today’s classrooms already orchestrate social interaction for learning. Networking, however, offers the potential for the formation of new social structures and new ways of interacting in the classroom. The scenario about a class

learning about volcanoes (see page 44) illustrates some of these broader ways that networked classrooms might evolve. To support this evolution, at least three types of research are critical:

1. Understanding the patterns and evolution of social interactions and their differential values in achieving specific learning goals.
2. Designing architectures for networks and applications that help teachers and learners achieve specific patterns of interaction.
3. Providing evaluation as an organic part of learning environments so that social transformations in the networked classroom can be charted in relation to the goals of designers, users and researchers.

Research efforts focused on these themes should coalesce to guide the development of architectures that will support applications that are deeply informed by the ways of learning and interpersonal communication.

## **2. EVOLUTION OF SOCIAL STRUCTURES**

A key focus of research is how networking changes social interaction and activity in classrooms. How it impacts the formation of small groups and communities and their patterns of interactions are particularly important research issues.

### **2.1 FORMATION OF GROUPS**

Research questions should ask:

- How do individuals find collaborators?
- What are the centralized and emergent means of choosing groups?
- What mechanisms exist to ensure group continuation and cohesion through transitions?

### **2.2 PATTERNS OF INTERACTION IN GROUPS**

Research questions should address:

- Designing taxonomies of peer-to-peer (symmetric) and peer-to-non-peer (asymmetric) interactions.
- Designing frameworks that interweave social communication and the influence of material objects.

## **3. ARCHITECTURE**

Architectures make certain things easy to do and, by implication, other things hard to accomplish. Presently, most software applications have single-user models. If networked classrooms are to be served well by software, those applications must be supported by an architecture with an explicit model of multiple users and the range of possible interactions among them. Ultimately, application developers and others must have basic protocols that support socially aware applications.

The following elements should coalesce for developers and users into specific applications responsive to the social and communicative needs of teaching and learning as carried out across a range of synchronous and asynchronous situations (briefly, synchronous interactions are those where people, either in the same or different locations, work together on common problems at the same time;

asynchronous interactions refers to those situations where people work together on common problems at different times).

Some of the most basic interpersonal operations that will be necessary include:

- Sharing attention.
- “Baton passing,” coordination and synchronization.
- Voting.
- Brainstorming.
- Reciprocity.
- Privacy.

These basic interpersonal operations will require a companion set of services to assist students with active knowledge construction, including search and retrieval; critiques and annotations; active documents with embedded analysis tools (visualization); and curriculum support tools, with active connection to curriculum.

The architecture must also be sensitive to the special needs of schools, teachers and learners. Services that encourage the development of a range of automated learning management tools include:

- Audit trails and event logs.
- Time management for learners.
- Scheduling.
- Task management for learning (e.g., division of tasks).
- Priority setting and ranking.
- Reporting.

An electronic portfolio, wherein students could store, review and assess their own work in private space with invited reviews, is one example of an application that could be built using these architectures. Another application is public spaces to “publish” within and/or beyond the classroom, allowing for peer review, teacher assessment or researcher evaluation. To support the flexible and iterative redesign of applications based on these architectures, new evaluation tools and methods are needed.

## 4. EVALUATION

Understanding how educational goals are being achieved through computer and networked tools is critical for the evaluation of the tools. It is important to note that the goals of different constituencies are markedly different. In addition, as mentioned earlier, most prototype educational technologies are moving targets. These evaluation challenges can be addressed through different sets of analytic lenses, i.e., differentially examining issues of design and the activities of students and a comparison of learner outcomes for individuals and populations.

Assessment tools must be built into the software. They must enable different communities of interest to get the information they need in ways that are meaningful to them.

This suggests that in addition to building the data collection structure into the software, there also need to be tools for analysis and reporting of the log files that are generated. These tools will also need to be flexible enough so that the data can be viewed from all user perspectives. Such an infrastructure should be more than simple event logs because different audiences have different needs. For example, building behavior traces that separately track the use of teachers and students would

enable a teacher to build a useful profile of students' activity by compiling their contributions to priority setting, brainstorming activities or group work.

Finally, any system of data storage must have several levels of progressive anonymity so that, at the broadest level of use, individual student, teacher and school identity is protected.

### How A Classroom Community Might Explore Volcanoes

A deep rumbling noise was heard, then wisps of smoke came from the rocky tip. With an abrupt roar the mountain blew its top, throwing tons of ash into the air and spitting hot lava down its sides. Enrapt students sat around the monitor watching Mount Saint Helens explode.

"I heard an old man who wouldn't move was killed during this eruption." The voice came from another window on the monitor showing a group of students watching the same video at another school. One of Mr. Rottenbury's students responded, "Yeah, once the lava starts, it goes too fast to outrun it."

Mr. Rottenbury listened with interest to the conversation and then directed his attention to another group of students who were composing an e-mail letter to their mentor at NASA: "OK, suppose we, like, tell them, since the oceans came from volcano eruptions and Venus has as many volcanoes as the Earth does, why isn't Venus covered by water like most of the Earth?"

"Remember to cc: me on any e-mail that you send," Mr. Rottenbury reminded the group as he continued walking around the class. He thought how posting that news message asking for suggestions on Internet resources on volcanoes had really paid off. He had received a number of responses giving addresses of Web sites about volcanoes that had recently erupted, describing them through images, video and data sets. Even better, another teacher was starting a unit on volcanoes the same day. It was her students who were now watching the Mount Saint Helens video with his.

Yet one of the most intriguing resources to turn up was a volcano construction kit built around a MOO. His most adventuresome group of students were in the MOO, collaboratively building a new volcano complete with audio and visual sound effects. The group was still wrangling with other remote builders over what should happen when it blows and the effect it should have on anyone nearby. Everyone was in favor of some semipermanent change to those visitors unlucky enough to be too virtually close, but the group could not agree on whether it should also undo the volcanoes some of those remote builders had designed. The debate was taking a long time to resolve because it involved students in several different time zones, so it had to be conducted asynchronously. Then the bell sounded, and the pitch of activity grew dim as students printed out copies of what they were working on, signed off their remote conversations, finished the e-mail messages they were working on and drifted out the door.

The large smile that flashed across Mr. Rottenbury's face as he congratulated himself on the excitement and involvement he had just witnessed slowly disappeared as he remembered the logs of computer activity, e-mail messages and catching up with mentors that he still had to do tonight. Perhaps that new program for automating analysis of student computer usage he had heard about coming from NSF would save him some time, making classes like this more manageable.



## B. 5 Facilitating Use of the Network: Integrating School, Home, Industry and Community

*Group Leader: Beverly Hunter*

### 1. BACKGROUND ASSUMPTIONS AND VISION

The technological and organizational infrastructure that enables creation, storage, communication and use of information in electronic form is evolving rapidly within and among neighborhoods, communities, institutions, households and individuals. It is also changing the very concept of “community,” with information repositories, online events, virtual work groups and electronic communications redefining communities’ temporal and geographic boundaries. These changes, in turn, are generating changes in the roles and responsibilities of traditional institutions for providing educational opportunities for children and their families. Schools’ new roles are now extending to other citizens, workers and researchers as well.

There are a multiplicity of views concerning the future. Today’s new technologies and communications infrastructure have the potential for positive and negative effects. People are dealing with increasing complexity in their work, social and personal lives. This same complexity is also driving expectations and requirements regarding lifelong learning, teaching, literacy and education. As individuals, families and collaborative groups play new roles as learners, teachers, mentors, researchers and creators of knowledge, they are also developing new senses of identity and new ways of representing themselves to others.

Cumulatively, these changes have created the potential for major shifts in distribution and control of resources, affecting the very roots of our democratic society.

Clearly, the relationship of learners to knowledge is more complex than in the past. People who can add value to a community’s knowledge base have better survival skills than those who are only knowledge consumers. Parents can more easily become involved in their children’s learning, both at home and at school. The school-to-work transition can be eased and facilitated through the use of remote mentors, electronic tools, and media and authentic simulations of the workplace. Workers can access instruction while on the job. People in all walks of life can take roles as mentors, experts, tutors and advisers to students. Libraries, community centers, museums and town halls can provide citizens with access to communitywide education and information services. Collaborative teams can share tools, work spaces, knowledge and tasks in response to new learning requirements or opportunities.

Creating a vision of educational opportunities integrated across a community raises challenges of all kinds—social, institutional, financial, ethical, political and educational as well as technical. This vision assumes not only the solution to all the technical challenges identified in the NII R&D agenda but also the large-scale implementation of such solutions in the form of a physical and informational infrastructure for entire cities or geographic regions. The information infrastructure must include very large repositories of digital information, millions of small personalized digests of

knowledge and millions of local community services. Beyond these considerable prerequisites are the additional challenges unique to learning, teaching and knowledge creation. Pursuing research inquiry that addresses these unique educational challenges will lead to technological supports for critical skills such as media literacy and reflection on the nature of one's own learning.

To effectively manage these changes in ways that will equitably benefit people and communities, we need to form multidisciplinary groups to conduct research on the interactions of technology, technological and informational infrastructure, individual and group learning, and knowledge creation and institutional contexts. This research requires collaborations among the disparate disciplines of computer science, cognitive science, psychology, sociology, anthropology, economics and education.

## **2. RESEARCH GOALS AND ISSUES**

### **2.1 A NEW CONTEXT FOR RESEARCH**

The overriding conceptual framework for future research and development (R&D), especially in relation to the NII, must be informed by the perspective of human learners, i.e., it must be responsive and relevant to the numbers and variety of people and institutions that interact across a community.

Research—whether focused on technology, cognition, education, infrastructure, knowledge, economics or combinations thereof— must be conducted in the context of these highly heterogeneous and large-scale user populations and institutions. This is a major departure from past design constructs and poses unprecedented challenges in collaboration among researchers and practitioners from academic, commercial and government organizations.

We recommend that research projects incorporate the following three levels of focus and context for knowledge representation, collaboration, learning and physical infrastructure: individual, institutional and community.

### **2.2 KNOWLEDGE REPRESENTATION AND HUMAN UNDERSTANDING**

Heretofore, much research has focused on information repositories, digital libraries, and associated tools and intelligent agents for organizing and retrieving information from large repositories. New priority should be given to knowledge and the processes by which humans, individually and collectively, convert information to knowledge. For example:

- How can we create the multiple representations of the same information that are needed by different individuals and groups having different backgrounds and different learning goals?
- What mechanisms, conventions and protocols are needed for assessing from multiple perspectives the quality and relevance of the information provided?
- How does understanding vary among social contexts?
- Heterogeneous groups and individuals use and understand different conventions, notations and icons in different contexts. What conventions across contexts are possible? How will people learn them?
- How can components of knowledge bases be reused by different users and for different purposes and applications?

- How can we interrelate physical objects and data with electronic and virtual representations, such as computer simulations?
- How do humans extract meaning from images, sounds and icons?
- What tools might support individuals and groups as they represent and organize information?
- How can people be credited or compensated for their contributions and their intellectual property rights?

### **2.3 VIRTUAL, COLLABORATIVE GROUPS**

Knowledge is created and represented at differing levels for different purposes. Meaning is constructed to serve humans, e.g., individuals and groups living within a geographic community, within institutions and/or within virtual communities of interest that cut across traditional institutional boundaries. Interdisciplinary research should support our evolving understanding and infrastructure, addressing such issues as:

- How can the privacy of individuals and groups and levels of approved access to and participation in knowledge bases and group processes be ensured and maintained?
- How do individuals and groups represent themselves in cyberspace?
- How can infrastructure support be provided for rebuilding and sustaining geographic neighborhoods and local communities?
- What infrastructure services will support cumulative knowledge constructed over time through contributions of diverse groups and individuals?
- How can infrastructure and tools facilitate or obstruct the formation, management and operation of virtual communities and collaborative groups?
- How can economic compensation be provided for individual and group contributions to a community knowledge base?

### **2.4 LEARNING**

Continual, lifelong learning on demand by all citizens will require changes in traditional approaches to research on learning, teaching and cognition. For example, little is known about how people of different ages and from different social contexts learn how to learn.

Other lifelong learning issues include:

- How can the design of tools and environments facilitate learning?
- How can information retrieval systems include embedded instruction on human retrieval strategies?
- How do the processes of data manipulation affect learning?
- How can novices and experts productively collaborate in shared knowledge-building tasks for the benefit of individuals and the community?

### **2.5 INFRASTRUCTURE**

Every citizen should have access to a low-cost computational and communication device from any location at any time that would provide connectivity to the Internet.

R&D is needed to develop connectivity that is low enough in cost that no segment of society is kept out of the infrastructure. This connectivity must possess high-enough bandwidth and capability so that all relevant and important information and functions are available.

Every user should also have the ability to publish from this device and connection. Connectivity should allow for voice, text, image and video, along with asynchronous and synchronous tools for collaborating, communicating and performing individual work.

Connectivity and computational management must be simple enough for any competent human to learn and understand, yet flexible enough to allow for the management of the quality and quantity of information received. Privacy and security should be built into the infrastructure of the connectivity. The connectivity should possess the same capabilities and features, regardless of hardware or software platform.

### 3. EXAMPLES AND ONLINE RESOURCES

New research in the areas discussed above should build upon relevant prior and current lines of R&D from industry, civic, educational and academic contexts. The following are two out of many such examples.

- *Civic networks.* See the RAND Corp. study at <http://www.rand.org/publications/MR/MR60>. In Chapter 5, Sally Ann Law and Brent Keltner report on in-depth studies of five civic networks. By synthesizing findings across the five networks,<sup>1</sup> they offer preliminary answers to two questions: 1) What are the individual, group and societal benefits (and potential disadvantages) of access to networked communication technologies, especially for traditionally underserved individuals and groups? and 2) What can we learn from the implementation of civic networks that will help us understand what it takes to deliver online access to all groups in society?
- *School-community linkages.* The National School Network Testbed at <http://nsn.bbn.com>, funded by NSF, is focusing on the new roles of schools within their communities and the development of local information infrastructure. The testbed Web site includes links to many testbed communities, schools and other institutions that are forging new collaborations for learning among institutions.

<sup>1</sup>Public Electronic Network, Santa Monica, CA; Seattle Community Network, Seattle; Playing to Win Network, Boston; LatinoNet, San Francisco; Blacksburg Electronic Village, Blacksburg, VA.

# B. 6 Tools for Authoring Educational Technology

*Group Leader: Chris Riesbeck*

## 1. INTRODUCTION

Educational technology can provide rich learning-by-doing environments—some collaborative, some one-on-one, some carefully scripted and scaffolded, and some student-generated and open-ended. “One size fits all,” “spray and pray” teaching is replaced by a wide variety of motivationally rich, personally relevant, pedagogically sound learning experiences, a vast menu that would respond to the needs of all students—from the at-risk to the gifted.

This vision depends on the development of new roles for teachers, new social contexts for learning and significantly new kinds of technological support. Advanced technology cannot act as a vehicle of change for these new teacher roles and new social contexts for learning unless it is widely and pervasively deployed. In order for this widespread deployment to occur, technology-based learning environments must become dramatically less expensive and easier to build. While some examples of excellent learning environment systems exist, these systems were incredibly difficult and costly to build and have been hard to replicate in other domains. Furthermore, they are islands unto themselves, sharing neither content material nor interface elements with any other environment. There are several causes, including:

- Current authoring tools are basically generic programming environments. Some support the development of enticing graphical interfaces, but most do little more than construct electronic books with multiple-choice quizzes. Such tools are theory-free. They neither guide nor critique the pedagogical soundness of the applications authored. Thus, today’s authors have to be experts in programming, education and subject content, all at the same time.
- The applications these tools create support very few forms of student input. A student can either pick from a predefined list of choices by selecting an item in a menu or by clicking on some region of a picture, or use open-ended drawing and text-entry tools. The former are limiting, unrealistic and counter to good pedagogy. The latter are uninterpretable by the application, preventing any significant feedback or guidance.
- The applications are closed systems. Each has its own representational format for subject and pedagogical knowledge and its own set of interface elements. For example, a student wishing to use a simulated physics lab to run variations of experiments on forces and torque seen in a tutorial application has to learn a new interface and manually translate and re-enter all content.
- The applications are rarely matched to student and community needs because application development is a one-way process. Students, educators and the community at large have only minimal opportunities to influence the development process. Authors get virtually no feedback on how their applications are used—and misused—once they are widely deployed.

- The applications are difficult, if not impossible, for a classroom teacher to adapt to the particular needs of a given set of students.
- Applications neither take into account nor integrate well into the curriculum and the social structure of the classroom. Time spent on the computer is not integral to the rest of the class experience. At best, computer time is fun. At worst, it is just one more thing for students to learn and one more loss of instruction time for teachers.

Overcoming these problems will require interdisciplinary research as well as basic computer science research.

In our vision, sophisticated, interoperable tools are needed for all three populations: students, teachers and authors/developers. Students need tools to support active learning, i.e., problem-solving, knowledge construction, articulation and presentation. Teachers need tools to support their central activities—i.e., identifying the knowledge (or lack thereof) of the learner, eliciting individual learning styles and modalities and engaging the learner in activities that match his or her knowledge state and learning style—to facilitate effective collaborations of learners and help effect the skill of learning to learn. Authors need tools that provide pedagogical guidelines and facilitate the reuse of both domain knowledge and process components.

More specifically, the next generation of educational tools should include:

- Tools for authors that include libraries of 1) flexible, consistent, interchangeable interface elements; 2) robust, extensible, explicit representations of content materials and task activities; 3) design rules, course templates and exemplars based on solid pedagogical theories; 4) mechanisms for the automated collection of in-field usage data; and 5) knowledge-acquisition tools for capturing and generalizing pedagogical strategies from teachers and content experts.
- A coherent, open-ended set of activity support tools for students that can be used in both highly scripted scenarios and open-ended, project-based problem-solving situations.
- Tools for teachers and course facilitators for monitoring, diagnosing, interpreting and summarizing student activity; modifying and adding subject matter material; and reconfiguring students' activity environments.

## **2. R&D DIRECTIONS**

In our vision, subject matter experts, educators and teachers are empowered to create learning environments that are engaging, relevant and effective for their particular student population, based on sound pedagogical principles. Research to support this vision includes:

- Developing a catalog and taxonomy of tasks and task scenarios—many derived from real-world situations—for use by authors, teachers and as part of authoring tools when developing educational systems.
- Developing a catalog and taxonomy of general cognitive and social activities that students can perform within task and project activities to enrich learning by reflection, articulation, rehearsal and so on.
- Developing a library of design rules and templates for project scenarios that can be incorporated into authoring tools to guide teachers in choosing frameworks appropriate to their needs and instantiating those templates in coherent ways.
- Studying the pedagogical impacts of these different tasks, cognitive activities and social activities, in different student populations.

Students, teachers and the community at large (parents, business and government) must play a significant role in the development process. It is essential that they understand the intent and value of the tools and applications that are being developed and have an open channel for providing feedback of all kinds to authors, tool developers and researchers.

Presently there are fundamental gaps in understanding how technology enters the educational system, what impact it has and what factors contribute to its successful, or unsuccessful, use and integration. Most studies are either usability tests or pilot studies driven primarily by developer questions and are not particularly sensitive to what teachers and students perceive as important. Research to bridge these gaps in understanding must include:

- Developing a library of case studies on how existing tools and applications have been used and misused.
- Developing and maintaining an ongoing, easily accessed “requirements analysis” of how the needs and tasks of teachers, students and the community at large are changing as technology spreads and develops.
- Developing models of student-computer interaction, based on human-computer interaction and computer-supported collaborative work models, which take into account the distinctive need to promote learning (e.g., through reflection, articulation and collaboration) and the varying modes of collaboration (from individual work to student teams to student-teacher-technology triads).
- Developing tools and network infrastructure to allow applications to automatically maintain external repositories that record their own usage, at dynamically adjustable levels of detail.
- Developing tools and infrastructure for collecting, categorizing, indexing and delivering appropriate summaries of this rich data to other applications, students, teachers, authors, tool developers, researchers and others in the community at large, while always protecting the rights to privacy of the students and teachers.

In our vision, the student has access to a wide variety of intelligent tools for projects and problem-solving. These tools need to be highly interoperable so that schools can acquire libraries of tools appropriate to their needs, students can choose the tools they want to use in projects and problem-solving and students can easily connect tools together (e.g., linking data-generating tools to spreadsheets to visualizing tools to computer-aided design tools).

These tools need to be usable not only in collaborative, open-ended, project-based problem-solving, but also in carefully crafted, scenario-based, guided simulation environments. Thus, tools that can work with knowledge as well as data must be developed. Research to support this vision includes:

- Developing open-ended communication protocols and representational vocabularies (domain and task ontologies) to support messages and indices of domain and task-specific artifacts.
- Developing reconfigurable environments of plug-and-play components that communicate and share knowledge using these protocols and vocabularies.
- Developing a large set of interoperable, pedagogically helpful tools for students, such as data and knowledge bases (e.g., problem repositories and case libraries), qualitative simulators that can explain what is happening, text interfaces that can interpret natural language responses and data visualizers that can adapt to different levels of student knowledge.



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the 1990s, the number of people in the world who are under 15 years of age is expected to increase from 1.1 billion to 1.5 billion (United Nations 1999).

There are a number of reasons why the number of children in the world is increasing. One of the main reasons is that the number of children who are surviving to adulthood is increasing. This is due to a number of factors, including improved medical care, better nutrition, and a decrease in child mortality rates.

Another reason why the number of children in the world is increasing is that the number of children who are being born is increasing. This is due to a number of factors, including a decrease in the age at which women are having children, and an increase in the number of children who are being born to women who are already having children.

There are a number of challenges that are associated with the increasing number of children in the world. One of the main challenges is that there is a need for more resources to care for these children. This includes more schools, more teachers, and more social services.

Another challenge is that there is a need for more resources to care for the elderly. This is because the number of people who are living longer is increasing, and this means that there are more people who need care in their old age.

There are a number of ways that we can address these challenges. One way is to invest in education and health care. This will help to ensure that children are getting the best possible start in life, and that they are able to live longer and healthier lives.

Another way is to invest in social services. This will help to ensure that children and the elderly are getting the care and support that they need. This includes things like housing, food, and financial assistance.

There are a number of other ways that we can address these challenges. For example, we can encourage people to have smaller families, and we can encourage people to take care of their children and the elderly.

It is important that we take action now to address these challenges. If we do not, the number of children in the world will continue to increase, and this will have a negative impact on the world's economy and society.

There are a number of things that we can do to help address these challenges. We can start by investing in education and health care. We can also start by investing in social services. And we can start by encouraging people to have smaller families and to take care of their children and the elderly.

It is our responsibility to ensure that the world is a better place for all of us. And one of the best ways that we can do this is by taking care of the children and the elderly. Let's work together to make a difference.

There are a number of ways that we can help address these challenges. One way is to invest in education and health care. This will help to ensure that children are getting the best possible start in life, and that they are able to live longer and healthier lives.

Another way is to invest in social services. This will help to ensure that children and the elderly are getting the care and support that they need. This includes things like housing, food, and financial assistance.



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