Technology Enhanced Learning

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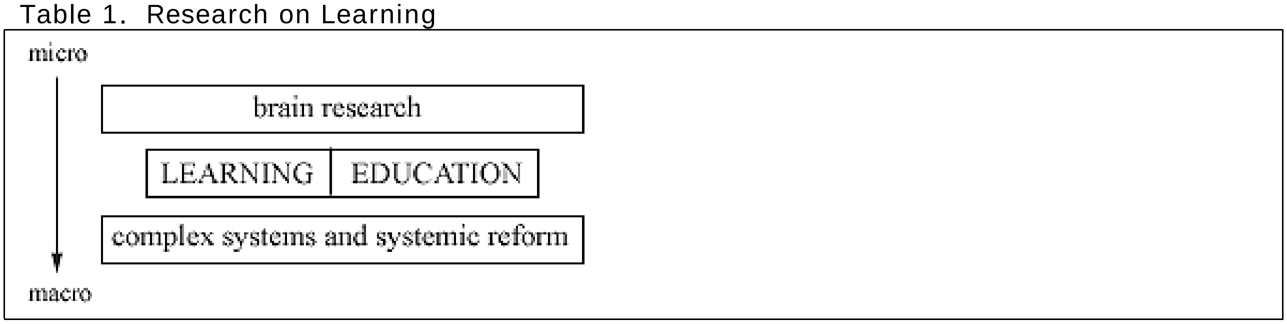
Abstract

Research issues and challenges related to technology-enhanced learning are discussed for classroom learning at a distance, online learning, digital libraries, special collections and online resources, virtual laboratories, e-collaboration, and virtual environments. Recognizing the potential of small changes in technology to have large effects on learning and learning systems, treating the development process as a living laboratory, documenting and collecting technology enhanced learning anecdotes (both positive and negative), gathering hard data across projects, and designing with dissemination to real teachers and learners in mind are highlighted.

1. Introduction

Sabelli describes research on technology enhanced learning spanning a range from micro to macro focus, starting with basic brain research and ending with the study of complex systems [13].

Table 1. Research on Learning



Internet2 (I2) promises a services-rich network environment being grown through application demonstration projects and core technology development. The broad education and technology research issues include:

- How can technology enhance learning? (invention, theory, prototyping)
- How do we know what works, and in what contexts? (assessment, pedagogy, revision)
- How do we extend demonstrated concepts in sustainable, scalable ways? (knowledge base, system research, policy)
- How do we extend access to technology to the *haves* and *have nots*, to naïve and expert teachers and learners, to individuals with individual differences? (practice)
- Can research on technology enhanced learning research inform general education theories and practice even beyond the technology realm? (theory, knowledge base, practice)

• What are potential unintended consequences of learning technologies and how do we minimize them? (individual, classroom, system, society)

Resta [11] reminds us the job description of most professions have changed dramatically since the beginning of the last millennium, but the job of *teacher* has changed very little (perhaps until now). Technological implementations increasingly affect both teaching and learning experiences. Technology evolves as a natural part of the technology development process. Software goes through a development cycle from conception to "just barely working" to ongoing refinement. Leifer [8] studies technology effects as a moving target because technology doesn't stay the same.

As director of the Stanford Learning Lab, Leifer studies how small changes in course protocol and technology can have profound effects on learning efficacy and efficiency. His lab treats each online course development project as a research opportunity. Like Leifer, other I2 designers are part of a living laboratory and should remain watchful for possible profound intended and unintended effects of their creations. Detection of effects may begin with anecdotal observation and should move to more formal research and systematic observation when a potentially meaningful possible trend is identified

Some projects start with technology, others with educational pedagogy and others with science (or other subject matter) experts. Although all I2 projects are research projects, not all projects with educational implications include research on their technology-enhanced learning aspects. It would be useful if someone associated with I2 collected and encouraged collection of both anecdotes and hard data across these projects into a pair of online databases.

2. Areas of I2 Invention for Learning

This paper will discuss research agendas for seven areas of Internet2 invention with potential to alter teaching and learning.

2.1. Classroom Learning at a Distance

The pedagogy for most instructional television developed by university professors is not much different from what those same professors employ in the classrooms without a television camera. Instructional television received extensive comparative research attention in the 1960s when it began. Studies compared in-person learning to televised instruction, routinely finding no significant differences in learner performance between TV-instructed and in-person students. More recently two-way television transmitting video by satellite with access to a telephone for question and answer (or via compressed television in both directions) allows distant students to be seen and to ask questions. Again, the dominant research found no significant difference in learning performance between the two groups. Many initial uses of Internet2 for learning at a distance began as a new means to transmit video of a professor lecturing or speaker speaking. Live netcasts of speakers and of classes are regularly programmed at BIBS (Berkeley Internet Broadcast Service). It's not quite the same as traditional instructional television, but initially the differences are subtle. Many programs (classes and seminar speakers) are archived for viewing on demand. Do students use the archives? how often? in what way? What difference would it make to be able to pause, repeat and perhaps even save outstanding clips? to take notes hyperlinked to places in the program?

Instructional television is a delivery and exchange system much less flexible than Internet 1 or 2. Even when I2 is used for instructional-television-like applications, the designers and the design of the particular software may have (good, bad, or neutral; intended or unintended) profound effects on the teaching and learning experience.

Microsoft uses an internal video network to allow individuals throughout the corporate complex to virtually attend guest speaker presentations without leaving their offices [4]. Physical attendance at the seminars has dropped, but a virtual attendance screen in the room with the speaker is now used to show who is attending virtually, and to allow virtual attendees to raise their hands when they want to ask questions. Unlike real life, a virtual hand can easily stay raised until the listener gets a chance to make their comment or ask their question. Does this mean more virtual listeners who have questions get to ask them? Are virtual listeners more satisfied and involved because of this? Do the distant listeners have a better chance of being called on than the in person listeners, or vice versa?

BIBS multicasts multiple simultaneous windows – one of the professor, one of a whiteboard, one of the live audience (http://bmrc.berkeley.edu/bibs/).
Distant participants can also have video windows. How do learners divide their attention among the windows? Do multiple views distract or allow for selective focus to enhance learning? Is it a more effective interactive environment for group participation? Do teachers teach differently in this system?

Many other I2 participants are using digital video for learning applications (items on the list are taken from the database of the National Laboratory of Applied Network Research (NLANR)). (http://www.nlanr.net/)

Table 2. I2 Distance Learning Digital Video

•Old Dominion University is developing the Interactive Remote Instruction controller for live multistudent A/V connectivity and tools for the instructor to control. •The Living Schoolbook in New York State is working with Video on Demand and demonstration projects for K-12 •Johns Hopkins is developing multicasting protocols for multimedia conferencing. •NCSA (National Center For Supercomputing Applications) has created DETA (Distance Education Teaching Assistant) to manage network access. •iCAIR's (International Center for Advanced Internet Research) Advanced Internet Digital Video is working on store and forward repositories, streaming media and multiway interactive conferencing. •Research TV Consortium is looking for new means of distribution and interaction, including the Video Conferencing Cookbook.

Classroom 2000 by Gregory Abowd [1] at Georgia Tech University is an automated capture and retrieval system for live lectures, including automatic capture and text conversion of class notes and timeline history, electronic whiteboard, extended whiteboard or web pages, and projected most recent history of pages presented (in addition to video and audio of the professor). More than 100 courses have been captured. Abowd and his team treat this as a living laboratory, collecting anecdotal and formal research data to constantly improve the system and understand its impact.

The Classroom 2000 project began as a way to capture multiple views of the classroom experience. Teachers can teach exactly the way they always have. Adoption was facilitated because little change was needed on the part of the professor. The system is affecting the learner and the learning experience more than it is affecting the teacher. As is often the case in technology-impact learning studies, no significant difference in test scores was observed. However, 60% of the students take fewer notes, and some take no notes. Students like the system and don't want the system to go away. Teachers are starting to reuse and refine their archived material to improve subsequent classes. Thus the technology is affecting teaching although change was not the original intent. New Classroom 2000 developments will focus attention on the student experience, bringing students closer to the technology and letting them interact with and add to the captured content. Classroom 2000 is evolving into an augmentable, reusable repository and an anchor for collaboration.

2.2. Online Learning

Online learning is a subset of distance learning, sufficiently technologically different from traditional instructional television to merit separate discussion. The basic premise of online learning is to electronically connect physically separate teachers, students and learning experiences. Original content and learning experiences are placed online, links can be to anything and anyone on the Internet, communication and other software connects people with each other. By definition, class always meets in a technological, information-rich environment.

Cisco Academy's e-learning online educational ecosystem is currently implemented for 2500 academies internationally [9]. According to Jim LeValley, Program Manager of Cisco Press, technology enhanced learning was isolated in the 1980s, supplemental in the 1990s and will be integrated in 2000. Cisco e-learning tools include constant feedback, large forum collaboration tools, as well as assessment tools. More than 50 companies sell integrated online learning systems or individual tools to educational institutions. Some universities now offer online degrees. Many offer online courses. Motivations for universities offering online courses (and for students wanting to take online courses) are diverse.

Table 3. Motivations for Online Courses

- to reach new markets (distant students) with traditional degree programs
- to reach nontraditional/distant students with certificate programs or individual courses
- to offer a more flexible/different learning style alternative to on-campus students
- to serve workers whose professions require ongoing certification
- to allow high school students and prematriculants to begin taking college courses from home
- to provide alumni with access to continuing education from their alma mater
- to experiment with new modes of teaching and learning
- to teach more students with fewer resources
- to improve the quality of instruction

Some pedagogies are easy to implement online. Not surprisingly, online learning is conducive to multiple-choice, automatically graded exercises and exams. CBT (computer based training) with branching and programmed feedback translates easily to online courses.

Perhaps less intuitively obvious, online courses also excel at seminar discussion formats. Asynchronous communication tools let students in different time zones on different schedules participate more fully in graduate seminar discussions than might occur in a traditional 2 hour classroom seminar where only one person gets to talk at a time. Online professors can divide their class into small discussion groups of 4 or 5 students and guide each group in discussion assignments.

One-to-one professor-student interactions can be initiated by the professor far more easily than in traditional classroom instruction. In the classroom, 20 to 200 other students attend class together. Asking a student a question during class only happens while all of the others watch and wait. A few students stay after class to ask questions. And a few attend office hours. But the instructor is not easily able to ask each individual student how she is doing and what material she would like to see covered in more depth. Online it's easy to keep in touch with and to keep track of each student's progress as an individual. Instant messaging even allows a professor or fellow students to ask and answer questions instantly, providing both parties are online.

Professors *and* students are both more accountable in an online course. In the classroom where, like a conversation, no record of the teaching persists other than student notes after the hour is up. But in an online course most or all of the content and the discussion exists online and can be viewed and reviewed later. Some courses let students know they will be monitored and then track how many lectures they have listened to. Privacy and ethical considerations guide access to such content. But the potential for review, even if just for self- improvement, is much more detailed than for in-person courses.

Creating course materials is a lot more work in online courses. Perfection matters more and takes longer. Classroom handouts don't need to be designed with elegant navigational consistency. "Getting it just right" is an involved process including both substance and myriad details, which, if done poorly, hurt the overall impact of the course materials. Televised courses faced the same comparison: broadcast television and live university instructional television courses were not at all comparable in quality, production values and polish. Online web pages are compared with big budget corporate web sites, but more often than instructional television, online courses try to rise to the challenge of presenting commercial quality polished products.

Once a course has been created online, it can be refined and improved in subsequent semesters. The first time through tends to be a struggle between creation and interaction – both aspects take large amounts of time.

Another strand of online learning R&D is being conducted in association with I2 by IMS (Instructional Management System), part of Educause's National Learning Infrastructure Initiative. (http://www.imsproject.org/) IMS is attempting to create new component tools to allow content developers to create more robust and integratable "knowledge objects" for learning. XML metatag protocols for indexing content can combine with interactive tools for course construction and administration. The development of the IMS process itself also needs to be studied, to understand how formal structural requirements and homogenization affect the design process and course design outcomes. In the IMS model the content, who designs the online course material is often different than the instructor who offers the online course. The role of teacher changes to be coach and guide, but not the content expert who created the online course materials.

Many forms of pedagogies being used in different courses:

Table 4. Some Online Pedagogies

- discussion-based seminars
- self-paced problem solving with online homework and exams
- digitized, synchronized audio/video lectures
- case studies and small group problem solving
- changing instructor role from lecturer to facilitator or leader use semi or not throughout
- guiding students through necessary information in a non-linear, hyper-linked environment, that enables them to construct knowledge in new and more meaningful ways
- building a sense of "classroom community" and enhancing learning by incorporating collaborative elements
- insuring academic integrity
- project-based courses
- community of learners building a knowledge database
- public submission of all assignments can change the exchange into student-class rather than student-teacher
- use of online portfolios for assessment

While the validity of classroom teaching is rarely questioned, teaching with technology invariably attracts the cautious question: does online learning work? Chickering and Ehrmann distilled education research and collective experience down to seven principles, offering seminars in exactly how to implement them for online learning. Their approach, described below, is more prescriptive than evaluative.

Table 5. How to Teach Online, from Chickering and Ehrmann

- Encourage Contacts Between Students and Faculty
- Develop Reciprocity and Cooperation Among Students
- Use Active Learning Techniques
- Give Prompt Feedback
- Emphasize Time on Task
- Communicate High Expectations
- Respect Diverse Talents and Ways of Learning

Hara and Kling [5] raise the issue of student frustration in online courses, claiming negative aspects of online learning are a taboo topic among researchers and practitioners. Kling suggests the major body of literature on distance education is favorable, and the tendency, once a technological utopian consensus has been reached, is to resist dissonant ideas.

Their case study was a detailed examination of an online course taught by a doctoral student who took over an already developed online class at the last minute because the instructor who developed it became ill. The course used an email listserve rather than online conferencing. The instructor failed to send out assignments on schedule. And the university appeared to lack technical support mechanisms to help online students when they had problems. In other words, it was a "worst case scenario" situation. Lots of student frustration was documented in the six-person online course, and the authors concluded that this frustration inhibited their educational opportunity.

One explanation for why frustration gets ignored by researchers (and in student evaluations) is that frustrating failures feel like a temporary technology problem outside of the actual course. For example, when the network dies in the middle of one student's final exam, the exam does not get blamed – the network is at fault. The locus of fault for frustration with online courses is widely distributed. And the expectation for "things getting better next time" has basis in fact (engineers continually try to fix problems and often succeed) and past experience with technology (this year's computer is more powerful than last year's computer).

Kling's suggestion to pay more attention to failures of educational innovation remains well taken. Anecdotes collected at informal phases need to include the bad as well as the good.

Many speakers at the 1999 September Internet2 Sociotechnical Summit called for hard data documenting the effects of I2 (and other) technology. Leifer's learning lab exemplifies this spirit of constant experimentation [8]. Approximately 50% of course-development resources are spent incorporating elements of learning theory, pedagogy, domain content, and design theory to work with researchers from the content discipline for an online learning course.

The Learning Lab's online courses tend to be international, engaging academic, corporate and cultural institutions around the world to collaborate with residential learners in fields as diverse as mechanical engineering and English literature. Their research demonstrates how small changes in protocol and technology can have profound effects on learning. An example is online multiple-choice exams. When the course developers added a form requiring students to explain why they picked the answer they thought was right, the multiple choice exam transformed into a sophisticated tracking tool to help the instructor know what students understood at any point in the semester.

Leifer's Learning Lab research also notes how small changes can alter student and faculty time-allocation to the course (sometimes taking more time than they can give). This brings up the often -repeated remonstration that students and teachers are also people, with complex lives, and that taking an online course occurs within that personal context. For both personal context and other individual difference reasons, the effects of technology are not uniform. And, as mentioned previously, every change begets another change, leaving us to study a moving target.

2.3. Digital Libraries

Digital libraries are a major development domain for I2. Donald Waters, Director of the Digital Library Federation, offers this definition: "Libraries are organizations that provide the resources, including specialized staff, to select, structure and offer intellectual access to, distribute, interpret, preserve the integrity of, and ensure the persistence over time of collections of intellectual works so that they are readily and economically available for use by a defined community or set of communities [16]."

Table 6. I2 Digital Library Projects

- Archeological Research Institute
- Baden-Wurttemberg Project
- Case Western Reserve Library
- CBS News
- Digital Library Federation
- Four Directions Virtual Museum Project
- Library of Congress
- Luthehalle Wittenberg Museum
- National Gallery of the Spoken Word
- National Museum of Ethnology
- National Palace Museum
- New York State History and Art Project
- Cyberzoo
- Pontifico Catholic University of Rio
- State Hermitage Museum
- University of Essen
- Vanderbilt Archive
- Vatican Library
- Virtually Hawaii
- Yale's Beinecke Library

Research foci for digital libraries include the basic processes of encapsulating and collecting diverse content and diverse data types for digital storage and online distribution; creation and analysis of search and browse mechanisms; development and application of metadata to enhance to value of the collections. Digital libraries must each define their purpose (i.e., to collect digital information, to support scholarly research, to serve the general public or particular constituencies). Not surprisingly, most digital libraries are primarily concerned with teaching and learning but focus instead on their collections and on scholarly research.

Digital libraries are working to increase the coherence, usability and accessibility to their large amounts of collected data. This includes study of interactions between learners of all ages and digital libraries.

The Middle Years Digital Library Project (MYDL) (http://mydl.eecs.umich.edu), underway at the University of Michigan's Center for (HiCE) Highly-Interactive Computing in Education, supports middle school children in carrying out science inquiry according to the national science guidelines put forth by the National Research Council and the AAAS. Using a digital library rather than the Internet (http://www.scienceseeker.org) as the repository to be searched, children develop their own driving questions (e.g., why do earthquakes stop? how did scientists discover sprites?) and then find resources registered in the digital library that pertain to their question. Furthermore, Artemis, the search interface, scaffolds (i.e., supports) children through the hard tasks of identifying good key words, saving intermediate results, etc. The MYDL is attempting to move children from doing searches to doing research.

Looking through the lens of technology enhanced learning, what impact does the online Library of Congress (or any other digital library) have on K-12 education? on college education? lifelong learning? For all but a handful of instances, the answer is probably none. Digital libraries parallel the larger Internet in their vastness and rate of expansion. The amount of available, high quality information resources grows continually, at a faster rate than the resources are being used. Unlike most of the Internet, the content of a digital library can be expected to be vetted, well-organized, accessible, and linked to commentary and metadata.

If digital libraries are to become more accessible and useful resources to enhance learning, teachers and learners first need to know about them. Perhaps a portal of libraries would be useful. Right now there is an "Information Portal for Science, Mathematics, Engineering and Technology Education" (http://www.smete.org/) directed toward educators and librarians. Currently it only links to five digital libraries. Some form node to interconnecting online libraries is necessary, so classes can simply "go to the library". This would be a step toward making it easier for people to know about and go to digital libraries.

It would also be useful to include e-Collaboration software to allow a digital reference librarian to guide teachers to useful collections, suggest possible lesson plans, and guide students to information and the objects they seek. Perhaps there is an "ask a librarian" button that opens a chat window at every digital library. Research on how this gets used would inform wider implementation.

2.4. Special Collections / Online Resources

Digital libraries are a special kind of online resource. Millions of others exist, on all manner of topics, with widely varied depth and authority. These range from major institutions such as museums, NASA and other government agencies to sites run by individuals.

Major institutions with an education outreach mission should implement live curators to help teachers and students use their site. They should co-develop, accumulate, and disseminate curriculum ideas and lesson plans and they could provide referrals to other resources when others better answer constituent questions. Participation in learning portals with other online resources of parallel authority and depth may help connect learners to learning experiences. Research should be conducted on how individual learners and classrooms use these online service.

Digital Video Portals provide windows to the world. Again the same recommendations apply. With I2's added bandwidth, it should be possible to create "I-Windows" – flat screen displays posted like picture frames dedicated to a particular (selectable, changeable) digital video portal. One I-Window might be open to a watering hole in Africa. Another I-Window might be focused on a pond in a children's garden. The I-Windows could be open all the time, like a window. Automated capture tools allow time-lapse retrieval of still frames throughout a defined measurement period.

In this way, a class could meet inside the textbook. Or at NASA headquarters. Situated learning takes on new meaning, and the pedagogical challenge is how to manage the richness of resources.

Subject matter portals such as The Math Forum (http://forum/swarthmore.edu/) are essential to informing teachers about online resources. The Math Forum's mission is to build an online community of teachers, students, researchers, parents, educators, and citizens with an interest in math and math education. They encourage communication throughout the mathematical community, make math-related web resources more accessible, provide high-quality math and math education content; offer model interactive projects, and "grow the web" by encouraging new sites.

Portals typically provide a brief description and link to a site. Experts could develop metadata, commentary and annotations to sites in their domain of expertise, and serve as an information resource to schools; even about sites they did not create and are not associated with. Software tools such as Third Voice allow annotation of third party web sites to happen today (http://www.thirdvoice.com/) but the tool is not well suited for expert commentary and K-12 learners. Common standards would make the time investment more worthwhile.

The One Sky, Many Voices Project (http://www.onesky.umich.edu/ is an exemplary online resource specifically targeted to K-12 inquiry-based learning about current weather and air quality. More than 10,000 children from around the world have participated in Kids as Global Scientists, four-week and eight-week programs around environmental themes. Students, teachers, parents and scientists can participate from classrooms, homes, after-school programs or other educational settings.

2.5. Virtual Laboratories

Much of I2 development has served to connect geographically dispersed teams of scientists through creation of collaboratories and virtual laboratories. The virtual laboratories include the Astronomy Group and Kit Peak, Remote Sensing, 4D Microscopy, and Nanomicroscopy.

The InVsee I2 project makes a Nobel Prize winning scanning probe microscope (SPM) technique available online for students and teachers to operate and learn about nanotechnology. Students and teachers can view the live system, look through a gallery of images taken by others, capture their own images, and explore learning modules. (http://invsee.eas.asu.edu/Invsee/invsee.htm)

On the opposite end of the scale spectrum, the MicroObservatory is a network of five automated telescopes that can be controlled over the Internet. Developed at the Harvard-Smithsonian Center for Astrophysics, the telescopes were designed to enable students and teachers nationwide to investigate the deep sky from their classrooms. Users are responsible for taking their own images by pointing and focusing the telescopes, selecting exposure times, filters, and other parameters. (http://mo-www.harvard.edu/MicroObservatory/)

Both scientists and students can use these virtual laboratories. Research (perhaps already conducted) could refine the description of how to offer an online virtual laboratory to a rare instrument and examine the impact of the tool on different classes and individuals. The resulting how-to manual could then be used to entice other collaboratories and virtual labs to open up an education outreach resource.

2.6. e-Collaboration

Exploring the web is usually a solitary user experience, void of other human presence even if 100,000 other people are concurrently reading the same web page. Browsing doesn't need to be solitary. Online learning, e-commerce, public relations, and museum/collection sites would all benefit from integrating e-collaboration in different ways.

This paper has discussed adding live human presence/resource person/guides to libraries, museums and other online learning sites. Expert annotation, commentary and other third party metadata have also been suggested. Middleware for children to be able to explore the web together, in teams, with the teacher being able to observe all of the groups and join them periodically would probably enhance classroom use of the web.

Email was the first collaborative killer app made possible by the Internet. Newsgroups and Listserves connect strangers with common interests, as do text and graphical chat rooms.

Instant Messaging is the latest online collaboration tool to achieve widespread adoption, connecting family, friends and co-workers. A variety of other new software tools are being introduced for messaging, co-browsing, screen sharing and other new forms of collaboration. The Michigan State University Comm Tech Lab has catalogued existing ecollaboration tools and is experimenting with ecollaboration for K-12 learning. (http://commtechlab.msu.edu/r&d/collaboration/) Few of the new tools have been widely adopted so far.

TAPPED IN, created by the Center for Technology in Learning at SRI, is an example specialized online collegial community of more than 5000 K-16 teachers, staff and researchers engaged in professional development. Members hold real-time discussions and classes, browse the web together, explore options, and interact asynchronously. (http://www.tappedin.sri.com/) Community and communication are incredible resources. But the cohort of individuals in a community needs to be carefully chosen and kept to manageable levels to ensure quality interactions. What is the optimal number and makeup of a collaborating group? What new tools might enhance collaboration?

We have only begun to realize the potential connectivity possible in a networked world. Parents, teachers, scientists, community leaders, friends, reporters – anyone can participate in a learning experience, particularly if it is online. Kozma and Shank [6] in their vision for twenty-first century education predict a model where schools, homes, the workplace, libraries, museums, and social services integrate education into the fabric of the community. Children learn to solve problems, work with others to develop plans, broker consensus, communicate ideas, seek and accept criticism, and generate joint projects. Connectivity and collaboration tools are needed to enable this shift.

2.7. Virtual Environments

The technologies for enhancing learning discussed so far are in some form available already. This last area of virtual environments and telemmersion is still in early research phases. The systems are extremely expensive, some costing millions of dollars. They include immersive virtual reality but also other forms of embodiment in virtual environments such as the Vivid Group's Virtual Theater system for networked high bandwidth group experiences (http://www.vividgroup.com/) Educational research happens only in a laboratory for a small number of learners. The June 1999 issue of the MIT journal, *Presence*, featured five research articles on education and immersive virtual reality. Details about each study are abstracted below as a means to generalize to the kinds of research on technologically enhanced learning one might expect for I2 applications.

2.7.1 NICE: Narrative-Based Immersive Constructionist/Collaborative Environments

Electronic Visualization Laboratory and Interactive Computing Environments Laboratory, University of Illinois at Chicago [12]

Funded by the National Science Foundation, DARPA (Defense Advanced Research Projects Agency) and the Department of Energy, this high-end demonstration project used a networked CAVE and Immersadesk to immerse fifty-two second grade children in a 3D world where they could "collaboratively plant and harvest fruits and vegetables, cull weeds, and position light and water sources to differentially affect the growth rate of plants." Teams of 7 to 8 students were split into two groups to use the Immersadesk and CAVE. The groups collaborated in the virtual space, lead by a randomly assigned leader for each group. A teacher-avatar also appeared in the world, to offer advice and ask questions.

The immersive VR systems innovated extensibility, moving beyond the limitation of being in the same room with an Immersadesk to being at a computer. They created a Java Applet

2D-environment interface that allowed students to join in the immersive experiences over the web, even if they were at home. This web interface also recorded the entire experience for future learning experiences.

Their evaluation schema looked at Technical issues (usability), Orientation issues (navigation, spatial orientation, presence and immersion, and feedback); Affective issues (engagement, preference and confidence), Cognitive issues (conceptual change/new skill), Pedagogical issues (content general and specific teaching techniques) and Collaborative VR issues (added value of collaborative VR to instruction and learning).

Prototype technologies are less mature than commercial technologies, and laboratory VR systems are rarely used with children. The stereo glasses were too big to fit on children's heads. Most of the children had to hold their glasses with one hand to keep them from falling off while using the other hand to control the wand. When they got tired they would take the glasses off. Only 5% experienced motion sickness.

Like most VR systems, navigation was unfamiliar and somewhat difficult to learn. The researchers felt collaboration was a double-edged sword that got in the way of science learning. Only the leader had a wand to control the experience and wear the stereo glasses. It turned out those who were assigned to be leader did better at getting spatially oriented if they listened to their own idea and ignored the different advice offered by other members of the class.

After collecting data, the authors concluded the most serious shortcoming was the inadequacy of the science model. Including umbrellas, sunglasses and facial expressions on plants and rain got in the way of the concepts. Students learned some things not correct and not intended to be taught.

2.7.2 Virtual Environments for Special-Needs Education

Virtual Reality Applications Research Team (VIRART)
University of Nottingham, UK [11]

Six special needs students between the ages of 7 and 11 participated in this observational pilot study, using three Virtual Learning Environments (VLEs): a virtual grocery store, a virtual house, and a Makaton communication system (using symbols to communicate simple concepts). The VLEs used 486 PCs running Superscape Visualizer to allow users to navigate through 3D worlds and interact with objects. The student and their regular classroom teacher were videotaped and observed using the VLEs together.

The authors note six characteristics of virtual learning environments:

- VLE use may encourage self-directed activity;
- VLEs are motivational;
- VLEs can offer Naturalistic Learning;
- VLEs can provide a safe space in which the student can experiment;
- Desktop VLEs offer shared public experiences;
- VLEs can act as equalizers of physical abilities.

Adapting Jonassen's seven principles of constructivism [7] to use in evaluation, they looked at how well their VLEs:

- Represent the natural complexity of the real world;
- Focus knowledge on construction, not reproduction;
- Present authentic tasks;
- Use case-based rather than predetermined sequences;
- Foster reflective practice;
- Enable context-dependent knowledge; and
- Support collaboration through social negotiation.

According to the theory, following these guidelines should result in VLEs that enhance and facilitate the learning process. A behavioral coding scheme was developed and applied to the videotapes, counting behaviors related to the seven constructivist principles.

One finding was that individual differences in teaching style of the teacher elicited different results. Like the NICE study, this one concluded that complexity of tasks in VLEs should be increased to the levels experienced in the real world -- but also not any more difficult than the real world.

2.7.3 Student-Built Virtual Environments

Human Interface Technology Laboratory
University of Washington [17]

Funded by US West, 365 students in grades four through twelve from fourteen schools build VEs (virtual environments) to demonstrate some concept related to wetlands ecology and the interaction of objects such as nitrogen, carbon, water, and the energy cycle. These researchers also invoke constructivism and constructionism, positing "the expression of mental models as objects that can be inspected and handled offers powerful advantages for solving problems and building understanding."

Three workshops prepared students and teachers for the 6 to 10 week period of project planning, modeling, programming, and experiencing. Project staff did most of the programming. Projects included:

- Tree World: make a sick tree healthy with sunlight, water and nutrients
- Space Station (recycling)
- Castle;
- Rain Forest;
- Endangered Species;
- Washington State

15% reported some degree of motion sickness. Students who relied on simplistic metaphors in their designs seemed to be limited by the metaphors. They tended to undergeneralize principles to fit the metaphor. The authors suggest that a sense of presence contributes to enjoyment and to the ability to move around in a VE. Helping other students aided learning for the helper, but not for the helpee. Low ability students improved more than high ability students did.

2.7.4 Project ScienceSpace: How VR Aids Complex Conceptual Learning

Human Factors and Applied Cognitive Psychology
Graduate School of Education
Virtual Environment Technology Lab
Computer Science
George Mason University and University of Houston [14]

This group is interested in applying VR for envisioning abstract phenomena -- to help students reify or perceptualize abstract models. Specifically in the realm of physics, perceptions and conceptions of physics phenomena are often incorrect. NewtonWorld (nature of mass, acceleration, momentum as well as Newton's laws and laws of conservation) addresses areas of common misconception for physics students, MaxwellWorld and PaulingWorld have been designed to aid users in understanding abstract information spaces.

They focus on three VR features to maximize the learning of abstract models: 3D immersion can support more learning than 2D; multiple and flexible frames of reference (FORs, or, spatial metaphors), and multisensory cues also enhance learning. They posit a model of how VR features impact learning outcomes, mediated by learner characteristics, the particular concept to be learned, and also the characteristics of the learning experience. For example. Flexible frames of reference increase motivation. Simulator sickness and poor usability inhibit learning.

To construct new worlds, these designers rely on a combination of domain expertise, educational research and research with students to identify the concepts they want to teach and to understand learner needs. Within that domain they select the concepts most suitable for the VR environment.

The research included both small and large samples. Nine students evaluated NewtonWorld initially. The prototype testing resulted in revisions to the design including addition of sound and tactile cues, energy cues to represent velocity and energy, and additional points of reference in the scene. They discovered that designing for learning an designing for interaction is not always congruous tasks. Next they conducted a survey of 107 physics educators and researchers who were experts in the field. Teacher feedback resulted in more iterative changes in the design of Maxwell's World. Thirty high school students participated in the next phase of research, using a range of user interface devices to perform a series of typical and critical tasks, thinking aloud as they did them and then completing a questionnaire. The research project began with a model, implemented a learning experience, and tested prototypes iteratively revising after each phase of data collection.

This group analyzed four dimensions: Learner characteristics; Interaction Experience; Interaction Experience repetition and Learning. They considered VR Features and the interaction experience as well as learner characteristics and the interaction experience.

2.7.5 Virtual Zoo Exhibit

College of Computing
College of Architecture
Georgia Institute of Technology [3]

This virtual learning experience was based initially on a previous Zoo Atlanta VR exhibit in which the visitor became an adolescent male gorilla and tried to approach virtual adult gorillas to see how they responded. Middle school children did not learn as much as the designers had hoped, most likely because the experience was too unstructured. When a guide pointed out behaviors and made suggestions, more learning occurred.

The next time, instead of middle school children, the immersive environment was intended to teach college students the design principles used in constructing an animal habitat within a zoo setting as part of a college course on environmental design.

Based on previous experiences, the authors now believe success depends on producing a satisfactory and believable experience for the user. In addition they recommend tightly coupling experiential learning with embedded abstract information in the virtual environment. They call this combination an information-rich environment. Student assessment of the system was overwhelmingly positive. None of the differences in test scores of learning performance were statistically significant.

For the study, 24 students were divided into three groups:

- CONTROL = normal (n=5)
- INFO GROUP = explore habitat then gather info within VE (n=8)
- HABITAT GROUP = Lectures plus VE but not embedded information (n=3)

The outcome-measure comparisons were not statistically significant.

The project used some interesting design elements. Voiceholders or cubes were placed in the 3D environment and would start an audio clip when the user grabbed them. Static gorillas helped illustrate concepts and give a sense of scale. (This makes sense for designing a gorilla exhibit, but could be quite humorous in other worlds as well!)

They also innovated a navigation interface designed to prevent users getting lost or disoriented. In addition to a helmet, users held a tablet in their nondominant hand and a stylus in their dominant hand. A map of the environment was projected onto the virtual representation tablet. Children could click the stylus on the location they wanted to get to. When they release the stylus button, the system flew them to the chosen location. Navigation was easy, but users tended to face only one direction, needing to be reminded that they could look around. For pointing at and selecting objects a virtual ray of light was found to be nearly ideal for selecting an object although not for manipulating objects.

3.0 Technology Promise and the Real World

Internet 1 is already commonplace, while Internet2 is experimental. What's the reality of Internet 1 penetration in public schools?

In 1998, 90% of public schools had at least some access to the Internet [2]! The number continues to grow. Looking closer at the classroom rather than school level, 39% of teachers had Internet access in their classrooms.

Having access in the classroom does not necessarily equal use. Twenty-six percent of elementary teachers have actually used the World Wide Web in their classrooms. Twenty-six percent of middle school teachers do so. Thirty-four percent of high school teachers have used it.

Some teachers use the Internet to prepare lessons.
Twenty-eight percent of teachers use the Internet themselves weekly, or more often, to find information to use in lessons. Thirty-two percent do not use the Internet at all in preparing lessons; forty percent do so occasionally. In other words, nearly three fourths of teachers do not regularly use Internet 1 to prepare for teaching.

Some teachers make creative, extensive use of the World Wide Web. Eighteen percent have posted information for students; seven percent of teachers had students email at least three times in a year; four had kids publish on the web.

Internet 1 may touch some K-12 teachers and their students deeply, but it impacts the majority of K-12 teachers and their students hardly at all. Other research by the same authors suggests computer technology is more likely to be welcomed and used by teachers who embrace constructivist-compatible teaching practices. "However, changing other teacher's philosophies and beliefs to be more constructivist simply by having them use computers may not work [2]."

Elliot Soloway's HiCE (Highly Interactive Computing in Education) group has been studying what it really takes to put technology in real K-12 schools in Detroit and Chicago [15]. His goal is routine, daily use of computational media and technology in a modeling-intensive, project-based science classroom. Nationally, the average high school student uses a computer 30 minutes a week, or about 19 hours a year. Students in the HiCE program each used the ClarisWorks program alone for over 130 hours during the pilot year.

However, Soloway challenges Internet2 to actually do what Internet 1 promised. Access and speed of access with Internet 1 is not guaranteed. In Detroit schools the Internet doesn't work. Teachers face a 50/50 chance that Internet in a computer lab will not work when they go to use it with their class. In the classroom, it's a thirty- percent chance of working. The question is not how many Internet connections there are in schools, but how many Internet connections are there that work.

Two HiCE projects focus on methods of studying and changing public school organizations to move technology adoption processes from politics to engineering. Chicago and Detroit provided one centralized and one decentralized school system and it turns out the equation for introducing technology is different. Centralized school systems, work with IT professionals. Decentralized school systems make decisions independently. In both cases, a key recommendation is to bring IT and curriculum people to the table so that curriculum needs are integrated into technology planning.

4.0 Concluding Comments

The domain of technology-enhanced learning research is vast. Each of the subsections in this paper could be a paper unto itself, identifying more specific key research issues in that domain.

Writing this paper made clear to me how difficult it is to locate a comprehensive list of I2 projects. The National Library for Applied Network Research (NLANR) hosts on online database currently with 147 projects (http://dast.nlanr.net/) last updated in April 1999. Some are and some are not I2 projects, and it is hard to tell how complete the list is. Fields in the database include Status, Description and Usage. Sociotechnical dimensions are *not* part of the database. (NLANR should consider adding *sociotechnical issues and research* as a database field for all projects.)

The Digital Library Federation lists twenty-two partner institutions, and coordinates initiatives across those partners. However even they do not have a listing of digital libraries. I2 management itself should maintain an active online I2 and related projects database which includes sociotechnical considerations.

Some I2 projects are conducted by education scholars but most are developed by engineers and content experts. Education researchers might consult with emerging I2 projects to identify areas of potentially fruitful research and to provide education research expertise. Some projects already developed by engineers and content experts present opportunistic research test beds. Other I2 projects should be developed with education researchers as key participants from their inception.

Nora Sabelli, Senior Program Director for NSF, describes different outcomes that drive technology-enhanced learning research [13]: theory building, building the knowledge base, and establishing education practice. She calls for research on education practice to be systemic, research on education policy to be credible, and long term reform research to be achievable, fundable, and lead to *demonstrable, sustainable* and scalable outcomes.

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