Improving Undergraduate Education in the Mathematical and Physical Sciences Through the Use of Technology

Report to the National Science Foundation

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Credits

The Workshop on which this Report is based was organized by an External Steering Committee (ESC), working with colleagues at the National Science Foundation (NSF) from the Directorate of Mathematical and Physical Sciences (MPS) and the Division of Undergraduate Education (DUE) of the Directorate for Education and Human Resources (EHR). The ESC is especially grateful to Drs. Henry Blount (MPS / NSF) and James Lightbourne (DUE / NSF) for their support and encouragement in developing the Workshop and to the NSF for providing funds for this project.

External Steering Committee

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At Madison, we are grateful to colleagues in the Wisconsin Center for Education Research (WCER) and the NSF-funded National Institute for Science Education (NISE), directed by Dr. Andrew Porter, for providing additional support to organize the Workshop and the ensuing investigation of its themes.

In particular, we thank Patricia Blaschka, Jerry Grossman, Christine Lee, Sally Lesher, Ingrid Rosemeyer, Sandy Treptow, Paula White, and Sandy Yulke for their assistance with logistical issues.

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Note: Comments on this Report can be sent to Arthur Ellis (ellis@chem.wisc.edu) or posted on the Workshop's interactive Web board (www.wcer.wisc.edu / teched99 / webboard.htm).

Foreword

This report summarizes results from a two-year effort that began with the planning of the ***Workshop on Improving Undergraduate Education in the Mathematical and Physical Sciences through the Use of Technology*** and continued with over a yar of follow-up activities subsequent to the workshop. This effort has been co-sponsored by two NSF Directorates: Education and Human Resources (EHR) and Mathematical and Physical Sciences (MPS). The EHR portfolio of programs to improve education and training in science, mathematics, engineering, and technology advances the vision and goals of NSF's Strategic Plan in all areas of science and engineering supported by Foundation. MPS supports a diverse portfolio of research and education in astronomy, chemistry, materials research, mathematical sciences, and physics. This two-year effort represents another instance in which the missions of EHR and MPS complement and support each other, as part of the fundamental NSF strategy to improve both research and education through their integration.

The NSF portfolio of programs and areas of emphasis reflects the Foundation's continued commitment to support and promote the effective use of technology to improve student learning. Research on IT-enables tools that facilitate and enhance learning opportunities across many levels of formal and informal education, and the development and testing of these tools, will remain a high priority.

We recommend this report to you. It includes a 'snapshot' of technology-enriched undergraduate education in the mathematical and physical sciences, a vision for the future that embraces all students and faculty, and recommendations to lead us toward this vision.

On behalf of NSF, we express our appreciation to the leaders of this effort and the participants who contributed through the Workshop and during the subsequent dialogue.

Robert A. Eisenstein
NSF Assistant Director for
Mathematical and Physical Sciences

Judith S. Sunley
NSF Assistant Director (Interim) for
Education and Human Resources

The Workshop on Improving Undergraduate Education in the Mathematical and Physical Sciences through the Use of Technology was held at the National Science Foundation, July 20-22, 1999. Approximately 80 invited participants from a broad spectrum of postsecondary institutions, industry, government laboratories, state and federal agencies, and private foundations met to discuss the impact of technologies ranging from databases to digital libraries to sensors to distance learning in undergraduate mathematical and physical sciences (MPS) instruction. These developments are redefining both the tools and boundaries of undergraduate MPS education, whose objectives are to promote science literacy and lifelong learning, and to develop a diverse, skilled technical workforce. The Workshop participants are leaders in areas that contribute to, and are impacted by, these technological advances. In addition, the Workshop launched a year-long effort to study further the effective use of technology in college MPS courses.

Technology is a rapidly moving target whose introduction into undergraduate MPS classrooms and laboratories involves a complex interplay of technological, pedagogical, political, and economic issues. The charge to the Workshop was to provide a “snapshot in time” of the use of technology in college MPS courses, a vision for the appropriate role of technology in these courses, and recommendations for how to achieve this vision. This Report summarizes the Workshop’s activities, vision, and recommendations and results from the subsequent year-long study.

A “snapshot” of technology-enriched undergraduate MPS education

A series of presentations and discussions revealed breathtaking scope in the use of technology in undergraduate MPS education. Participants heard about the benefits of student-centered learning and how it is being promoted by new forms of technology-equipped classrooms and laboratories; how students and instructors are assessing student learning on-line through customized instructional software; how technology is permitting state-of-the-art research instrumentation and tools maintained at one location to be shared across the nation for use in classes and for original student research; how MPS instructors and their students are collaborating in coursework and in collecting, analyzing, and sharing data across disciplinary, institutional, and national boundaries using technology; and how academic institutions are developing technology-based hubs that connect them to industry, government agencies, and private foundations in an effort to bring MPS education and research results to broader student and community audiences.

Enthusiasm for these powerful new technologies was tempered with concern over their effectiveness and cost. Evidence from cognitive and behavioral sciences suggests that students often do not learn from technologies as well as MPS instructors believe they do. Assessment and evaluation of technology-enriched courses are in their early stages of development, but examples were provided that many students do not want to use available technologies or may use them inappropriately. Some institutions cannot afford to provide access to certain technologies. There is also evidence of differential impact, with students from some population groups alienated by the manner in which new technologies are used. The current structure of rewards in academia can create disincentives to efforts to introduce technology effectively into MPS undergraduate education.

This “snapshot” reflects an undergraduate MPS educational enterprise that has historically been static and has only recently begun to experiment with new content and pedagogical methods. The Workshop created a vision of a dynamic technology-enriched MPS undergraduate educational enterprise and developed recommendations for achieving it.

A vision for technology-enriched undergraduate MPS education

The vision that emerged from the Workshop is that the undergraduate MPS educational enterprise should have a vitality commensurate with that of the MPS research enterprise, and a reach that effectively embraces all students and instructors. An “integrated research” model for undergraduate MPS education would use technology as the research enterprise uses it — as part of continuous experimentation to identify better ways to create and communicate MPS knowledge and methods.

This dynamic undergraduate MPS enterprise would be characterized by a continuous stream of new instructional tools and methods, whose pedagogical value is informed by research studies from the cognitive and behavioral sciences, whose efficacy is monitored by critical assessment and evaluation tools, and whose reach can accommodate diverse student learning styles.

Supporting this vision is an academic culture that rewards the scholarship associated with creating and implementing effective technology-enriched MPS undergraduate education, recognizes the importance of multidisciplinary approaches to MPS education, supports mechanisms for continuous professional development of current and future MPS teachers throughout the educational system, and promotes efforts to share MPS knowledge with society as a whole.

Recommendations for technology-enriched undergraduate MPS education

Implementing this vision requires systemic partnerships, as undergraduate MPS education is intimately linked to K-12 and graduate education, the workplace, and the community. Implementation also requires an infrastructure that parallels that of the research enterprise, which is nurtured by a culture that promotes experimentation and provides resources and rewards for it.

Specific recommendations are to:

- Foster an “integrated research” model for undergraduate MPS education.

  The MPS community should couple research and technological advances more tightly to its educational missions. These advances create an opportunity to update the curriculum continuously, keeping it perennially fresh and exciting.

  Technology should be used to expand research experiences so that, ideally, all undergraduates can develop an understanding of MPS research methods and tools.

  The use of new MPS research results and technologies in undergraduate classrooms and laboratories should be informed by results from the cognitive and behavioral sciences and by critical assessment and evaluation methods. These studies should be recognized by the MPS community as an important field of scholarly research.

Achieving such an “integrated research” model requires partnerships with the MPS research enterprise, with educational product developers and distributors, with cognitive and behavioral scientists, with schools of education, and with professional organizations.

- Broaden MPS academic scholarship to include the scholarship of teaching.

In partnership with campus administrations, MPS faculty should take a more proactive role in creating and critically implementing technology-enriched education. Campus administrators and senior faculty can create a culture that encourages faculty to bring appropriate technologies into their courses by publicizing successful technology-enriched courses, by presenting meaningful examples of how well they work, by providing the resources and training to implement these changes, and by valuing these contributions as essential to the academic mission of the institution. The co-sponsorship of this workshop by the NSF research directorate for MPS indicates the priority of that directorate to engage the MPS research community in effective uses of technology in education.

Promotion of interdisciplinary scholarship, which can enrich MPS education, should be a campus priority.

Academic institutions need to facilitate the gathering of statistics, including longitudinal databases, that can help evaluate the success of instructional projects. Technology can potentially improve student performance, persistence, and attitude, by providing assistance with articulation, advising, and tutoring.

- Support teacher professional development.

Partnerships of the broad MPS community with K-12 teachers and teacher education programs should be supported, as they provide exciting opportunities for teacher professional development, including the preparation of new instructional materials for the K-12 curriculum based on MPS research and technologies.

College MPS instructors need to communicate to MPS majors that K-12 teaching is a valued career choice, and should work with teacher education programs to prepare students for teaching MPS subjects effectively, using appropriate technology.

MPS graduate students should be involved in the development and delivery of technology-enriched instructional materials.

- Strengthen links to the workplace and community.

The MPS community should work with employers to obtain continuous feedback on how well their students have been educated in the MPS disciplines, and to inform efforts to incorporate technology into MPS undergraduate instruction. Using technology to share projects and courses among academic institutions, industry, and national laboratories has great potential for increasing access to resources in MPS education and should be promoted.

At the community level, there should be support for expanding the availability of MPS instructional materials to non-traditional students through distance learning systems, and for giving citizens access to MPS research tools and results using the World Wide Web. These initiatives represent extraordinary opportunities to make MPS research and technologies a more meaningful part of daily experience.

- Treat all students as partners, ensuring equity and access.

  The ability to learn through technology and to use technology is now a core competency. In partnership with the K-12 community, institutions have the responsibility to ensure that all students have the technological foundation to learn in their restructured, technology-inclusive curricula.

  Women and students of color, who have historically been underrepresented in the MPS disciplines, are at risk in that technology may create new barriers to their participation. Resources should be directed toward learning how technology affects recruitment of students from underrepresented groups to MPS disciplines, and how it affects their retention in these disciplines. Promising solutions may come from technology, as in the creation of learning communities and more effective advising. Such solutions, once identified, should be strongly supported.

- Invest in technology wisely.

  As the examples above indicate, technology provides almost unlimited choices for investing in undergraduate MPS education. There are likewise a multitude of opportunities for partnerships through which funds can be leveraged. Given the high cost associated with many technologies, it is imperative that information about what is and what is not effective be shared quickly and widely so that our limited resources can be used prudently. The high stakes associated with the undergraduate MPS educational enterprise demand our best efforts to make wise investments.

Undergraduate MPS education is critically important to our society, as it shapes attitudes toward science and influences career trajectories. Without question, technology is profoundly altering what we can teach in college MPS courses and how we can teach it. If undergraduate MPS education in the 21st century is to reflect the vigor and effectiveness of the MPS research enterprise, the systemic partnerships outlined above are the foundation upon which to build it.

Introduction to the Report

Breathtaking advances in technology are having a profound effect upon the way instructors can teach and students can learn mathematics and the physical sciences (MPS) in college curricula. Databases, digital libraries, modeling software, sensors, and other current and emerging technologies are redefining both the tools and boundaries of MPS education. Analyzing current and potential capabilities of these technologies associated with teaching and learning involves a complex interplay of technological, pedagogical, political, and economic issues.

In many respects, the emergence of these new technologies affords an opportunity to enhance student learning across the broad spectrum of post-secondary educational institutions and MPS disciplines, and to create a more learning-focused culture in the MPS undergraduate instructional community.

To explore such issues in detail, leaders from areas that contribute to these technological advances convened at the National Science Foundation from July 20 to 22, 1999. The Workshop consisted of the following eight sessions:

1 **"What are the issues?"** A "big picture" overview of the Workshop theme
2. **"What's out there?"** A sampling of the state of the art in information technology
3. **"What works and how do we know?"** Assessment and evaluation issues
4. **"What are the principles underlying the effective use of technology?"** A cognitive science perspective
5. **"What are new paradigms for undergraduate research?"**
6. **"Where are we going? The brave new world and pitfalls"**
7. **"Where are we going? Institutional and Infrastructural perspectives"**
8. **"How do we get there?"**

This report updates the Preliminary Report on the TechEd99 Workshop that was issued in the Fall of 1999. Participants who made presentations at the TechEd99 Workshop were invited in the Spring of 2001 to update their section of the report to reflect new developments. Their edits are indicated in italics. The TechEd99 Workshop was also used to launch a year-long effort by the NSF-funded National Institute for Science Education (NISE) to study key elements of the effective use of technology in college SMET courses. This effort and the resulting Web site, Learning Through Technology (LT^2), are briefly summarized in this Report along with some related developments. The Resources section of the Appendix, which consists of an annotated list of useful Web sites, has been updated; all Web sites that were accessible as of June 1, 2001 are included.

The preparation of this Report highlights how rapidly the undergraduate MPS educational landscape continues to change through use of technology. To encourage timely and continuing dialog on the many important issues raised at the TechEd99 Workshop, this Report is posted on the web at http://www.wcer.wisc.edu/teched99. We invite you to share your thoughts on these issues with your colleagues.

Workshop agenda

Tuesday, July 20

8:30 Continental breakfast
9:00 Welcome and Workshop Objectives
Robert A. Eisenstein, Assistant Director, Directorate for Mathematical and Physical Sciences
John B. Hunt, Deputy Assistant Director, Directorate for Education and Human Resources
Arthur Ellis, University of Wisconsin-Madison
9:30 "What are the Issues?" A "big picture" overview of the Workshop theme
Session Chair: Jeanne Narum, Project Kaleidoscope
Manuel Gómez, University of Puerto Rico
Jack Wilson, Rensselaer Polytechnic Institute (RPI)
10:30 General discussion
10:45 Coffee break
11:00 "What's Out There?" A sampling of the state of the art
Session Chair: Jean-Pierre Bayard, California State University at Sacramento
Theresa Julia Zielinski, Monmouth University
Kelly Keating, Pacific Northwest National Laboratory
David Pritchard, Massachusetts Institute of Technology (MIT)
Noon General discussion
12:15 Lunch

1:15 Breakout session on "What's Out There?"
2:45 General discussion
3:15 Coffee break
3:30 "What Works and How Do We Know?" Assessment and evaluation issues
Session Chair: Deborah Moore, University of Puerto Rico at Mayaguez
Harvey Keynes, University of Minnesota
Gloria Rogers, Rose-Hulman Institute of Technology
Steve Ehrmann, Director, Flashlight Project, American Association for Higher Education
4:30 General discussion
5:00 End session
5:30 Reception at Arlington Holiday Inn

Wednesday, July 21

8:00 Continental breakfast
8:30 Reflections on Tuesday sessions
Robert Chang, Northwestern University
Arnold Ostebee, St. Olaf College
Josefina Arce, University of Puerto Rico
9:00 "What are the Principles Underlying the Effective Use of Technology?"
A cognitive science perspective

Session Chair: Susan Millar, University of Wisconsin-Madison
Andrea diSessa, University of California, Berkeley
Phil Kellman, UCLA
Marcia Linn, University of California, Berkeley

10:00 General discussion
10:15 Coffee
10:30 Breakout session
11:30 Discussion with session speakers
12:00 Lunch

1:15 "What are new paradigms for undergraduate research?"
Session Chair: Rex Adelberger, Guilford College
Ray Turner / Paula Robinson, Roxbury Community College
Preethi Pratap, Haystack Observatory
Michael Doyle, Research Corporation and University of Arizona

2:15 General discussion
2:45 Coffee break
3:15 "Where are we going? The brave new world and pitfalls"
Session Chair: Fennell Evans, University of Minnesota
Richard Larson, Massachusetts Institute of Technology (MIT)
Philip Agre, UCLA

4:15 General discussion
5:00 End session

Thursday, July 22

8:00 Continental breakfast
8:30 Reflections on Wednesday sessions
Marco Molinaro, University of California, Berkeley
John Jungck, Beloit College
Christine Massey, University of Pennsylvania

9:00 "Where are we going? Institutional and Infrastructural Perspectives"
Session Chair: Edward Davis, DuPont Experimental Station
Frances Houle, IBM
Maria Klawe, University of British Columbia
Gary Wixom, Utah System for Higher Education; Richard Cline, Utah Educational Network; Todd VanderVeen, University of Utah, Center for High Performance Computing

10:15 General discussion
10:30 Coffee
10:45 Breakout session
11:45 Breakout reports and responses from speakers
12:15 Lunch
1:00 "How do we get there?" Breakout sessions
2:00 Reports from breakout sessions
3:00 Concluding remarks and adjourn

Workshop session summaries

Introductory remarks

Robert A. Eisenstein, Assistant Director, Directorate for Mathematical and Physical Sciences, National Science Foundation

Eisenstein welcomed the participants and introduced NSF, particularly the Directorate for Mathematical and Physical Sciences (MPS). MPS supports research in many very exciting areas of physical science and mathematics. This work, being at the forefront of science, provides an excellent background for a wide variety of educational activities that relate to the physical sciences. MPS prides itself on providing research experiences for students and instructors across a broad spectrum of post-secondary institutions. MPS also supports international postdoctoral fellowships, technology-enhanced education, curriculum development, and research sites for educators in chemistry.

Eisenstein encouraged participants to explore the MPS Web page within the NSF Web site (www.nsf.gov/home/mps/).

John B. Hunt, Deputy Assistant Director, Directorate for Education and Human Resources, National Science Foundation

Hunt greeted the participants and thanked them for attending. As evidence of the challenges associated with teaching with technology, he cited a recent Milken Foundation report stating that the majority of professors of education do not know how to use or teach about educational technologies.

Hunt said that a recent report published by the National Academy Press called "How People Learn: Brain, Mind, Experience, and School" could help inform the MPS instructional community about relevant findings from the behavioral sciences.

Hunt reinforced the EHR directorate's strong support of undergraduate MPS research and emphasized the need to consider the impact of technology on teacher preparation.

Arthur Ellis, University of Wisconsin-Madison

The charge to the Workshop is to provide a “snapshot in time” of the use of technology in college MPS courses, a vision for the appropriate role of technology in these courses, and recommendations for how to achieve this vision.

The MPS research enterprise has great vitality, producing a stream of exciting research advances, many of which lead to widely used technologies. The pocket laser is an example: a product of basic research, the laser has provided new research and teaching tools, and is now commonly used as a presentation pointer.

By comparison, until recently the undergraduate MPS educational enterprise has been nearly static, with little change in content and delivery over a period of decades. Within the past decade, however, undergraduate MPS education has increasingly become the same kind of moving target as the research enterprise, with much of its vitality derived from the introduction of new technologies.

As in research, technology has facilitated the development of a community. Instructors have historically taught largely in isolation from their colleagues, but increasingly they are sharing information. A few years ago, describing a modified class to a colleague would have been done at “low resolution,” by sending a paper syllabus. Today, with the Web, lessons, labs, problem sets, exams, and even class photos can be shared immediately at “high resolution.” And sharing can occur across disciplinary, institutional, and national boundaries. As these changes take place, we are increasingly seeking ways to assess and evaluate whether our changes are benefiting our students.

Undergraduate MPS instruction plays a critical role as a systemic “pressure point,” in that changes made in these courses can influence many other parts of the educational enterprise. There are important connections, for example, to K-12 education, teacher preparation, outreach to various communities, and to the workplace. These links provide an opportunity for developing powerful partnerships that can be used to enhance science literacy for all students and citizens, and to attract a diverse group of talented students to technical careers in MPS and related fields. Undergraduate MPS education has benefited from having flexibility in what instructors teach and how they teach it, and from access to resources that allow the use of new ideas and technologies. This is not universally the case, however, and there are important issues associated with equity and access, particularly as new technologies are introduced.

Many of the Workshop participants have contributed to dramatic developments in undergraduate MPS classrooms and laboratories, and their perspectives can help the MPS community understand key issues associated with the use of technology in these learning environments. The Workshop Report is an attempt to capture the current landscape, to articulate a vision for technology-enriched undergraduate MPS education, and to make recommendations for future developments and investments that wisely use our financial and human resources.

"What are the issues?" A "big picture" overview of the Workshop theme

Session Chair: Jeanne Narum, Project Kaleidoscope

Manuel Gómez, Vice President for Research and Academic Affairs, University of Puerto Rico, "Information and computing technologies converge with the need for a paradigm shift in the teaching/learning process at the crossroad of the 21st century"

Gómez compared the growing use of technology in MPS teaching and learning to the introduction of perspective into Renaissance painting. Artists radically changed their style because of their dissatisfaction with a flat representation of the world. MPS instructors are changing their teaching styles to accommodate new technologies and external pressures.

These pressures are being generated by: the transition to the knowledge economy, which places new demands on skills that a student must acquire in college; changing demographics of the last 50 years (college enrollment has increased from 1.4 million to 13 million); and, the increased popularity of information technologies and the Internet. Yet, a true paradigm shift has not taken place in the way we teach.

While the general population and the business sector have embraced the Internet, higher education has been slower to respond. Society no longer needs encyclopedic knowledge that is centered on content, mastery of algorithms, and traditional models. Instead, society needs graduates who can think critically, analyze, synthesize, design new solutions for problems, and correctly interpret models and fast-changing information. The future work-life will consist of several careers, each requiring new skills, attitudes, and values. The essential goal of higher education, therefore, should be the formation and nurturing of independent, lifelong learners who master higher-order cognitive skills. Traditional teaching and learning methodologies must be altered accordingly.

Evidence suggests that the average student does not master the necessary cognitive skills to become a true independent learner. A specific example is the Force Concept Inventory test, which is used in introductory physics to test for mastery of thinking with fundamental physics concepts. The test showed that the value of the Introductory Physics course was almost nil, because students were unable to apply concepts to predict the behavior of physical objects. Why? The course is traditionally designed with respect to content, mastery of algorithms, and the memorization of standard models and theories, not for the development of cognitive skills that enable independent learning. Too much content is taught under spatial and temporal constraints that do not permit the development of higher-order thinking skills.

Figure 1a shows what happens in a traditional course for the average student. The student struggles for understanding amid a barrage of new concepts. The constraints of space and time, and the emphasis on mastering content, impede the development of independent learning skills. After the course ends, the student retains only a few loosely connected concepts and algorithms. In Figure 1b, by contrast, the curriculum has been redesigned to develop cognitive skills that harness the content to the fundamental concepts needed to think within the discipline. The course has been retooled to use new technologies and the findings of cognitive science research.

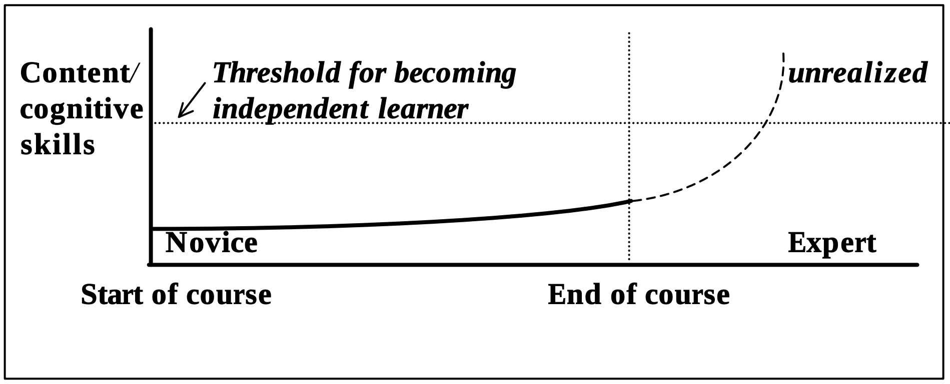

Figure 1a. Learning curve in traditional, teacher-centered, textbook curriculum

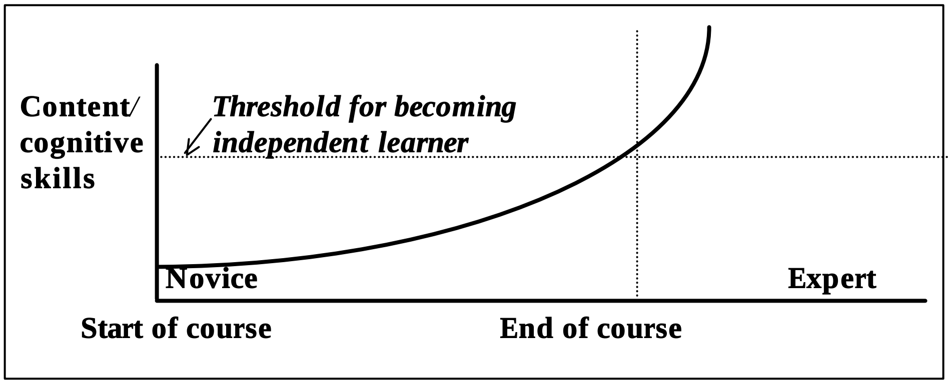

Figure 1b. Learning curve in student-centered, technology-enriched curriculum

Technology should provide a nurturing learning environment, where students can explore and experiment with concepts, models, and algorithms to construct knowledge, just as researchers would in a laboratory. By using technologies properly, the learning curve can be raised so students can become self-sustaining, independent learners.

There are many examples of how technology can develop independent learners, particularly a well-known study by Eric Mazur of introductory physics. In all cases, improved student performance was achieved through a holistic approach to educational reform, by changing curriculum and teaching/learning styles, and by incorporating technology to achieve carefully defined educational goals. (More details on these experiments are available from Gómez at **m_gomez@upr1.upr.clu.edu**.)

We have also learned much about diverse learning styles. Information technologies can help address this diversity by freeing the educational process from the constraints of linear written materials, the 50-minute lecture, and the “snapshot” evaluation process. Technologies allow the introduction of alternate assessment tools, which permit student assessment of their own progress and longitudinal views of how students master cognitive skills and content. This is what the knowledge economy demands, and if we as professors don’t do it, somebody else will.

Jack Wilson, Rensselaer Polytechnic Institute (RPI), "Creating new learning environments for higher education"

Wilson opened his presentation by listing his "10 commandments" for developing new learning environments in higher education:

1. Restructure around the learner. Neither over-emphasize nor under-emphasize technology.
2. Build upon research results, which inform design; don't try to reinvent the wheel.
3. Remember that technology has an intrinsic educational value beyond helping students learn better.
4. Do systematic redesign and not incremental add-ons.
5. Benchmark your plans and build upon examples of systematic redesign.
6. Count on Moore's law ("What is hard today is easy tomorrow"). For example, computer processing power and bandwidth have consistently improved.
7. Cost is an important aspect of quality. There is no lasting quality if there has been no attention to cost.
8. Avoid pilots that linger. Design for a large scale and pilot only as a prelude to scaling up.
9. Develop a balance between synchronous and asynchronous distributed learning.
10. There is no longer any way to do good science without technology, and there is no longer any way to teach good science without technology.

The three drivers for change are computing, communication, and cognition.
The Workshop focused on the growing region of convergence among these three components.

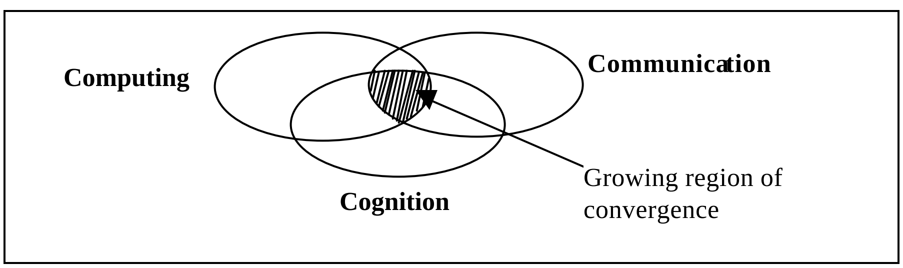

Figure 2. Regions of convergence discussed at Workshop

There are many "bright spots" — current teaching methods and curricula that others can use as inspiration and encouragement:

- Lecture-based models: Active learning physics systems (Ohio State); Peer Instruction / ConcepTests (Harvard); Interactive Demonstrations (Oregon)
- Studio / Workshop models: Workshop Physics (Dickinson); The Physics Studio (RPI); Physics by Inquiry (Washington)
- Lab models: Tools for Scientific Thinking (Tufts-Dickinson); RealTime Physics (Dickinson-Oregon)
- Recitation models: Cooperative Problem Solving (Minnesota); Tutorials in Introductory Physics (Washington); Mathematical Tutorials (Maryland)
- Distributed Education models: Sloan Asynchronous Learning Network; ILINC LearnLinc; many Web-based approaches

RPI's approach to new learning environments consists of the following elements:

- Replace traditional, large lectures with studios of 48 to 64 students each. These studio courses break up classrooms into smaller, more active units that de-emphasize the traditional lecture format, and combine elements of lectures, recitation, and laboratory. The studio course uses a constructivist approach, multimedia courseware, and a theatre-in-the-round classroom. It offers a multi-point, collaborative approach through the use of audio and video.
- Change the core curriculum to a 4 x 4 curriculum (i.e., four 4-credit introductory courses for freshmen). This approach represents a break from the traditional six core courses of three credits each.
- Expand into new markets with distributed (distance) learning.
- Create a faculty of information technology drawn from across the institution. Students can obtain joint degrees in a traditional major and in information technology. RPI faculty from many disciplines are participating in this initiative.
- Deploy computers, especially laptops, on a large scale. A new desktop computer room at RPI cost the institution approximately $100,000. A similar "laptop" room cost $25,000. With an expected life of five years, the rooms were not as expensive as some might have thought. Of course, computer technology has consistently improved and changed on a much faster schedule, as a participant pointed out after the presentation.

A Web-based approach to teaching need not involve only a single distinguished professor. Rather, the Web can be a networking tool, representing a collaborative approach. Teleconferences using video, audio, and the World Wide Web offer great potential for conducting courses simultaneously at multiple sites.

The incorporation of this technology does not mean that teachers will lose their jobs, as some educators fear. Web applications, on-line tutorials, and other technologies should be considered useful, complementary tools, but they are not the same as teaching.

"What's out there?" A sampling of the state of the art in undergraduate SMET classes

Session Chair: Jean-Pierre Bayard, California State University at Sacramento

Theresa Julia Zielinski, Monmouth University

Zielinski's dream for using technology in MPS is that students will reach for a computer as a problem-solving tool as easily as they reach for a telephone as a communication tool. The computer should be as important as the test tube or spectrometer.

The key to this dream is to provide students with active learning materials and authentic problems. The more that teachers can engage students in the learning process through hands-on activities, the more students can develop critical-thinking and problem-solving skills, lifelong learning habits, and mastery of concepts.

After 15 years of computational chemistry research, Zielinski has focused on the uses of computers in chemical education and the development of instructional materials for physical chemistry using commercial software. These materials are designed to take advantage of research in learning styles and intellectual development stages, and to create more active learning environments for students.

The speed of the development of technology for conducting science needs to be linked more quickly to how we teach science. The efficiency of learning science needs to be enhanced by using the wisest pedagogical techniques. Educators cannot be deterred from incorporating technologies by critics who constantly raise the requirement of proof before changing their teaching strategies.

Collaborators have created a series of interactive projects by which students can explore and learn key scientific concepts. If a topic is interesting, students can be left to unravel the mathematical models from available written resources. Alternatively, one can package a series of related concepts into one teaching module that students can use for independent study, with the instructor as coach. Examples of these approaches are Physical Chemistry case studies and a Mathcad Physical Chemistry documents collection (http://www.monmouth.edu/~tzielins/), and Mathcad documents from the Journal of Chemical Education (http://jchemed.chem.wisc.edu/jcewww/columns/McadInChem/).

More on-line case studies are available from the Physical Chemistry On-Line (PCOL) consortium of faculty (http://pcol.ch.iup.edu/project.htm) and the Spartanburg consortium (http://TRUTH.WOFFORD.EDU/~whisnantdm/p_chem.htm). These examples include:

- **"How Hot is that Flame Anyway?"**, in which junior-level chemistry majors from three participating campuses work together to answer the question. (http://www.monmouth.edu/~tzielins/FlameS99/)
- **"It's a gas"** (the study of real gases, comparing the van der Waals equation and the Redlich-Kwong equation using non-linear curve fitting and model choice based on statistics), a group project shared by students from four universities.(http://pcol.ch.iup.edu/itsagasf99/index.html)

- **The thermodynamics of polymer elasticity, structure, and function**. Students work together to understand how thermodynamics is related to polymer structure and function. Physical chemistry concepts are used to establish the important parameters for setting up a bungee-jumping site. (http://pcol.ch.iup.edu/polymer/bungee.htm)

Students work collaboratively on these case studies in their local campus groups, write their papers by working with students on other campuses, and peer-review the papers.

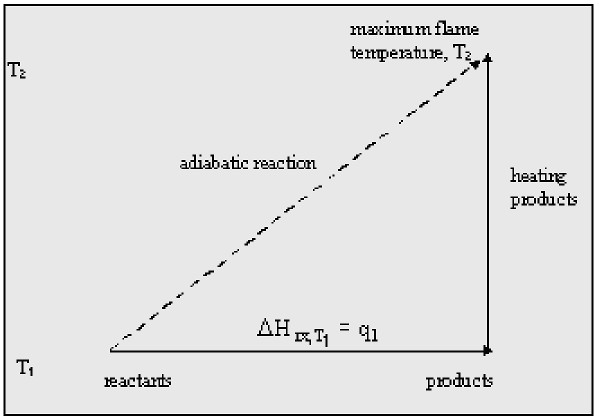

Figure 3. Estimation of maximum possible temperature of flame, from the on-line group project "How Hot is that Flame Anyway?"

Educators need to move beyond considering computer-based delivery of traditional lectures as the model of technology-based MPS instruction. Computer and software tools need to be placed in the hands of the students to use as learning tools. Well-designed materials need to be created to support learning. These materials should, by their structure, encourage active learning and include self-assessment and open-ended components. Significant writing assignments should form an integral part of this learning scheme. Furthermore, we should continuously focus on formative assessment of our instructional materials in order for them to keep pace with rapidly changing technology, research in pedagogy, and research in science.

Just as Web and multimedia technologies offer opportunities for learning through collaboration, teachers need to determine cooperatively how these technologies and resultant learning issues should best be addressed in the classroom. Educators need to ask the following key questions:

- What are the most appropriate uses of Web technology?
- What are the pedagogical issues, including learning style and learning effectiveness?
- How do we use technology to increase efficiency in the learning process?
- What are the best methods for motivating faculty to champion these new methods? The tenure system encourages "lone rangers"; how do we appropriately recognize the creative effort required for pedagogical research and project development?
- How do we provide time and support to develop the required learning resources?

Kelly Keating, Pacific Northwest National Laboratory (PNNL), "Remote research using a virtual scientific facility"

Keating discussed the Environmental Molecular Sciences Laboratory (EMSL), the Department of Energy's new national scientific user facility in Richland, Washington. The EMSL "Collaboratory" (http://www.emsl.pnl.gov:2080/docs/collab/) is a collaborative environment where scientists can share knowledge and resources via the Internet. It is operated by PNNL for the Department of Energy's (DOE's) Office of Biological and Environmental Research.

EMSL's mission is to provide advanced resources to scientists engaged in research on critical problems in the environmental molecular sciences, and to educate young researchers in the molecular sciences to meet future environmental challenges. The EMSL collaboratory functions as a "center without walls," where researchers from smaller institutions can simultaneously work with their colleagues and EMSL's instrumentation in all phases of research without having to come together physically. The Collaboratory can expose students to real-world science and the latest scientific techniques, and can connect in-service and pre-service teachers.

EMSL's Collaborative Research Environment (CORE2000) is a multi-platform environment available to users of UNIX, PC, and Macintosh computers. It integrates technologies from EMSL, DOE, the National Center for Supercomputing Applications (NCSA), and the public domain. In the CORE2000 interface, users can share instrument views and computer desktop displays in real time, and use the latest tools to share ideas and research. Using a series of windows shown on a single screen, collaborators can simultaneously see colleagues in one window, use electronic notebooks in another, communicate ideas through an electronic whiteboard, use remote-controlled laboratory cameras, and communicate thoughts via a "chatbox." Users can close any of these views as needed to reduce screen clutter.

Keating predicted that all researchers will be using electronic laboratory notebooks in five years or less. These notebooks are primary repositories of scientific knowledge that can be shared across a distributed research group over the Web. Researchers can browse through plans, instrument diagrams, experiment parameters, graphs of data, and multimedia notes. EMSL is working with its partners at DOE to build a secure, extensible system that improves these capabilities.

A growing number of EMSL's scientific resources are becoming accessible for remote research, including mass spectrometers, nuclear magnetic resonance spectrometers, computational chemistry software, and an IBM SP supercomputer. Data acquisition, analysis, visualization, and modeling tools can be linked with CORE2000 to allow group control of these applications and to support real-time consultation and training while experiments are being run.

Applications also can be linked directly to the electronic notebook, allowing researchers to save data to them as easily as they can to local disks. Notebook viewer extensions allow the development of custom spectroscopist notebooks, in which mass spectra are shown as live, zoomable graphs and protein geometries can be rotated as 3D structures.

EMSL has partnerships with other national laboratories such as Argonne, Lawrence Berkeley, and Oak Ridge, and has a wide range of collaborations that focus on the development and use of technologies for sharing research and education.

Despite EMSL's exciting technology and potential, some collaborators have had trouble making the transition from more traditional research methods. Some researchers are troubled by the lack of personal presence, and say that the technology can feel intrusive, even while allowing that it is impressive and helpful. At the technical level, network outages are still too frequent, and the audio/video technology doesn't work as well as it might.

David E. Pritchard, Massachusetts Institute of Technology (MIT), "Web-based homework administration and tutorials"

Pritchard discussed the development of Web-based homework presentation and administration systems. One popular example is WebAssign (http://webassign.net), in which students can view a problem, go off-line and solve it, and then submit their answers on the Web site.

Next, Pritchard introduced Cybertutor (http://cybertutor.mit.edu), an interactive program at MIT he helped design to improve the homework experience of students and teachers.

Cybertutor presents students with qualitative or quantitative problems that their teacher has chosen from its library. Like a Socratic tutor, Cybertutor provides hints or simpler sub-problems at the student's request, grades student responses quickly, and provides feedback if the answer has recognizable deficiencies.

Using each student's unique path through the branched hint structure of each problem, Cybertutor will update the student's skill profile on each of the approximately 150 topics in the syllabus. About 50 of these topics cover foundational skills in math and physics. Cybertutor can discover deficiencies in these foundational skills, allowing their remediation before a student becomes discouraged.

Cybertutor tries to equal the range of questions that a human tutor could ask. In addition to multiple-choice and numerical answers, special Java applets have been written to analyze analytic expressions, word strings, and mouse-drawn vectors and curves.

A group of experienced teachers and tutors have written a library of about 150 problems for introductory Newtonian mechanics at the freshman college level and another 75 problems at the high-school level. Using Cybertutor's Web-based author module, they can write appropriate multi-part problems that incorporate the branched logical structures and special answer types discussed above. This utility also allows the group to communicate and collaborate on the development and checking of new problems. The average library problem took about three hours to create, including simple graphics, subparts, and hints.

Teachers can adapt Cybertutor for any scientific or technical subject by writing a customized syllabus and suitable problems (and new Java modules if necessary). Cybertutor provides an immediate, detailed analysis of each class’s performance, allowing teachers to correct misconceptions from the previous lecture in the next one. Teachers and tutors will be able to access a student’s skill profile and determine where the student needs additional help. A grade book displays the students’ homework scores to the teacher, and will display each student’s performance relative to the class.

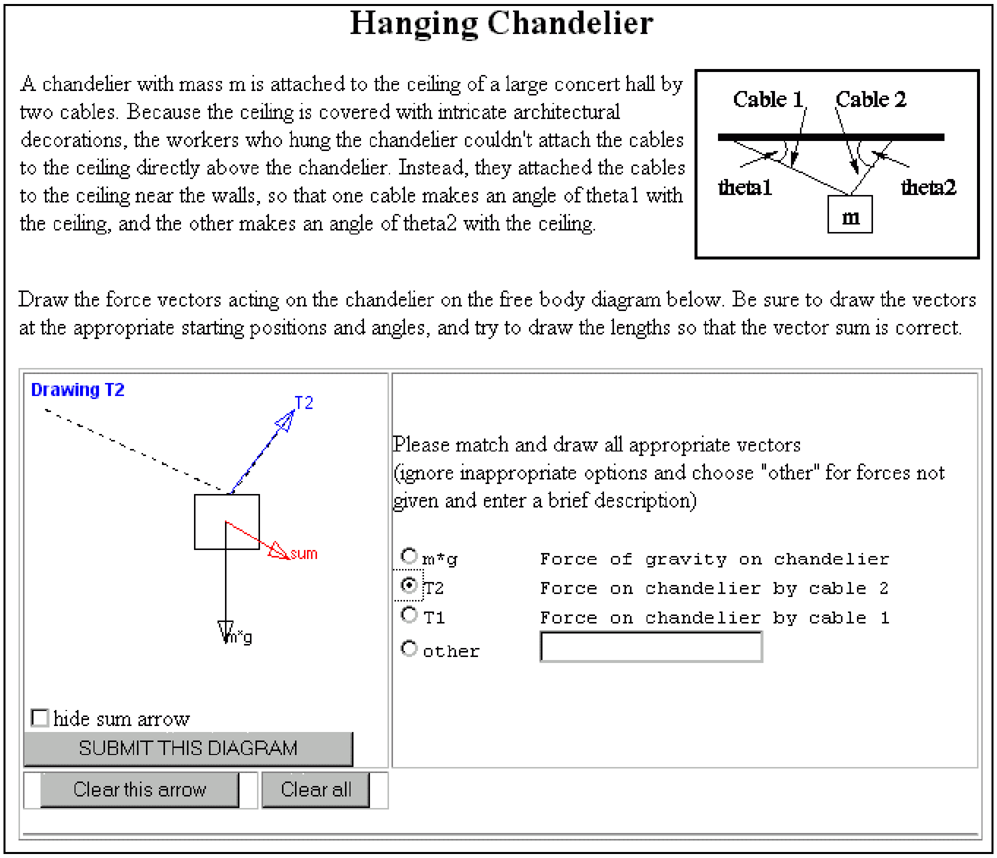

Figure 4. A problem in Cybertutor

Because Cybertutor will eventually be used by thousands of students, it is worth the effort to develop and improve its library. Toward this end, Cybertutor analyzes the amount of time students spend on each problem and subpart, which hints and subparts helped students to a solution, and the number of wrong answers that preceded the correct response. The author group will work to identify and eliminate confusing questions that consistently elicit the same wrong answer, overly time-consuming problems, and those that students consider ineffective. The hint structure will be extended so that students rarely exhaust the hints and subparts. Ultimately the educational efficiency of each problem can be determined by dividing the average increase in skill level of the students solving it by the time they took to do so. This approach should allow Cybertutor to optimize the homework by providing more learning per unit time.

MIT is also working to improve Cybertutor by adding an on-line teaching assistant during selected hours, a data bank of questions that students submit (and the answers), and a continually updated and displayed skill profile for each student. Software is being developed to help teachers write customized class assignments using Cybertutor's problem library, examine the special learning problems of their students, and keep a class grade book.

Breakout sessions from the "What's out there?" presentations

After the morning presentations, Workshop participants broke into eight groups and discussed two questions:

- "What is being tried in technology-enriched MPS education, and why?"
- "What is working, what is not working, and why?"

Participants reconvened after the breakout sessions, and group representatives reported the results of the breakout discussions. The following comments are combined from the eight discussions.

What technologies are being tried?

- Streaming audio and video via the World Wide Web
- On-line tutorials using multimedia
- Interactive quizzes that require minimal monitoring
- Demonstrations and remote experiments using video delivered via the Web
- Problem-solvers and modelers
- Graphing calculators
- Video disks and tapes
- Workshop physics applications
- Molecular modeling
- Perceptual learning modules (PLMs)
- Virtual, bi-directional learning communities

Why are these technologies being tried?

- Technology provides access to education for more students and learners, especially non-traditional students. Educational facilities can be expanded beyond the physical classroom. Students in lower socio-economic groups can be encouraged to see beyond their immediate environment — and expand their future — through use of the technology.
- Students can be motivated to learn using creative technologies and "real-life" applications.
- In some ways, technologies make teaching and learning more convenient and cost-efficient.
- Interactive tools can inspire collaboration between teachers, students, administrators, and the community at large. Computers can enhance participation on many levels.

- There are pressures and encouragement from industry and administration.
- Computers change the temporal dimension of what is learned, which can lead to "real-time science." You can collect and display data rapidly, change parameters, and receive feedback very quickly. This immediacy can excite and motivate students.
- Simulations can help simplify the presentation of complex ideas. Motivated students can learn to design simulations.
- New technologies can provide methods for new learning paradigms and persuade all students to believe they can contribute to a field.
- Visualizations are powerful and can help make abstract concepts more concrete.
- Computers can promote discovery learning via the World Wide Web and other sources.

What technologies are working?

Most of the participants believe that technologies, when used properly, can improve learning, although no one thinks they can prove it. Participants said they were waiting for better assessments and evidence. Technologies that they *think* work include:

- CD-ROMs, demonstrations, e-mail, Physics Classics disks, calibrated peer review, graphing calculators, dynamic geometry, visualization, and animations.
- The World Wide Web, if used appropriately, not just for publishing books on-line.
- On-line, interactive tutorials, which can be extremely important to "fill in the holes" of learning.
- Modeling software and mathematics software.
- Distance education, if students are properly motivated and goal-oriented.
- Digital libraries, on-line Web libraries, and on-line access to peer-reviewed journals.
- Tools that accommodate diverse learning styles and that motivate students by offering them the ability to solve real-world problems.

What technologies are not working, and what are the groups' concerns about technology use in MPS curricula?

- The specter of reinventing the wheel. Educators can potentially spend great amounts of time developing innovations and curricula that have already been developed elsewhere. Faculty must find better ways to collaborate across campuses and across the country, and must help improve methods for finding material on-line.
- In assessments, what is the value added on the faculty / teacher side, and on the student side, considering the time constraints on both groups? Teachers need criteria-based, outcome-based, and longitudinal evaluations of technology. Assessments must be made over the short term and long term, and economics must be considered.
- Computers crash, networks go down, and software may have defects.

- "Plug-and-chug" exercises do not promote the understanding of concepts, but only the mechanics.
- When using technologies, there is sometimes no link to the physical world.
- Students and teachers can lapse into over-reliance on Internet-based exchanges.
- The Internet makes plagiarism and cheating easier for students.
- Although the Internet offers huge amounts of information, there is an inadequate amount of critical evaluation. Also, the Internet has an "ornamentation" problem: The form can obscure the fact that the content lacks utility and substance.
- There is a constant temptation to buy the "latest and greatest" software and technology, only to have it become obsolete or unsupported by the manufacturer. Innovations are sometimes based on technology that has a short half-life. For example, how much good data cannot be accessed easily because it is stored on 8-inch diskettes?
- Technological innovations are not accompanied by appropriate changes in the rest of the curriculum.
- Technology can be overwhelming to both teachers and students. How can we make it more accessible and available?
- Any education reform requires that the reformer speak the language of the audience in order to be effective.
- Even when reforms are well-implemented using technology on a local level, it can be difficult to engage the electronic publishing community to disseminate the project.
- The issues of technology and student-centered learning raise the need for more flexible course design.

Other comments from the breakout discussions

- Many of the issues discussed today, noted one participant, reflect those noted several years earlier at a similar conference he attended. The issues of student-faculty interaction, collaboration, active learning, prompt feedback, time on task, high expectations, and diverse talents for learning are still concerns today.
- The SMETE (Science, Mathematics, Engineering, and Technology education) digital library proposal currently before Congress can open opportunities for dissemination and collaboration.
- The technology instructors use depends on their students. Some are focused consumers of computers, but some students are not yet engaged. How a teacher uses technologies depends on the training students need to earn research positions, to obtain jobs in the business world, or simply to become part of a "knowledgeable electorate," to paraphrase Jefferson.

“What works and how do we know?” Assessment and evaluation issues

Session Chair: Deborah Moore, University of Puerto Rico at Mayaguez

Harvey Keynes, University of Minnesota, “IT: How much information? How much technology?”

Keynes presented preliminary results *from one survey in the second year multivariable calculus course. This survey was one aspect* of a 4-year study of major revisions in the engineering calculus curriculum at the University of Minnesota. The study constitutes an evaluation and assessment of the role of technology in education, focusing on how the technology influenced student learning and faculty teaching.

Students participating in *this class* incorporated TI-89 graphing calculators, computers, and the Internet into their coursework. *Another* major course revision was a reduction in the number of lectures and an increase in the number of workshops. (This approach is consistent with methods implemented at RPI, as Jack Wilson described earlier in the Workshop.) The revised calculus *sequence* used the following organizational and teaching strategies:

- Two 50-minute weekly class sessions of 100 students. These sessions primarily used a lecture format, but also included up to 15 minutes of group work per session.
- Two workshops per week with 25 students, one lasting 100 minutes and the other 50 minutes, consisting primarily of group work in year 1 and computer labs in year 2, to encourage active learning and peer collaboration. Homework was discussed and short quizzes were given.
- Periodic workshop visits by the lecturer, and visits by workshop leaders to the lectures, to facilitate group work.
- Three large-scale team projects, including computer lab applications, in year 1, and an increase to weekly computer labs in year 2. Half the labs required a written report, and one lab was assigned over several weeks as a group project.
- In year 1, “gateway exams” on differentiation and integration consisting of standard computations to be completed at a high level, without the use of a calculator.
- Calculus texts with rich applications.

Some of the preliminary findings of the *survey* were:

- Participating students felt proficient using graphing calculators for lower-level operations, but not at more complex levels. For example, 78% of the 175 students surveyed reported using their TI-89 graphing calculators “very frequently” or “frequently” for arithmetic calculations, such as addition, subtraction, sine, and cosine. However, only 20% reported using the TI-89s to solve equations or systems of equations, or for symbolic algebra. About 13% said they used the TI-89s for calculus operations such as finding derivatives.
- In the same survey, students seemed enthusiastic about using graphing calculators as a more integral part of the curriculum. More than 83% of the 175 students felt that an initial “calculator orientation” would be useful. About 70% felt that calculators

should be further integrated into lectures and workshops, and that some computer labs could be replaced with labs that could be done on a calculator.

- Students seemed less enthusiastic about the computer labs than the calculators. About 77% found the labs useful in visualizing complex surfaces and figures, but only 16% found them useful in understanding the overall course material. About 29% found the labs useful for exploring concepts that were difficult to learn from the textbooks or lectures, and about 40% found the labs useful for doing homework.
- Many students bought TI-89 calculators as a result of *this intervention*. When 140 students were asked whether they preferred calculators or computers for use in labs, 46 said they preferred calculators, 10 preferred computers, 57 preferred a combination of both, and the rest had no opinion. In the same survey, when asked if the TI-89 had sufficient graphics capabilities to supplement those of computers, 63 students said "yes" and 9 said "no."
- In another survey, 19 of 30 students (63%) found the computer labs "not useful," of "limited use," or "moderately useful." By contrast, 15 of the 30 students rated homework assignments at the same three levels of usefulness as the computer labs.

In addition, some Minnesota faculty felt it might be unrealistic to expect a large number of instructors, even if they are interested and motivated, to devote more time and energy to computer labs without receiving more resources and more compelling evidence of the labs' effectiveness. The *survey and other evaluations* concluded that perhaps new approaches to distributed learning, such as CD-ROM applets that provide workshop-style, interactive exploration of important concepts, might improve the computer labs.

The *survey* data might suggest that students needed a better conceptual overview of material, more background, and more clearly stated expectations. If students do not receive these elements at the beginning of a course, they can become lost. Also, professors and administrators should not assume that, just because they are impressed by a new technology, students will be impressed and motivated as well.

New Developments since the Preliminary Report

Based on these and other surveys and evaluations, the IT Center for Educational Programs (ITCEP), University of Minnesota, explored how to utilize technology most effectively in a first-year calculus course. Although students valued the user-friendliness and versatility of graphing calculators, we found that extensive faculty effort was still necessary to develop quality labs for the calculators, and that their features do not support the graphical displays, color capabilities, and speed necessary to duplicate the learning and experimentation possible with computer applications.

In an attempt to address these positive aspects, ITCEP developed a CD-ROM for single-variable calculus using technologies that encourage active learning while presenting important concepts and applications in which graphical and numerical approaches could increase student understanding. The Tools for Enriching Calculus CD-ROM (TEC) is a collection of mathlets (using a term found in MAA, FOCUS, v.21, n. 1[1], to define single-topic, interactive JAVA™ -based applets) developed as a technology supplement for a major calculus textbook (J. Stewart, Calculus: Concepts and Context[2]

[CCC]). In addition to the mathlet labs, TEC supports the student by providing key homework hints for representative problems, thus playing the role of a 'silent tutor.'

Given that TEC could be used in all types of higher education environments, where faculty interest in and availability of technology vary widely, we incorporated the user-friendliness and versatility of a graphing calculator within a richer laboratory approach. Explorations for these topics were chosen only if technology could provide enhancements to learning mathematical ideas that are difficult to duplicate by well-written texts or good lectures and recitations. The mathematical content, intellectual approach, and technical format of both the mathlet labs and homework hints were created after looking carefully at student learning and the influences of technology on learning. We wanted to encourage genuine exploration within the mathlets by students (and possibly faculty) at either very elementary or very deep levels, while keeping the technology virtually transparent. We also tried to use contemporary technology, while not expecting a high level of technical expertise nor any understanding of customized syntax for its use. A point-and-click laboratory environment enables students to visualize concepts easily, experiment with suggested examples and exercises, and possibly to develop and explore some of their own examples and conjectures.

Preliminary results from several pilot tests of TEC indicate that both students and faculty appreciate its level of user-friendlessness and how the TEC approach permits them to concentrate intensively on mathematics with virtually no additional technical background. TEC will be field-tested by a wide range of students and faculty who will be using CCC for their coursework. These results should help to identify new approaches in using technology to add value to the learning of mathematics.

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Gloria Rogers, Vice-President, Rose-Hulman Institute of Technology, "A discussion of assessment issues"

Assessment is a process that can provide information to an academic program or project. When properly conceived and executed, assessment can provide information to improve the delivery of education and the quality of learning, and can enhance academic support. Assessment techniques can be used to prove the efficacy of innovations involving the use of technology in classrooms and curricula, and can provide meaningful data that informs academic decision makers.

Before you begin assessment, you must define your terms and be clear about what is being assessed. Determine the main foci of the assessment, which populations and programs will be assessed, and which tools will be used to collect the assessment data. For the participants in the Workshop, for example, an assessment would focus on the use of technology in education, including its impact on cognitive, behavioral, and affective characteristics of students and faculty and organizational competencies.

The assessment could address "first-level learning" skills, which focus on learning the technology itself. The assessment could also address "second-level learning" skills, which focus on how students learn through the use of technology. The assessment could study how the school's infrastructure supports technology use through allocation of resources and services, and evaluate the effectiveness of the technology and the effectiveness of in-service and technical support.

It is important to establish which groups the assessment will affect. Primary stakeholders in the assessment can include faculty, staff, students, administrators, and funding agencies. A decision needs to be made about which groups will be served through the assessment and what questions need to be answered to meet their needs.

After defining the desired outcomes and the assessment foci and stakeholders, the next step is to choose and implement the tools for collecting the necessary data. Examples of assessment tools are standardized exams, locally developed exams, oral exams, competency-based methods, simulations, performance appraisals, surveys and questionnaires, interviews, third-party reports, portfolios, capstone projects, archival records, and behavioral observations.

Student assessment issues can include competence in the use of technology, cognitive growth, learning style preferences, access, and attitudes toward the use of technology for learning. Examples of questions to be answered are: "How can I learn to use this technology? Do I have access to the technology when I need it? Am I really learning the concepts I need to know, or just how to use the technology? Does this have anything to do with what I'm going to be doing after graduation? Is it going to be on the test?"

Faculty assessment issues could include technological literacy, the cost/benefit of using the technology, availability, level of confidence that the technology can be used effectively in the learning environment, efficiency, support, and control. Examples of questions that could be answered are: "Can I learn to use the technology? Will it enhance student learning? What will I have to give up to use it? Can I use it effectively in the context of the course? Will the computing center be able to provide a stable platform for delivery? Will I be able to deliver the material more efficiently? Will I have to give up control of the learning environment? If the experiment doesn't work, will I be jeopardizing my own promotion and/or tenure?"

Assessment questions of interest to administrators might include those of cost/benefit, access, faculty buy-in, infrastructure support, maintenance, and capital (both monetary and political). Specific questions are: "What will it cost, in both the short and long term? Can we get the financial support for it? What will we gain? What are the barriers to implementation? Will the faculty support it? Will students? Do we have the infrastructure to assure proper implementation?"

Technology assessment issues encompass several areas:

- Instructional design, including interactivity, cognitive and conceptual change, multimedia use, and instructional use and adaptability

- Software design, including engagement, learner interface and navigation, and technical reliability
- Content, including accuracy, organization, consistency with learning objectives (see NEEDS evaluation criteria, which are available at www.needs.org/
- Infrastructure, including Internet and Intranet issues, and internal and external technical support

Keep the following points in mind when planning for assessments:

- There is always more than one way to measure any objective. No single method is good for measuring a wide variety of different attributes.
- There is a consistently inverse relationship between the quality of measurement methods and their expediency.
- Pilot testing can be an important gauge of whether the method is good for your school's particular situation.
- Assessments can be impeded by a lack of planning, time, money, and confidence.
- Assessments can also be hampered if participants do not have access to proper resources, if they do not believe that the assessment will be meaningful, and if no one is ultimately accountable.

Steve Ehrmann, Director, Flashlight Project, American Association for Higher Education (AAHE), "Strategic evaluation of the use of IT in programming improvement"

Ehrmann's TLT (Teaching, Learning and Technology) Group is a non-profit organization affiliated with AAHE. Its mission is to motivate and enable the improvement of teaching and learning with technology, while helping educators cope with continual change.

If you want to evaluate the efficacy of technology in improving your programs, do not focus just on the technology itself, and the narrow question of whether it is working. Do not limit your evaluative focus to just one course, project, or software application. A key study issue should be the programmatic changes brought about as the technology is used. The evaluation should represent an effort to determine how students learn, and how changes can improve student learning.

Educators should evaluate for large, programmatic outcomes. These outcomes can produce bigger effects, which are easier to see, and might be required if the investments in technology are also great. Technologies, in turn, can be applied to help make a difference in these outcomes. To create a successful distance learning program, for example, you most certainly need the World Wide Web, but you must study the need for other effective technologies as well.

Study the degree of pervasive, coherent, cumulative change in how teachers teach and how students learn — across your entire curriculum. Some changes already may be occurring to a much greater extent than was realized. One effect of the evaluation might be to publicize campus innovations that relatively few people knew about.

Evaluations can have two types of focus. The first focus is on *transformational* goals, programs that enrich education for each student. The second focus is on *improvement* goals, designed for larger, more diverse enrollments and intended to help improve mastery of basic ideas through the use of new technologies.

With the evaluation results in hand, what do you do with them? The data could be used to encourage useful discussion and collaboration in making necessary changes. If the improvement of programmatic outcomes is the goal, then shared decision-making is required. Use the evaluation data to make decisions about the next steps and to identify areas of agreement.

Evaluators should develop "tool kits" to help them catalog and study the most frequently asked questions that emerge during evaluations. Evaluators should also develop training courses that explain how to use these kits, while recognizing that individual departments will still need to customize techniques that focus on their own needs and goals. Departments must share their findings to augment and complement longitudinal data.

Finally, evaluations should be framed to persuade "adapters" and "transformers"; in other words, the campus decision-makers. In the early stages of an evaluation project, you need to tap into people whose decisions could make the biggest difference in turning the evaluation into actions. Otherwise, even the best-written evaluation might produce no meaningful results.

Reflections on the assessment and evaluation session

In the absence of a general discussion on the assessment and evaluation session Tuesday afternoon, the following reflections on the session were added after the Workshop by Susan Millar and Flora McMartin.

The issues raised during the session illustrated that the processes of gathering and using "feedback" data should be conducted at every organizational level and are critical to the success of innovative teaching strategies such as new computer-based technologies.

It is impossible to assess student learning effectively or to evaluate the effectiveness of an educational program — whether at the course, program, or institution-wide level — unless the key participants begin by clearly articulating their goals for deeper and more relevant student learning. Only when these goals are stated can participants systematically think through the question of which teaching and learning strategies — including new technology-based tools — are likely to help them achieve these goals. Only when these goals are made clear can participants develop tools that will tell them whether their strategies have achieved particular goals.

Assessment and evaluation methods should not be designed to gather data on the effects of isolated technology-based learning strategies, but on the interactive effects of all the learning strategies in play within the environment (course, program, or institution) under consideration.

When planning an assessment or evaluation process, participants must ask the following questions:

- Which goals for student learning or project success do they want to evaluate?

- What will they and their colleagues accept as evidence that they have achieved their goals?
- How much emphasis will be placed on understanding the students' learning processes and the organizational and cultural factors associated with project success?
- What data-gathering methods are feasible for obtaining information about both processes and outcomes?
- Given the limitations of the research design, resources, and timetable, what kind of "formative" and "summative" feedback processes and products will optimize the achievement of the goals?

A good resource for developing assessment tools is the "Field-Tested Learning Assessment Guide" (FLAG), which can be found at http://www.wcer.wisc.edu/nise/CL1/. This Web site has been developed by the NSF-supported National Institute for Science Education (NISE). It is designed to introduce MPS instructors to the importance and value of assessing student learning in their classes. The Web site also provides a variety of classroom assessment techniques (CATs) and associated tools that can be used or adapted for college MPS courses. The CATs include concept maps, concept tests, and portfolios, to name a few examples.

Finally, a critical element in any assessment and evaluation process is a strong commitment to use the feedback to improve teaching strategies, fine-tune goals, and publicize educational improvement efforts.

Reflections on first day sessions

Robert Chang, Northwestern University

"Higher education is big business," Chang said, "so how's business?" We should be worried that we are not adequately preparing students for the marketplace. Some corporations, such as Motorola's "university," have begun providing education themselves.

Students are our products, and we need to train them to have marketable skills. Students need to be lifelong learners, and we need to train them to perform many different tasks.

How can we use information technologies more effectively? We know that computers work well for storing, manipulating, and calculating data. They also provide exciting possibilities for interactive learning and distance learning; for remote lectures and "field trips" that break the boundaries of time and space; and for modeling and systems design, either on a "nano" scale or an astronomical scale.

We need good evaluation programs that gauge the effectiveness of these tools.

Arnold Ostebee, St. Olaf College

This is an exciting time for pedagogical innovations and new tools. So much material is out there, but there is still the problem of finding the *right* materials. Also, how do we learn about important innovations that other educators are using, and not duplicate effort? How do we improve cross-disciplinary communication, and how do we examine methods that educators in other disciplines use to solve problems?

New technologies can create new learning environments, and can be used as a catalyst for learning. The use of the technologies themselves is now part of the curriculum. What are the goals now for undergraduate education? We need more information about how students learn, and how they should learn. How do we balance the need for content with the need for developing higher-level thinking skills?

We need to promote a culture of evidence. We need information about how well these technological innovations work. Do they work? What is their cost benefit? Are these innovations taking too many resources?

Josefina Arce, University of Puerto Rico

Science studies the real world and thus is best learned directly from observation and experimentation. Innovations in technology help us in this process. Technology adds value to our teaching, especially in areas where nature cannot be directly observed for various reasons. Technology can enhance communication, but does not substitute for personal communication. The development of interpersonal communication skills requires human contact.

We need more data and assessment, not just the intuition of teachers, to prove that technological innovations are working effectively.

"What are the principles underlying the effective use of technology?" A cognitive science perspective

Session Chair: Susan Millar, University of Wisconsin-Madison

Andrea diSessa, University of California, Berkeley, Graduate School of Education

Studies in cognitive science can help educators understand how students think, how they learn, and how they learn best. A discussion of cognitive science, therefore, is vital in a Workshop that explores new learning paradigms and new technologies for MPS teaching.

diSessa described a study that illustrated the complexities and challenges that cognitive science results pose for educators. A student was asked by an interviewer about the forces at work on a ball tossed in the air. Interestingly, the student first provided a cogent explanation, correctly using gravitational force and other appropriate ideas, but when asked the same question later, provided a quite different explanation, not at all grounded in scientific principle. The student, who was quite intelligent, continued to alternate between the correct answer and the incorrect story, despite being prompted to think about the problem and tutored about the scientific ideas involved.

The process of human understanding involves complex systems. For example, the concept of gravitational force is complicated, and the development of its understanding takes care and time. The idea that teachers can adequately teach such a concept just by "saying it clearly" is incorrect.

All students begin with rich, intuitive knowledge systems, which provide for a wide range in the way they process information. Some students are very particular sorts who cannot be expected to respond productively to instruction designed for "the average student."

Accommodating different types of learners is just one of the challenges of using new technologies in education. Other challenges are to engage the intuitive thinking of students, to motivate extended and thoughtful knowledge building, and to provide students with the appropriate "material intelligence" and learning tools.

The work of Galileo provides a compelling example of how material intelligence works to enhance intellectual power. In what is generally considered his greatest work, Galileo defined uniform motion (motion with a constant speed), and supported his definition with six theorems and their lengthy proofs. A modern reader would judge the work to be a grandly overdone set of variations on the theme "distance equals rate times time."

In fact, Galileo's theorems can be presented and proven much more easily and quickly using simple ninth-grade algebra. The point is not that Galileo was on an intellectual par with today's average ninth-grader, but that algebra was not a tool at his disposal. A look at Galileo's work reveals not a single "equals" sign, because algebra had not yet been invented. To be more precise, although solving for unknowns that participated in given relations with other numbers had been practiced for at least 500 years, the modern notational system that allows the writing of equations as we know them — and the easy manipulations to solve them — did not exist.

New technologies also offer new opportunities and paradigms for learning. As an example, diSessa displayed a "tick model," which reconstitutes Galileo's theory of uniform motion in terms of computer programming. Programming is marvelously adapted to expressing many aspects of motion. In addition, the amount of programming involved in this model is much easier to teach, to much younger students, than algebra. The tick model is so named because it shows what happens at each "tick of the clock."

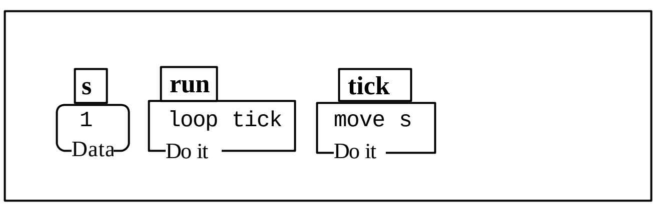

Figure 5. Tick model

The tick model (written here in the Boxer language), like any computer program, has two parts. The *informational* part, or data, is simply a number (shown in the first box) that represents the speed (**s**) of the moving object. The second and third boxes define the *procedural* part of the program, i.e., what happens with the data. These are "do it" boxes. The second box represents the overall shape of the process, which in this case is very simple. In order to **run**, you **loop**, or repeat over and over, the simple action **tick**. **Tick** is a simple movement (**move s**) that commands a graphical object to move the short distance specified by the speed, **s**.

Each part is independently important. The Run process tells us that exactly the same thing happens again and again — that the process is uniform. The Tick process is what happens over and over. The **s** quantifies the physical process.

Compared to a textual treatment, the tick model shows the strengths of a technical representational system. It is concise, which offers the advantage of being easily remembered. It is also precise; numbers fit naturally within the representation, and the depicted process is clear, if the "reader" is familiar with the computational meaning of the program. In addition, the tick model allows students to experiment and play with motion in a way that algebra does not.

The tick model illustrates the critical importance of using apt representations in teaching. The systems of representation that we use define the power and reach of our thinking. Instead of being dazzled by cute or flashy computer programs for instruction, we should look for fundamentally different ways to represent the world.

Phil Kellman, UCLA, "Understanding and creating the technology of expertise: The role of perceptual learning"

We all share the intuition that advances in computer and multimedia technology offer opportunities to improve and enhance MPS education. To achieve real improvement, educators need to grapple with the "bells and whistles" problem. In other words, how do educators distinguish technology that truly impacts the learning process from meaningless (and expensive) colorful animations, simulations, and sounds that distract the learner?

As an example, Kellman mentioned a study by Christensen and Gerber that contrasted two approaches of learning basic addition. The researchers compared students who learned addition using a multimedia software application that contained an elaborate story line, interesting characters, and sophisticated animations, with students who learned from a simple presentation of addition problems on the screen (called "plain vanilla" by the authors). "Guess what?" Kellman asked. "Plain vanilla won."

Two useful strategies in making the distinction between useful and useless technology are to emphasize the collection of appropriate, objective data that assesses and evaluates the technology, and to understand and apply principles of cognitive science in exploiting the capabilities of technology.

To illustrate both the use of objective data and principles of cognitive science, Kellman described research on perceptual learning modules (PLMs). Perceptual learning — changes in the way information is picked up as a result of experience — is a major component of expertise. With appropriate experience and practice in any domain, human attentional systems seem to focus on relevant details and structure needed for important classifications in that domain, while becoming able to ignore irrelevant variation.

Research in a number of domains has demonstrated dramatic differences between novice and expert information pick-up: Experts extract larger "chunks" of information, detect details better, discover higher-order relationships, and become automatic in extracting patterns. Novices begin with what cognitive scientists call a high "attentional load"; in other words, novices have to work much harder to sort through information that is irrelevant and ancillary to find important patterns.

When the distinguishing of patterns and "chunking" of information become more automatic, learners can seize "the big picture" more quickly. To quote Benjamin Franklin: "The eye of the master will do more work than both of his hands."

A classic example of this information processing is the sorting of newborn male and female chicks in the poultry industry. Experts sort rapidly and flawlessly, whereas novices can hardly detect any consistent differences.

In the same way, grand masters in chess use their expertise in information pick-up to memorize board positions almost instantaneously. These pick-up skills and learning patterns, according to research on chess players, illustrate learning of pattern structure specific to chess. In other areas, grand masters appear to have no greater visual memory skills than other people.

Although the importance of expert pattern extraction has been recognized, there have been few attempts to directly train these skills, and they are not well addressed by traditional methods. Cognitive scientists have been exploring the conditions that accelerate the development of pattern extraction skills.

The conditions for rapid training of pattern pick-up have been incorporated into domain-specific, perceptual learning modules (PLMs), which depend heavily on computer technology for timing, trial sequencing, and display variation. Advances in simulation, multimedia, and virtual-reality technology are helping the development of even more realistic and useful PLMs for many learning situations.

PLMs in a 5-year project in aviation training have been highly successful. In one experiment, subjects were exposed to many short trials on which they attempted to classify the flight attitudes shown by the instrument patterns. Surprisingly, after an hour of training, subjects who began with no knowledge of aviation were as accurate and faster at the end of training than highly experienced pilots were at the start of PLM training. (Pilots also improved from the training.) These results of direct attempts to train sensitivity to structure in information are typical of PLMs.

Ongoing projects applying PLMs to mathematics and science education are beginning to yield excellent results as well. One mathematics PLM teaches students to map graphical representations of functions and transformations of functions onto their symbolic representations (equations). Another shows promise of helping students extract structure from word problems and derive appropriate graphs and equations. In undergraduate organic chemistry, PLMs are helping students to learn structural constraints on molecules, such as bond angles and hybridization, and helping them to become more intuitive in extracting structure from the notation used to symbolize molecules.

Methods for developing expertise in pattern processing are sorely lacking in traditional instruction. This expertise can be trained, but it requires certain conditions and formats. Educators can make unprecedented advances in addressing neglected components of learning by combining a greater understanding of cognitive principles with the power of modern computer processing.

Marcia C. Linn, University of California, Berkeley, Graduate School of Education

Incorporating cognitive research into undergraduate instruction can greatly enhance learning and provide guidance for dealing with rapidly changing technologies. These new technologies force us to consider the redesign of MPS curricula.

For example, the Mathematica software program can be incorporated into the teaching of calculus. Simulation and modeling tools change the kinds of understanding that students need in many physics and chemistry courses. On-line resources such as Science magazine's forthcoming Signal Transduction Knowledge Network afford opportunities that instructors have never had before. Computer Aided Design (CAD) can transform engineering instruction, enabling students to conduct more complex design projects far earlier in their careers. All of these innovations provide opportunities to rethink curriculum design, but they also present great challenges in university planning and resource allocation.

Another innovation is the Scaffolded Knowledge Integration network, a synthesis of research findings from a broad range of cognitive traditions that suggests ways to design effective MPS instruction. This framework, based on 15 years of research by Linn and her colleagues, offers designers a head start in creating courses that enable students to become lifelong science learners. For details, see www.clp.berkeley.edu/.

One approach to using current cognitive research in new courses involves taking advantage of environments that can use these findings efficiently. An example is WISE, Cal-Berkeley's Web-based Integrated Science Environment. In WISE (http://wise.berkeley.edu), students collaboratively perform activities that help them add and reorganize scientific ideas to create a coherent understanding. Too often students isolate rather than connect scientific concepts; WISE is designed to fight that problem. WISE focuses on four main design issues:

- Choose accessible topics and use models that students understand.
- Make student thinking visible by using visualizations and representations.
- Help students learn from each other using collaborative tools, on-line discussions, and group projects.
- Foster lifelong learning with reflection, critique, argument comparison, and design activities.

WISE curriculum projects are written by partnerships of researchers, teachers, and natural scientists. The curriculum is continually improved, based on repeated cycles of classroom trial and refinement.

In all WISE activities, the World Wide Web provides a valuable source of "evidence" and information. Students must develop skills in critiquing and applying such materials, as they will invariably use the Web in their everyday lives.

One compelling WISE project is its "deformed frogs debate." Across North America, frogs are being found that have major physical deformities, and middle-school students in Minnesota used the Internet to bring media attention to this phenomenon when they published their field observations. The deformed frog controversy represents a complex, multi-disciplinary problem involving environmental, genetic, and chemical arguments.

Students explore this mystery by examining Web evidence and building an argument about what they think might be happening. Using this exercise, urban students have made dramatic gains in understanding complex science concepts.

The deformed frogs debate successfully engaged student participation and debate, even among students who teachers complained generally were sleeping in class. Students can lose interest in science because it does not seem connected to their lives. Often, students are not taught the practical applications of science. Under these circumstances students have no reason to revisit the ideas they learn in class and no opportunity to become lifelong learners.

When science is presented as a series of dry equations and laws that have seemingly always existed, students tend to memorize and forget the information. Teaching rarely discusses that scientific laws developed amid swells of controversy and even charges of heresy.

Students can be engaged by science if informed of its human element and its effects on human lives. To read more, see the Science Controversies On-line: Partnerships in Education (SCOPE) Web page (http://scope.educ.washington.edu/).

Creating instruction that nimbly responds to rapidly changing innovations demands flexible yet grounded processes for course design. Even though it could be painful, we must consider ways to narrow the curriculum, even if it might mean covering fewer topics in more depth. (For more discussion on the issue of narrowing the curriculum, see the next section, "Breakout sessions and general discussion.")

Educators must engage in sustained research by carrying out large, iterative projects using contemporary technology tools, and then manage the complexity of these projects. The Center for Innovative Learning Technologies is helping people who are interested in reform of instruction to become a community (http://cilt.org).

We must build a corpus of understanding in order to develop a comprehensive design science. We need to form partnerships that help us find better ways to share information and use technology effectively.

Breakout sessions and general discussion

Participants broke into groups after the cognitive learning presentations and discussed three questions:

- "What underlying research findings improve your pedagogical practice?"
- "What questions do you have for cognitive science researchers who study learning and instruction?"
- "What kinds of learning processes do you believe will be effective for you in using research on learning?"

After the breakout sessions, Linn, diSessa, and Kellman formed a panel, which was moderated by Christine Massey. Workshop participants asked the panelists questions they developed in the breakout sessions.

1. ***Many breakout groups wrestled with the tension between covering fewer topics in more depth and emphasizing robust understanding and higher-order skills, versus covering a larger quantity of encyclopedic knowledge considered to be important in a given domain. What's the panel's advice on this?***

It is a crucial question, the panelists agreed, that has no easy answers. They repeated their assertions from their presentations that students who become fluent with tools and concepts are then freed to achieve higher levels of understanding. The basic structures that students absorb in perceptual learning can bring this freedom.

Linn told about a girl she had observed during the Deformed Frogs project. The girl slept through classes in the beginning, and made no attempt to hide it. As the project continued, she became a star during group discussions. She became very animated and questioned other group members, challenging their opinions and positions. When the class returned to more traditional methods of teaching, she went back to sleep. When questioned, the girl explained that she was absorbed when asked "what she thought," but wasn't interested in being told "what was right and wrong."

Another panel member told a similar anecdote of an elementary-school student who, before a test, asked whether the teacher wanted students "to put down what WE think, or what YOU think?" These anecdotes indicate the need for passionate instruction by teachers, and for increased involvement and input from students.

The issue of depth versus coverage, of teaching that's "a mile wide and an inch deep," is a common concern. Too often, we as teachers move forward in the material before the students achieve understanding. Studies conducted in Japan and Korea indicate that these countries have achieved better success than Americans in mathematical instruction by spending more time on fewer topics. The issue of depth versus coverage is complicated, and might not be a matter that research can address. The issue might instead reflect our societal goals and values.

Cognitive research shows that many current goals for curricular coverage are not being met. The hard alternative might be to drop some freshmen courses and focus on fewer, important topics. One of our chief goals as educators needs to be the encouragement of lifelong learning. We need to move away from the idea that a subject can be adequately learned and retained by students who spend one hour a day in a classroom over the course of a few years.

2. ***How do we customize learning environments — especially those using technology — for different types of learners, for different domains, and for different environments?***

It can be as easy as recommending alternate solutions and options for further outside study to supplement labs and lectures. The WISE Web site (http://wise.berkeley.edu) could provide ideas for how technology can help. Technology offers tools that help you customize coursework, and provides a structure in which you can develop any problems you want, depending on your students' needs (which you know better than anyone else).

3. ***How do we set up learning environments that effectively motivate students to engage in the kinds of thinking and learning we would like them to do?***
How does learning change when learners feel a strong need to know?

diSessa said that cognitive learning specialists, frankly, do not know a great deal about the issues of interest and motivation. The issue is fundamental, and a lot of work needs to be done in this area.

There are problems with relying on the intuition that our innovations are working. Linn shared an anecdote about a student who didn't like a computer-based, interactive class but did like a "hands-on" chemistry class. Why didn't the girl consider the first, supposedly interactive, class engaging and "hands-on" as well?
The computer-based course, the girl explained, made her "think too much," but the chemistry class was fun. You cannot assume that students are interested, but you must always be conscious of trying to cultivate interest.

Students must somehow be made to feel that they have a real stake in learning and acquiring knowledge. Kellman explained how he had struggled to use Medline after a relative became sick. In such a situation, you are willing to push through the unfamiliar, arcane terminology and make the effort to learn because you care about your relative's well-being. You keep trying. Students sometimes walk away from hard topics because they don't get them the first time. They blame the teacher, the book, or the presentation, when in fact the subject matter is difficult, and takes time to learn.

4. *How should we change methods of testing students to encourage better conceptual understanding?*

Linn said she has been excited about some of the possibilities of students grading each other. At first, their grading is trivial and based on specious criteria, but in time the students begin to use more substantive criteria.

The issues of testing and grades are very troublesome and problematic, and offer the following challenges, among others:

- How can we develop tests that reflect how students think?
- How can tests make students evaluate themselves?
- How can we integrate testing into the learning process, instead of having tests that seem to be a distinct, "other" component of education?
- How do we convert tests from an *evaluative* tool to a *diagnostic* tool?

Educators should be ambitious when testing, and should encourage critical thinking as a component of testing. We've had a traditional teaching system in place for a long time, but is there any real data that proves lectures actually work? Do tests? Although educators well understand the pressures of the status quo, it has been shown that positive changes can occur in the area of testing, with the proper combination of funding and the support of administration.

5. *How can we use cognitive research findings to help design undergraduate courses?*

Unfortunately, most of the work thus far has been done at the K-12 level. There are innovations that can be incorporated into undergraduate curricula, but they are relatively incremental, and certainly not "templates."

One suggestion is for professors to ask software programmers on campus for ideas. Programmers use many cognitive learning principles and a great deal of system design in their work, and might be able to offer a fresh perspective.

“What are new paradigms for undergraduate research?”

Session Chair: Rex Adelberger, Guilford College

Ray Turner and Paula Robinson, Roxbury Community College, Boston

Turner has been involved in science education reform for more than 10 years, and Robinson has been developing models in learning through multimedia technology since 1984. Several years ago, Turner helped introduce two transforming programs to Roxbury Community College (RCC), an urban college with a large population of African-American students. One program introduced undergraduate research to upper-level students, and the other focused on improving the skills of entry-level students.

Almost one-third of the college’s students pursue science-related careers as a result of these two programs. However, the school has produced no chemistry majors, despite having more than 100 students in general chemistry courses in a typical semester. The basic problem appears to be the perceived irrelevance of chemistry to students.

In an attempt to attract minority students to careers in environmental chemistry, RCC proposes to use low-cost, “culturally relevant” research through a multimedia format. RCC believes that this approach may be the “magic bullet” needed to increase participation and boost interest among potential science majors and non-traditional students.

In particular, the college is using its newly funded “Technology Hub” to eventually link more than 20 community, HUD, and K-12 schools to Roxbury Community College, the provider of educational resources. More recently, the college has been targeted for funds to convert its Media Center to a Technology and Instructional Multimedia Satellite Center. The Center, originally proposed as a link to community sites for the purpose of creating virtual campuses, will be used to create a “virtual laboratory bench space” at city schools, with resources made available through multi-institutional collaboration.

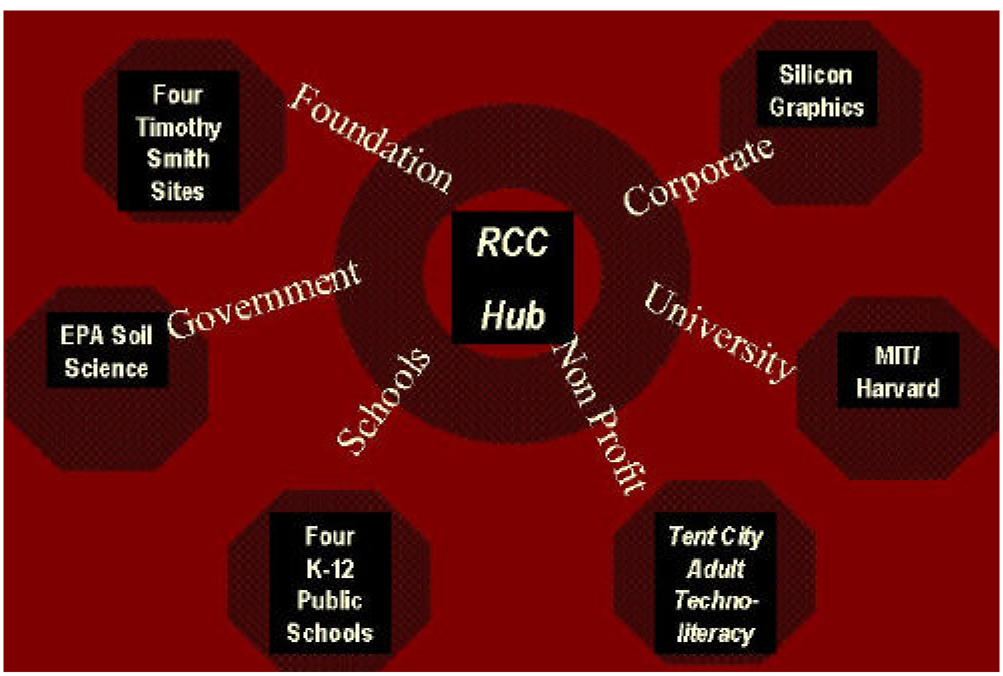

Figure 6. The new Technology Hub at Roxbury Community College

The creation of this virtual lab bench emphasizes the importance of educational collaborations and multi-level participation among foundations, government, schools, non-profit organizations, corporations, and community organizations. Funding organizations, of course, are important for providing endowments that can upgrade technology and sustain programs long enough to ensure quality change. Sustainability helps in the collection of long-term data.

A mixture of low-cost activities, strong collaborations, and the promotion of technology and Web access for all users can help safeguard against the formation of an underclass, or "techno-peasantry," in America. The virtual lab bench and similar programs can provide people of all ages and backgrounds with access to academic exposure and preparation for courses in science. The project can potentially become a model for other regions of the country.

The coupling of scientifically sound, research projects with multimedia technology gives students the advantages of hands-on experience and participation in a virtual learning community with unlimited resources. The "what's in my back yard?" approach to science exploration, using plants grown in soil, seems to involve all the elements of chemistry. For instance, electrodes obtained from a junkyard have been used to study the effects of AC and DC current on lead uptake into plants. In this single experiment, students can learn principles of electrochemistry and analytical chemistry.

Participants from linked sites can function as members of expanded research groups and share experiences traditionally reserved for exclusive research groups in private institutions. A program director will coordinate research projects between sites and participate in Web- and satellite-based communications. Everyone in the learning community can contribute to the results. Students can participate at levels appropriate for them, and potentially can be inspired to earn their undergraduate degrees in chemistry. After earning a chemistry degree, students can branch into other areas of science.

New Developments since the Preliminary Report

A partnership involving MIT, RCC and the EPA was implemented for the aforementioned phytoremediation project, in which plants are used to remove toxic materials from soil. An X-ray fluorescence spectrometer, a hand-held device that can electronically capture and download experimental results directly to a PC, was acquired with EPA support. Corn seeds were grown under controlled conditions. Students who participated in the project worked between MIT's Materials Chemistry Laboratory and RCC's Greenhouse. The team shared data and witnessed changes in biomass and uptake properties of lead and copper as a function of AC and DC current conditions. The plants from the experiment were harvested and analyzed using X-ray fluorescence spectroscopy. Initial findings indicated that lead extraction stunted the growth of the treated plants. High levels of heavy metal contamination in many inner city neighborhoods make the challenge of finding a technological solution especially appealing to minority students who are attracted to the possibility of harnessing science for the service of their community.

Implementation of the phytoremediation project illustrates the importance of collaborations. Robinson has helped catalyze the formation of an alliance between the City of Boston Trust, the Institute for the Integration of Technology and Instruction (of which Robinson is the founder and CEO), and RCC. This provided the framework for the creation of a technology hub that would link forty technology centers to RCC. Robinson's work, along with RCC's high-tech infrastructure and distance-learning mandates, provided the ingredients for a collaboration that will provide on-line resources in science and mathematics to "hub" members. Sites will be equipped with the latest technology. The completed infrastructure includes a satellite conference lecture hall with full global send-and-receive capacity for multimedia broadcast production and distance learning. The "RCC hub" and its "virtual laboratory bench space" enables students from all grade levels to contribute to experiments. Data exchange, advising, and scientific discourse can all occur remotely.

Recently, RCC has received a special bridge grant from the National Institutes of General Medical Sciences and a special technology improvement grant from the Commonwealth of Massachusetts. The potential for scientifically sound research projects using multimedia technology gives students the advantage of hands-on experience and participation in a learning community with shared resources. Students can be motivated to earn undergraduate degrees in science. Connecting nonprofit organizations that are working to empower disadvantaged groups to community colleges will enable each to share similar missions and pursue funds important for sustaining quality programs that ensure student success for traditionally excluded groups.

Preethi Pratap, MIT Haystack Observatory, "Undergraduate research through radio astronomy"

Research and teaching in astronomy have long involved the use of cutting-edge technology. The NSF-funded MIT Haystack Observatory carries on this tradition with the development of two radio telescopes that students and teachers can access via the Internet and use to learn the fundamentals of radio astronomy.

One of the goals of this "on-line observatory" (http://www.haystack.mit.edu/) is to provide opportunities for undergraduate science and engineering students worldwide to link their education with research through radio astronomy. The program consists of three main components:

- A small, 2-m diameter, radio telescope kit that will be sold to colleges and universities to teach the fundamentals of radio astronomy.
- A 37-m, research-grade, radio telescope that can be accessed over the Internet. Students use this telescope remotely to perform research experiments that can lead to new discoveries. Radio astronomy is still a relatively new science, with many exciting discoveries yet to be made.
- Extensive Web materials that help students and faculty use the telescopes and learn about radio astronomy. This program would not have been possible without the developments of the last decade in Internet technology. The Web site provides suggestions to faculty on how to include this experience in their curricula effectively. Examples include the use of the radio telescope for the spectroscopic detection of

ammonia and for the determination of temperature. The Web site also includes information about the radio telescopes' design.

Figure 7. Radio telescope at Haystack Observatory

Radio astronomy combines science and engineering, and allows innovative, hands-on observational experiments to be designed and conducted as real research experiences. Students receive a participatory experience in radio astronomy techniques; the on-line observatory is a test bed for real engineering experiences and study concepts.

To use the telescope, a potential user first makes a request and is then assigned an observation time. At that time, the user accesses the Web site to obtain information about remote operations and operates the telescope via the Internet, receiving real-time data in the process. This is a true example of distance learning!

As technologies improve, the on-line observatory will improve as well. Pratap mentioned several possibilities for future enhancements:

- "Backyard radio astronomy," conducted by converting small, 18-inch, television satellite dishes to radio telescopes.
- Radio interferometry experiments, conducted by linking the 2-m telescopes.
- Student research collaborations conducted nationwide, and even worldwide, through the use of the Web. Thousands of participants could contribute to massive data-gathering projects by monitoring their own "corners of the sky" and submitting the results.

Michael Doyle, Vice President, Research Corporation, "Research instrumentation"

Outstanding facilities for basic chemical science research can be set up and maintained at such a reasonable cost today that most undergraduate institutions can afford to be centers of excellence.

High-quality instruments for conducting basic research can be acquired and maintained for the tuition cost of fewer than three students at most private colleges, or for less than 0.5% of student tuition at a 10,000-student public institution.

Evidence is extensive and persuasive that research capabilities are a major contributing influence in drawing students into careers in science, among both undergraduate students and high-school students. Research differs from "discovery-based" laboratory experiences. "Research" is, in part, an apprenticeship conducted for the advancement of science.

Educators need to consider modernizing instrumentation when planning new science buildings or extensive renovations. Doyle reported visiting several new science buildings on private-college campuses and finding 40-year-old instruments within, or even worse, no instrumentation at all.

Undergraduate institutions that cut corners when buying research-grade instruments are sending the wrong message to potential students and the community at large. Students are discouraged from pursuing scientific study when they see outdated equipment in the laboratories.

Several institutions have recently built first-class, scientific learning environments for their students with outside funding from both public and private sources, including Furman University in Greenville, South Carolina, and Drury College in Springfield, Missouri.

Recent data indicate that while the number of chemistry majors at private colleges has modestly increased over this decade, the percentage change is substantially less than seen at research universities. There is also evidence, from data on grant-writing activity and refereed publications, that the emphasis on research at private colleges has diminished over this period.

Such research is vital, one Workshop participant said, because it is typical of the work that bench scientists actually perform. Undergraduate research promotes critical-thinking skills and teaches students how to draw conclusions based on real data.

Doyle has recently edited a book, "Academic Excellence: The Role of Research in the Physical Sciences at Undergraduate Institutions", Research Corporation, Tucson, AZ, 2000, that addresses many of these issues in additional detail.

“Where are we going? The brave new world and pitfalls”

Session Chair: Fennell Evans, University of Minnesota

Richard C. Larson, Massachusetts Institute of Technology (MIT),
“Learner as knowledge spelunker”

Video tutors, simulations, animations, and on-line laboratories can sometimes confuse and distract the learner. But, they offer another possibility: encouraging learners to be responsible for their own knowledge acquisition. If provided arrays of learning support, learners can behave more like spelunkers exploring vast caves of knowledge and less like hikers traversing a well-known path. MIT is exploring this possibility by presenting several new initiatives and then “thinking aloud” about their potential for the future, when Internet bandwidth is no longer a constraint. At that point, the major impediment to progress will be in knowing too little about how learners learn. To design truly useful learning environments, educators need to study the learning process with the same intensity that scientists study physical laws of nature.

A recent MIT initiative is PIVoT, the Physics Interactive Video Tutor project (http://curricula2.mit.edu/pivot). PIVoT is a hypermedia, Web-based video course for MIT students that attempts to integrate some of the tools that have been discussed at this Workshop. It is a highly interactive, student-directed environment that supports the learning of physics.

PIVoT offers video clips from physics lectures by distinguished professor Walter Lewin. Other rich media content includes physics problems and explanations for solving them, discussions of physics concepts, an on-line physics textbook, quizzes that confirm depth of learning, brain-teasers and unsolved problems, and links to related topics.

Several hypotheses supported the development of PIVoT. Newtonian physics is difficult for many students, and many could improve their depth of learning using a tutor, even students who have no apparent difficulty. The bandwidth of student-faculty interaction in a large lecture hall is minimal. Greater face-to-face contact between students and teachers can increase substantially with a software tutor.

In the future, PIVoT will include a software agent that guides the learner through the non-linear learning space. The agent will take each student’s history of using PIVoT as input and offer signposts for further study. This is an example of data mining that can assist in assessment and “learning about learning,” which can help address a key research question: How can educators find the best mix of facilitating technologies and teaching paradigms to educate a given set of learners in a particular knowledge area? *More, in-depth information about PIVoT can be found at http://caes.mit.edu/research/pivot/report_2000-10.html.*

Larson directs MIT’s Center for Advanced Educational Services (CAES), the main MIT facility for research in technology-facilitated education. To the community beyond campus, CAES (http://www-caes.mit.edu/) is the main source of MIT’s continuing professional education, often via distance learning. CAES assists faculty in using multimedia technology and in incorporating this technology into their classrooms.

An example of collaborative programs and distance learning is the Singapore-MIT Alliance (SMA) program. This five-year initiative establishes five new Master’s degree programs in engineering in Singapore. Internet II is a chief means of communication for the program. CAES is the production arm for this path-breaking project.

Philip Agre, UCLA, "Multimedia in university teaching: what can go wrong?"

Universities are pursuing numerous initiatives to incorporate multimedia technology in undergraduate teaching. At first experimental in orientation, some of these initiatives are moving into routine practice. Although some instructional uses of multimedia can easily be accommodated within the existing framework of the university, many proponents of multimedia instruction envision dramatic changes in the way that the university is run. Before such changes are undertaken, and before they are made inevitable by technical directions or public discourse, it is important for instructional uses of multimedia to be submitted to empirical investigation.

Agre's presentation sought to open a dialogue on the uses of multimedia simply by listing, from anecdotal evidence, the sorts of things that can go wrong with the technologies' use. The point is not that these pitfalls are inevitable, but rather that they can happen. Furthermore, many pitfalls (for example, the ones that involve suffering on the part of students) can be invisible unless one looks for them specifically. Consequently, serious experiments in the use of instructional multimedia should be accompanied by ethnographic investigations that can determine, in qualitative terms, what is working and what is not.

Here are some of the things that can go wrong when multimedia technology is used in university teaching:

- Many student computer labs are in peripheral locations on campus, which can create a perceived, if not actual, personal safety problem.
- Technical problems can result from having incompatible applications at various facilities on campus.
- The same incompatibilities can exist between campuses, frustrating and hampering attempts at collaborative efforts.
- There can sometimes be a failure to ask how the tools fit within the community at large.
- Critical mass problems: some applications have to be used by many students in order for the applications to be successful, and fail if not enough do.
- The academic community can create disincentives to sharing. Problems with sharing can also occur when academic departments attempt to administer and use the same technology resources. These turf wars frustrate integration.
- Formless "discovery" tasks: students can sometimes work on-line and do whatever they want, as long as they pass the institution's requirements, but is their work valid? Also, instructors can be stretched thin as a result of responding to countless e-mails from students who are all doing their own, independent projects on-line.
- Faculty, students, administrators, politicians, and the community at large can have different agendas and preferences for software and its use in the curriculum.
- At the K-12 level, there are often "violent fashion changes." Teachers can master a certain technology or teaching method that uses technology, only to be told it is being replaced by another, "better" approach.
- Stereotypes: administrators can begin to form stereotypes about how faculty view technology innovations, and faculty can form their own about the administration, leading to a "death spiral of stereotyping."

Problems can go unnoticed for many reasons:

- A university has many divisions of labor. Sometimes the decision makers might not see problems they are in a position to fix.
- Experts can forget what it is like to be a beginner. Small things make a difference to new users, and experts can forget about these things. (This point echoes the previous discussion by cognitive-learning scientists, who pointed out that beginners expend valuable energy processing unnecessary information, while experts know how to focus quickly on important material.)
- Teachers can forget what it is like to be a student.
- Power can inhibit feedback.
- Students who don't quickly understand a concept or the technology can feel stupid and blame themselves for the problem.
- Teachers can make the mistaken assumption that students know the technology, since they are less likely to be intimidated by it than previous generations. In fact, Agre said, students can use the World Wide Web and CD-ROMs, but in general they don't really understand the technology.

Finally, here are some solutions for addressing problems:

- Look at the "edges" of the problem. For example, what is the impact of the lost social interaction between student and teacher as a result of multimedia use? Teachers can miss important information when they don't see what is actually happening as students do their work.
- Find out about students' lives. Students can have family problems, social problems, or drug problems, among others, which impede learning. These problems can become even more hidden in a multimedia-driven learning environment.
- Be open about design space and what is needed in design. (For example, why has teleconferencing not been more successful?)
- Don't romanticize the idea of face-to-face contact. Conversely, don't romanticize the processing power of computers.
- Don't be afraid to write a coherent report and explain what we *don't* know.
- Develop common platforms. Universities will need an economy of scale, and thus will need to integrate their efforts to avoid duplication of effort and incompatibility. Many good developments can occur on an integrated platform, but many otherwise well-conceived initiatives can stall and fragment on a bad one.
- Let's stop fretting about the "next big thing" that's seemingly always on the horizon, and start thinking about the long haul.
- Don't just assume that a large percentage of the faculty are against technological change. Ask them what they really want and need from the changes.
- "Mind-meld" over the Internet with people who think in a like way and share your enthusiasms. Stop thinking that your problems are unique, when in fact many of your fellow teachers are facing the same issues on other campuses.

Reflections on second day sessions

Marco Molinaro, University of California, Berkeley

- Regardless of the technology we use, pedagogy comes first. Educators must create and use tools that are adjustable and flexible.
- We must share negative results. We are all learners, and we are not above our students.
- Naysayers question the new approaches, but rarely the old ones.
- Developing a usable suite of technologies that improve education will be a massive effort requiring assessment experts, cognitive scientists, instructional designers, and computer programmers, among others.
- Are staff and faculty motivated to change? Why? If not, why?
- One of our challenges is to create truly interdisciplinary courses. For example, whose class will incorporate the radio telescope Web site that Preethi Pratap described? Which courses should be removed from your current curriculum? How do you change the structure of the courses so that they are truly interdisciplinary? In which department will the course be placed?
- If your school uses great products and has motivated faculty, is sustainability really driven by economics? Can economics overcome the politics?

John Jungck, Beloit College

One of the benefits of the Workshop is the realization that you cannot do it alone. You need cooperation from many disciplines.

We face several problems as educators: how to ensure greater inclusion and access for students; a lack of discussion of how new technologies impact the laboratory environment; a lack of knowledge of the design issues; and the tendency to work in isolation, without fully exploiting the work of colleagues through networking.

Questions of sustainability, replicability, and transferability are critical. We need to develop more literature, and create more citations of heterogeneous literature to make it accessible to everyone. Also, instead of focusing on the teaching of concepts, might we not encourage original science from undergraduate students from the beginning of their college careers?

Christine Massey, University of Pennsylvania

We need to think about innovations in teaching and instruction as a design science. Viewed from the stance of design problems, frustrations about the difficulties of dealing with underspecified problems, technologies whose effects and properties in action might not be predictable or well understood, and the inadequacies of an incomplete research base are to be expected. In a complex design space, in which it is difficult to anticipate exactly what the pathway and outcomes will look like, it is important to focus our attention on supporting a good design *process*.

As part of this effort, we need to develop a culture of evidence that moves beyond intuition. Developers and innovators may feel burdened by the demands of rigorous assessment and evaluation, and baffled by the jargon that sometimes accompanies it. Instead of abandoning our reliance as scientists on systematic investigation and evidence because the focus is now on processes like thinking and learning, we should redouble our efforts to approach educational innovation from the stance of scientifically informed experimentation and investigation. Cognitive science and evaluation studies are two sources that provide much more powerful tools and methods for studying and assessing students' thinking and learning than the traditional student course evaluations or multiple-choice tests.

Collaborations and partnerships are an essential key to developing, implementing, and evaluating high-quality educational innovations and reforms. We need teams of people with interlocking expertise. It is important to combine multiple resources and partners, since individuals are likely to feel overburdened and overextended by the many demands of developing and institutionalizing effective technology-based innovations in education.

"Where are we going? Institutional and infrastructural perspectives"

Session Chair: Edward Davis, DuPont Experimental Station

Frances Houle, IBM Almaden Research Center, San Jose, California,
"Distributing Chemical Kinetics Simulator on the Web"

Chemical Kinetics Simulator (CKS) is a unique program that allows rapid and accurate simulations of many types of chemical reactions. Originally developed by Houle and W.D. Hinsberg for internal use at IBM, it has been available worldwide on the Web since 1996 for a no-cost license from www.almaden.ibm.com/st/msim/ . More than *15,000* copies have been downloaded in 90 countries, with a user base in industrial, academic, and national research laboratories, and government agencies. Its primary educational uses are as a tool for chemistry and chemical engineering courses, labs in grades 7-12 and at the college level, and for independent study and student projects. Houle hopes that CKS and other tools will help students "get over the hump" and embrace learning in MPS. IBM has found that too many graduates are entering technology fields with inadequate scientific and mathematical training.

In developing and distributing CKS, the primary focus was to create a reliable resource that would be of use to scientists at all levels. The designers were especially mindful that simulations are not commonly used in chemistry, and that chemical kinetics is no longer a major focus of the undergraduate curriculum. Accordingly, the materials on the Web site are designed for ease of use, with extensive documentation, references to scientific literature, and demonstration simulations to teach basic concepts in kinetics and simulation techniques. All materials were tested extensively by various expert and non-expert users, who helped refine the user interface. The documentation and context-sensitive help system were written by a non-expert, to ensure that materials were understandable to all levels of users, including novices.

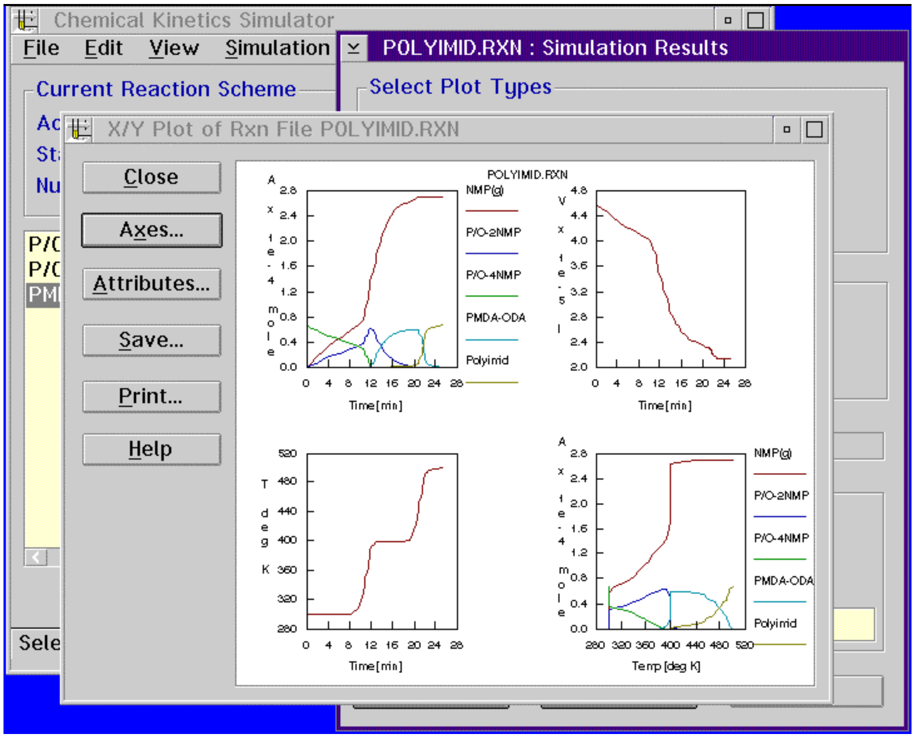

Figure 8. The Chemical Kinetics Simulator program, available via the Web

While creating the Web site, the developers used the following principles to guide decision-making:

- It was essential that the site and the CKS package be credible. Ensuring accuracy of the code was not enough; it was important to convey a sense of connection to the literature, and that CKS was a long-term priority. Contact information is posted on the site, and all user queries are answered promptly.
- The Web site and the package had to be easy to maintain, since simulator development and user support are not the developers' main work at IBM. Therefore, an application framework was used to write the user interface, so there is a single set of source code for all platforms. The site includes a great deal of information about the simulator and how to use it, which minimizes the number of user questions.
- The site and CKS had to obey all copyright laws. The code was certified to be completely original, and the developers had to obtain an IBM license.
- The site had to be easily accessible, especially to visitors with older computers and software. Downloadable materials had to be minimal in size, run on many computers and operating systems, and be available at no cost under a user-friendly license. The site had to be easy to find with all search engines, and listed on various resource sites. Educators should never underestimate the power of the Web; it is amazing how quickly users around the world found and then used the software.

In 1995, when CKS was being prepared for distribution, there were few models for how the Web site should be organized. The developers conducted an extensive, year-long business analysis on the feasibility of commercializing CKS, but could not find a means of distribution that made financial sense. The developers considered dissemination by IBM, by other vendors, and by a vendor under license, before ultimately deciding to publish the material on the Web with a no-cost license.

The commercialization exercise was valuable; CKS benefited from the market research because the developers were able to interact with potential users, and gain important insights into the realities of marketing something fundamentally new to a community that was unsure of its need for the product.

A concern for the long-term viability of CKS is its inevitable dependence on third-party operating systems and application frameworks that become obsolete and non-functional. This maintenance issue will affect many computer-based tools that the educational technology community creates and uses.

CKS has worked well, and has been widely accepted throughout the world in the education and R&D communities. Although most aspects of the project have been successful, the site does not yet include a great deal of user interactivity. In the future, the developers hope to introduce demonstration, laboratory, and lecture plan repositories, a user forum, and a discussion of CKS applications.

Maria Klawe, Dean of Science, University of British Columbia

Klawe addressed three topics in her presentation: gender access and equity issues in educational technology; the enabling of change at the university level, from the perspective of a university administrator; and, insights about the design and use of educational software from her experience as director of E-GEMS, an interdisciplinary project studying computer games and activities for mathematics education in grades 4 to 8.

Gender issues matter in educational technology. Although female participation rates in undergraduate mathematics, science, and engineering programs have substantially increased, females now make up only 15% of most physics departments. Female enrollment in computer sciences has fallen to 15% at most research-intensive universities, from a level of 35% twenty-five years ago.

Computers, especially games and programming, are perceived by many females as a male domain. Teachers must be aware of this perception, especially in grades 4 to 8, which is a critical period in influencing children’s decisions regarding what careers to pursue. Research indicates that girls aren’t interested in information technology and computer careers, in some part because they are perceived as male realms. Many girls lack confidence in these areas. The computer games they see are very “boy-oriented” in their focus on adventure, action, and violence.

A career interest survey of 7,300 high-school students in Vancouver shows a substantial gap between the numbers of girls and boys who are interested in taking courses in computer science and engineering. The survey also indicates that, unlike 20 years ago, the gender gap in mathematics interest is no longer substantial.

Longitudinal studies on student use of computers show that girls and boys express quite different program preferences. Girls like creative activities, such as writing. They like story lines and they want positive social interaction. Boys want fast action, challenge, adventure, violence, a sense of power, and more immediate feedback. Girls and boys also use computers differently: boys move through programs and games very quickly, sometimes as fast as they can. Girls do not rush to get through activities; they tend to explore more along the way.

Boys rush to use the computers in school, and control them before and after class. Girls, on the other hand, are much less assertive about getting computer time. Simple teacher intervention can be very important in changing this dynamic. By designating more equitable computer sessions and having separate discussions for boys and girls, teachers can help the girls become much more assertive and confident in their abilities.

At the college level, there are several negative factors that inhibit computer use and study for young women. One issue is safety; as Philip Agre pointed out, many computer labs are located on the periphery of campuses. Male students sometimes download pornographic materials in the computer labs, which can be threatening to women. Finally, many female students feel intimidated by "macho geeks," who have (or think they have) more proficiency and experience with computers. The alternative is for young women to use computers only within their own rooms, which can lead to isolation.

After discussing gender issues, Klawe turned to the topic of enabling change at the university level. The challenges for technology-enhanced science learning are similar to those for enhancing learning in general. Universities must develop a better reward system for tenure and promotion that recognizes innovative work in these areas. Many of the Workshop participants have worked very diligently on projects that they believed in passionately, and have seen their careers suffer.

Some helpful conditions that could engender change include: support from senior administrators, such as presidents and provosts; budget cuts, ironically, because cuts can force changes and experiments that would not be attempted otherwise, as well as encourage greater cooperation and sharing; competition, which could encourage more partnerships among universities; the willingness to learn (and fail); funds for innovation, as long as the money is well-spent; commitment to valuing contributions from other disciplines; and, patience and persistence.

To conclude her talk, Klawe discussed E-GEMS. Over the past six years E-GEMS has conducted a wide range of research studies and developed innovative prototype games, particularly for grades 4 through 8, which are available to educators for use in the classroom. E-GEMS research demonstrates that computer-based games and activities can be very effective in increasing both motivation and achievement in mathematics learning. Unless students are engaged and motivated, they will not be interested in learning.

E-GEMS research also pinpoints the critical importance of detailed elements of game design, the role of the teacher, and the integration of computer games with other forms of mathematics education. These games provide a means for children to use the patterns they are discovering and incorporate them into the types of mathematical concepts that can be useful in life. Prototype E-GEMS games are freely available to educators at http://taz.cs.ubc.ca/egems/home.html.

Gary Wixom, Utah System for Higher Education; Richard Cline, Utah Educational Network; and Todd VanderVeen, University of Utah, Center for High Performance Computing, "Improving undergraduate mathematics and science through technology"

Mathematics and science skills are becoming increasingly more important in the world economy, but research indicates that many Americans are under-educated in these crucial areas. A chronic shortage of engineers, scientists, researchers, and technicians appears to indicate a national problem. For example, Colorado currently has 7,000 job openings in high-tech fields, but fewer than 500 graduates in mathematics and sciences.

Part of the solution could be to provide increased opportunities for students to master MPS foundation skills early in their undergraduate careers. One area that could provide this support is the for-profit education and training industry, which includes the new "virtual university."

Utah has several statewide initiatives in virtual MPS studies. One example is the Western Governors University (http://www.wgu.edu), which has 10 degrees based on competencies, and provides on-line courses that include algebra, geometry, engineering mathematics, biology, environmental geology, and evolution. Another virtual university is the Utah Electronic Community College (http://www.uec.org), which began in the fall of 1998. At the moment, the college has no independent courses or degrees, but offers a variety of study areas that can help students master basic MPS competencies.

Although the number of virtual universities is growing, the questions of their effectiveness and future accreditation have yet to be answered. However, virtual universities have already shown that they can play a useful complementary role in several ways:

- Virtual campuses can be an attractive learning environment for non-traditional students.
- They can play a role in improving the level of MPS mastery by undergraduate students.
- The on-line format can offer greater levels of interaction with students than the traditional lecture hall format.

Another important initiative is the Utah Education Network (http://www.uen.org). UEN serves Utah's educational community, provides full-time network access from all schools and district offices, and acts as a clearinghouse for services that can aid teachers in developing and delivering curricula.

UEN provides a state-wide infrastructure that consists of a video conferencing system (EDNET), an Internet connection (UtahLINK), and broadcast television (Channels 7 and 9). EDNET provides a two-way, interactive, video system with access to over 200 classrooms. More than 11,000 students in 400 courses were taught via EDNET last year. In addition, more than 5,000 Utah educators received 50,000 hours of training via UEN last year.

UtahLINK provides Internet access to more than 98 percent of the schools in Utah (22,000+ classrooms) via T1 lines or better. UtahLINK also provides resources such as Utah's core curriculum, lesson plans, an on-line library, a database of educators state-wide, and special-interest listservs. Teachers use these resources to create curricula and design virtual tours, and use courseware toolkits to create instructional materials.

UEN's two broadcast television channels last year provided 1,550 hours of programming each, including courses that students can take for credit, programs teachers can use to supplement their curricula, and educational programs that anyone within the coverage area can view at home. Teachers can also participate in training opportunities provided by UEN to learn how to use these resources in implementing the use of technology in the classroom.

In the future, UEN is moving from analog to digital to combine the broadcast-quality video/audio and data communications networks into a single delivery system, which will reduce hardware and ongoing expenses while maintaining and increasing high-quality delivery of educational resources. UEN is currently in partnership with the University of Utah and MCI WorldCom Foundation, to develop materials that can be used in pre-service instruction to educate future teachers on how to integrate technology in the classroom.

Another exciting new program in Utah is a Web-based educational initiative called ASPIRE (Astrophysics Science Project Integrating Research and Education; http://sunshine.chpc.utah.edu). ASPIRE offers students:

- An array of engaging learning materials (including cosmic-ray studies and general physics)
- Access to university research data
- Interactive, Java-based science labs, with technical assistance
- A look into possible careers in science and technology.

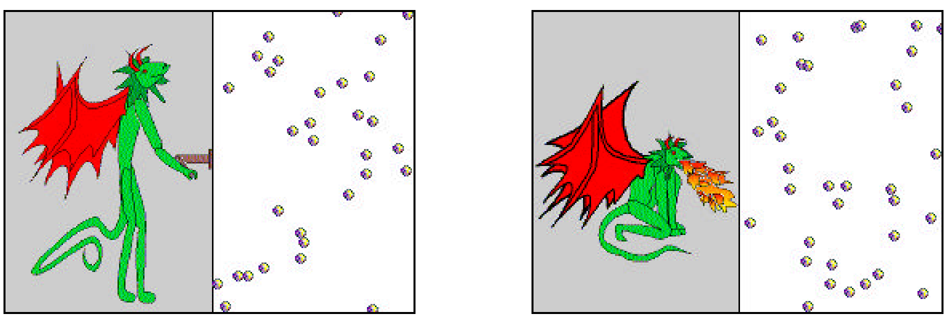

Figure 9. Maxwell's demon helps teach principles of science in ASPIRE. At left, the demon changes the volume; at right, the demon changes the temperature.

All of the labs come with preparatory materials for the teacher, including a science review, an invitation to learn, pre- and post-assessment tools, and in-class extension activities. While the lessons in ASPIRE currently are intended for use in the secondary school system, they (or at least the approach taken toward their production) could readily be extended to all levels of instruction.

From participating in ASPIRE, research scientists are positioned to gain a better perspective on how MPS issues are important to society at large. Furthermore, in working with teachers they improve their ability to communicate the relevance of their work.

ASPIRE uses Java, which is a general-purpose, object-oriented programming language. It is platform-independent, which is important when developing broadly distributed materials (particularly when targeting the educational community, where Macintosh is well-represented). Java is also a quite secure language, which is important because many schools are strapped for resources; it can be difficult enough for schools to invest in computers and other technology infrastructure, without worrying about spending more on security issues. It helps to start with a robust, intrinsically safe language.

Summary and recommendations of Workshop participants

The charge to the Workshop was to provide a “snapshot in time” of the use of technology in college MPS courses, a vision for the appropriate role of technology in these courses, and recommendations for how to achieve this vision. The concluding session provided a retrospective look at the Workshop themes through the reports of four breakout groups. These groups considered general issues along with issues of equity, teacher preparation, and the production and dissemination of instructional materials. Their perspectives and recommendations are included in the following summary.

How do we get there? What does “there” look like?

The vision that emerged from the Workshop is that undergraduate MPS education should have a vitality commensurate with that of the MPS research enterprise, and a reach that effectively embraces all students and instructors. An “integrated research” model for undergraduate MPS education would use technology as one of its elements in much the way that the research enterprise uses it — to create knowledge and to communicate it to diverse audiences. Such a model, however, needs to have an infrastructure like that of the extraordinarily successful research enterprise, which is nurtured by a culture that promotes experimentation and provides resources for it, and by a reward system that recognizes the importance of both incremental advances and “quantum leaps” in understanding.

A corresponding infrastructure for undergraduate MPS education will help produce a stream of widely accessible new instructional tools and methods, whose pedagogical value is informed by research studies from the cognitive and behavioral sciences, whose efficacy is monitored by critical assessment and evaluation, and whose reach can accommodate diverse student learning styles. Likewise, a culture needs to be established to ensure that the content and delivery of undergraduate MPS education is not static but dynamic — that our classrooms and laboratories provide opportunities for continuous experimentation to identify better ways to create and communicate MPS knowledge and methods to our students. A reward system that is in alignment with such a cultural change, and that celebrates both incremental advances and “quantum leaps,” is a critical element in effecting such a paradigm shift in higher education.

Partnerships for getting “there” and recommendations

Because of the central role that college MPS instruction plays in the educational enterprise, implementing this vision requires a systemic approach built upon partnerships. Many of the recommendations that emerged from the Workshop can be described as technology-assisted partnerships between the undergraduate MPS education community and at least eight other stakeholder groups. These collaborations are diagrammed below, with “student partners” and “funding partners” representing cross-cutting partnerships:

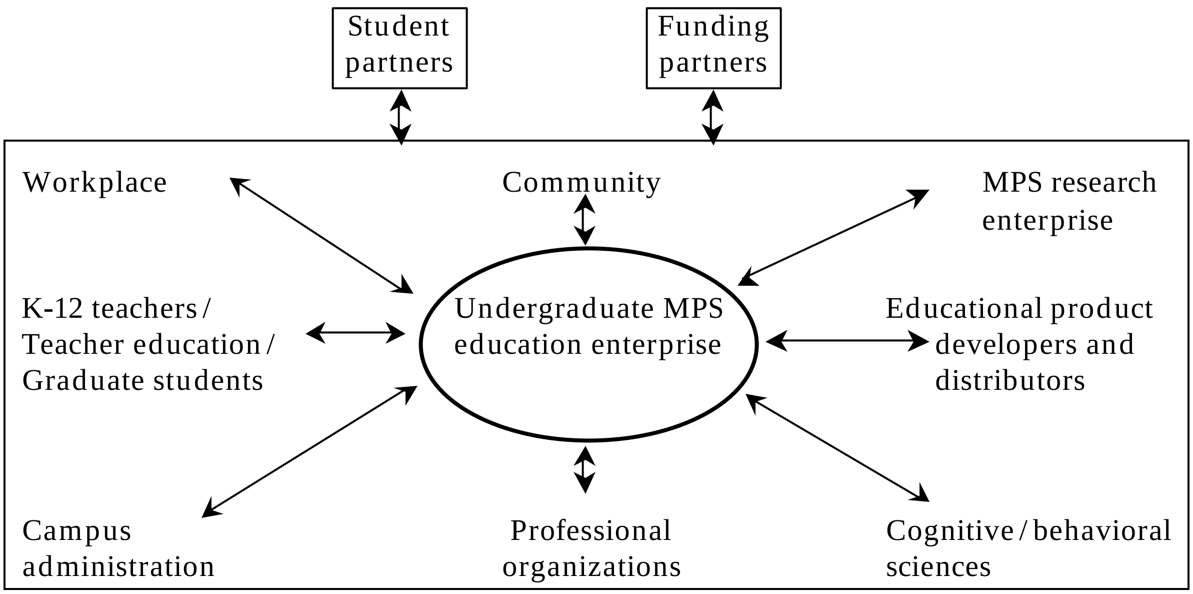

Figure 10. Partnerships in MPS education

Proceeding clockwise from the upper right corner, examples of these partnerships are provided from Workshop presentations and discussions. Collectively, they constitute a set of interconnected recommendations spanning many of the issues considered at the Workshop, but they are not meant to be exhaustive.

Foster an integrated research model for MPS undergraduate education

The MPS community should seek ways to couple research and technological advances more tightly to its educational missions. One mechanism for linking MPS research and education more strongly is to use new research results and technologies in undergraduate classrooms, informed by results from cognitive and behavioral sciences and by assessment and evaluation. Another is to expand opportunities for undergraduate research.

Partnerships with the MPS research enterprise

A vibrant educational enterprise requires infrastructure for creating, maintaining, and disseminating modern instructional materials and methods. Research in MPS and allied disciplines provides a steady flow of new examples and technologies, many of them interdisciplinary, that can be introduced into undergraduate MPS curricula. All members of the MPS research community — from 2- and 4-year institutions, comprehensive and research universities, industry, and the national laboratories — should be encouraged to participate in this effort. Programs like the NSF's CAREER Awards, Research Corporation's Cottrell Scholars Awards, and the Dreyfus Foundation's Teacher-Scholars Awards communicate this important message at an early stage of professional development. Researchers can be encouraged to incorporate their findings into undergraduate classroom and laboratory environments — a kind of "educational technology transfer" — by providing widely available, easily understood summaries of their work, and they should be recognized for exemplary efforts. A related initiative at the graduate level is the NSF's Integrative Graduate Education and Research Training (IGERT) program (http://www.nsf.gov/pubs/1998/nsf9896/nsf9896.htm).

Undergraduate research experiences — broadly defined and practiced across the full spectrum of postsecondary institutions — have been effective in providing an understanding of the methods and tools through which MPS knowledge is created, and for attracting students to MPS careers. Programs like the NSF's Research Experiences for Undergraduates (REU) and Research Corporation's Cottrell College Science Awards have given many undergraduates their first opportunity to conduct research. The Carnegie Foundation has advocated that all undergraduates at research universities have a research experience. Technology may provide a mechanism to enlarge the reach of research, as tools and data can be widely shared. Blueprints are needed for how to implement such an effort. Educational research on technology-enriched college MPS courses is a fledgling research area that may lend itself to undergraduate research experiences.

Partnerships with educational product developers and distributors

A recurrent Workshop theme was how to maximize the impact of instructional products to ensure their transportability and sustainability, and how to handle the associated costs. A dialogue with individuals and companies who develop and distribute instructional materials is needed. For example, use of a common, sustainable platform could facilitate large-scale distribution of new instructional materials on an ongoing basis. The publication and distribution of products that do not appear to be profitable, either because they are regarded as too innovative or as falling outside of traditional markets, needs to be addressed. Of particular importance is how institutions with limited resources can benefit from the use of technology-enriched instructional materials. Adopters and adapters can add significant value to these products by sharing their experiences in using them.

Partnerships with cognitive/behavioral sciences

The MPS community needs to recognize that research in how students learn about the MPS disciplines effectively through technology is an important field of scholarship. MPS instructors should collaborate with researchers from the behavioral and cognitive sciences in developing new instructional materials. Establishing methods that diagnose the learning needs of students and the effectiveness of new materials will greatly increase their value. Participation in such an effort will also help MPS instructors learn how to communicate their subject matter more effectively, by recognizing different student learning styles and by creating sharper tools for assessing student learning. This knowledge, in turn, can lead to more informed programmatic changes. Initiatives like Cybertutor and PIVoT illustrate the potential to combine findings from these allied disciplines with MPS subject matter in order to customize material, so that students can master it in a timely manner. Colleagues in departments of education can also provide valuable input to these efforts. It is noteworthy that cognitive research on student learning in MPS indicates that instructors overestimate how accurately and robustly students learn what is taught, an observation that may be obscured by examination grades.

Partnerships with professional organizations

Professional organizations can help to create and publicize new instructional materials and methods, and to disseminate information about them through the communities they serve. Some of these organizations, such as the American Association of Higher Education, have made the integration of technology into the undergraduate curriculum a centerpiece of their activities, through the Teaching, Learning and Technology Roundtables program and the development of evaluation tools like the Flashlight Project.

As products are created, the MPS instructional community needs partners to establish a clearinghouse for them. The NSF recently hosted a conference on the Digital Library, which is being developed to serve such a function. Besides easy accessibility, Workshop participants recommended that the library contain reviews, ratings, and recommendations of library materials and protocols; identify user hardware and software requirements; contain an excellent search engine; have mechanisms for monitoring usage; incorporate a long-term maintenance plan by submitters; include materials that are both free and for sale; and permit users to share experiences in how the material was incorporated into undergraduate MPS classes, including their views of its strengths, weaknesses, and impact.

Broaden MPS academic scholarship to include the scholarship of teaching

In partnership with campus administrations, MPS faculty should take a more proactive role in creating and critically implementing technology-enriched education.

Partnerships with campus administration

Campus administrators play a crucial role in allocating resources for technology-enriched instruction, facilitating buy-in from faculty, and determining the campus reward structure. They can create a culture that encourages MPS instructors to experiment with technology-enriched classes and to develop new instructional materials and methods. Teaming with the administration should be an essential element of MPS instructional technology projects, from conception to implementation. Campus teaching centers can provide effective organizational support for technology-based educational initiatives.

Administrators and senior faculty can encourage faculty to bring appropriate technologies into their courses by publicizing successful technology-enriched courses, by presenting meaningful examples of how well they work, by providing the resources and training to implement these changes, and by valuing these contributions as essential to the academic mission of the institution.

The scholarship associated with these efforts should be appropriately recognized and rewarded through merit, tenure, and promotion protocols. Guidelines for assessing the scholarship associated with teaching have recently been published in a work entitled "Scholarship Assessed: Evaluation of the Professoriate."

Incentives for encouraging interdisciplinary work on campus can enrich MPS research and education by introducing new perspectives, and can broaden the impact of instructional initiatives.

Administrators can facilitate the gathering of statistics, including longitudinal databases, that can help instructors evaluate the success of their instructional projects. By looking at databases of student achievement, persistence, and attitude, and data on subsequent enrollment, performance, and job placement, instructors and administrators can gauge the impact of instructional changes. By looking for evidence of different impacts among student populations, progress toward equity goals can be evaluated. New organizational structures may need to be created to assist instructors with assessment and evaluation efforts. Offices of institutional research, which exist on many campuses, can be partners in this effort.

New opportunities may exist in articulation, advising, and tutoring that can change the complexion of MPS undergraduate education. Articulation between high school and college, between 2-year and 4-year institutions, and between courses within a campus could all be aided by technologies that allow students and advisors to determine what MPS subject matter has and has not been mastered. Advising could become more consistent with such information, and with data on how students have fared in making such transitions. The kind of preparation and attitudes that students need can be communicated in greater detail. The development of tutoring tools based on technology, such as Cybertutor and PIVoT, may help to close the large gaps that still exist in some college MPS courses between instructor expectations and student performance.

These gaps often lead to significant student attrition and negative attitudes toward MPS disciplines. Administrators should work with MPS instructors to use appropriate technologies in curricula that promote science literacy, lifelong learning, and that develop a diverse, skilled workforce that can continuously adjust to changing workplace technologies.

Another area that may be ripe for investigation is the adaptation of the "incubator" model for developing start-up businesses. Venture research and development efforts in the commercial sector are frequently started in such settings, using temporary allocations of shared resources. Universities have begun to provide and market this service, which could potentially be applied to MPS technology-enriched instructional materials and methods. However, issues related to the appropriate use of institutional resources would need to be resolved.

Support teacher professional development

Instructors define the MPS educational enterprise. The development of a comprehensive program of professional development for MPS instructors — from recruitment to retirement — is needed to capture fully the potential benefits of technology-enriched education.

Partnerships with K-12 teachers/Teacher education programs/Graduate students

As illustrated by the ASPIRE project, PNNL Collaboratorium, Chemical Kinetics Simulator, and "Deformed Frogs" project, there are excellent opportunities for college and K-12 teachers and students to work with MPS researchers to create exciting new instructional materials, based on current research and good pedagogy. These materials can be widely shared using the Web.

Many more of these initiatives that bring research to the K-12 teaching community, such as the NSF's Research Experiences for Teachers, would be welcomed by pre-college and higher-education MPS instructional communities, and could increase communication among current and future teachers. Teacher networks like the Utah Education Network can facilitate sharing of information as part of professional development programs.

College MPS instructors need to communicate to MPS majors that K-12 teaching is a valued career choice. These instructors should develop collaborations with teacher education programs to identify potential pre-service teachers from among MPS majors, and to nurture their development in an appropriate blend of technology-enriched MPS and education curricula. Examples of successful partnerships can be found in the NSF-funded Collaboratives for Excellence in Teacher Preparation (CETP). The MPS instructional community can also help certify teachers who have non-traditional preparation, but may be qualified to teach MPS subjects in K-12 schools.

Many graduate student teaching assistants will become instructors themselves. Their inclusion in the development and delivery of technology-enriched instructional materials provides a foundation for making technology an integral part of their professional development. The new NSF GK-12 program, which links graduate students with the K-12 teaching effort, is an innovative approach for bringing these two communities together. Also noteworthy are programs like the Pew Foundation's "Preparing Future Faculty," Project Kaleidoscope's "Faculty for the 21st Century," and a variety of campus programs that are helping to prepare teaching assistants and to mentor junior faculty with regard to effective teaching practices.

Strengthen links to the workplace and community

Technology provides tools and methods that extend to virtually all work environments, and that have transformed society as a whole. Better connections to employers and the wider community are needed to develop support for MPS research and education missions.

Partnerships involving the workplace

Companies that hire graduates are in an excellent position to provide feedback on how well they have been educated in MPS disciplines. Their continuous input on the technical skills and knowledge students need in order to be effective contributors should inform efforts to incorporate technology into MPS undergraduate instruction. Academic institutions can partner with industry and national laboratories to share projects and courses, enhancing access to resources in MPS education. Internships can provide excellent opportunities for undergraduates to apply their technical skills and to acquire new skills as they work on real-world problems and research projects.

Partnerships with the community

Lifelong learning in MPS disciplines can be facilitated by technology. Distance learning technologies, as illustrated by the Western Governors University and the Utah Electronic Community College, permit students to continue acquiring knowledge and skills related to MPS disciplines, outside of a conventional academic setting.

Innovative community-oriented MPS examples presented at the Workshop include the Roxbury Community College Hub, which engages the community in MPS-related activities, and the Haystack Observatory project, which will enable common television satellite dishes to be used as home radio astronomy observatories. Projects like ASPIRE allow citizens to learn more about MPS research projects.

There are opportunities for new kinds of service learning in undergraduate MPS courses, in which students can collect data from their local environment and share it with the community.

Treat all students as partners, ensuring equity and access

The ability to learn through technology and to use technology is now a core competency. In partnership with the K-12 community, institutions have the responsibility to ensure that all students have the technological foundation to learn in their restructured, technology-inclusive curricula.

Technology makes it possible in principle for everyone to participate in the exciting developments associated with research and education in the MPS disciplines. How can broad access and equity be achieved? We consider these issues as they apply to traditionally underrepresented groups, the academic consequences of these issues, and then describe some solutions and plans of action.

Poor socio-economic background, lack of a college tradition for many students from underrepresented groups, and a Euro-American culture at most institutions limit enrollment in college and in MPS courses. Even after enrollment in these courses, however, lack of role models, lack of peer support, and the absence of a critical mass of students with similar backgrounds can discourage students from studies in MPS disciplines, as can socially unappealing or discouraging stereotypes of mathematicians and scientists. These students may find themselves marginalized or stereotyped as underachievers, or they may have different learning styles that are not supported by the kind of instruction they receive. Students transferring from two- to four-year institutions may be unfairly characterized by the perception that their preparation is inadequate. Technology can exacerbate these problems if underrepresented students feel that it negatively impacts them relative to their peers.

As a result of these problems, students may feel isolated. This feeling can result in low attendance and class participation, poor retention, and low graduation rates. Intervention programs that exist on many campuses may not be able to address the root causes of the problem.

Outreach efforts represent one possible solution to these problems. Greater involvement with communities and K-12 schools can help to ease the transition to college, but all participants need to recognize the role that technology plays in the transition. Undergraduate MPS curricula should be designed to recognize and enable different learning styles, and to accommodate different starting points and pathways through the curriculum. As noted above, technology may be able to help with these articulation and advising issues. Technology can also help to create learning communities, promote collaborative learning, and provide tutoring. For the instructor, technology can be used to share curricula, learning resources, and professional development opportunities that promote equity within institutions.

As a plan of action, three suggestions are to:

- Develop tools for testing competency in MPS disciplines using technology, recognizing that this needs to be done carefully.
- Reward and publicize innovative programs that are effective in increasing successful participation in MPS education and research by underrepresented groups.

- Develop mechanisms to update MPS skills and knowledge for returning students and to support the transition from two- to four-year institutions.

A philosophy that all students are our partners underpins all of these proposed initiatives and recommendations. Like the MPS instructional community, students must become lifelong, independent learners, and the seemingly daily advances in technology provide the most persuasive means of making this point. Technology can help the MPS instructional community by refocusing its teaching philosophy: rather than measuring our progress by how many ideas and how much material we have covered, technology frees us to make certain students understand how they can enrich their understanding of MPS on an ongoing basis.

Invest in technology wisely

Technology costs money, and there are significant economic advantages to developing partnerships that:

- Enable research and technological breakthroughs to invigorate the undergraduate and K-12 MPS curricula;
- Bring cognitive and behavioral science methods, and assessment and evaluation tools, into the service of MPS instruction to enhance its effectiveness;
- Make MPS knowledge and tools available to employers and citizens.

Many of the exciting initiatives described in this Report could not have developed from academic institutions alone, but required partnerships with federal, state, local, and private funding agencies and foundations. These partnerships represent successful leveraging models on which to base future funding efforts.

At the same time, it is imperative that information about what is effective and ineffective be shared quickly and widely, so that our limited resources can be used prudently. The importance of undergraduate MPS education demands our best efforts to make wise investments. Through judicious planning and partnering, we can ensure that 21st century, technology-enriched MPS undergraduate education meets its objectives of promoting science literacy and lifelong learning, and of developing a diverse, skilled technical workforce that creates the research advances and technologies of the future.

Workshop outcomes and related developments

The workshop whose proceedings are summarized in this report was also used to launch the Learning Through Technology (LT^2) Institute, under the auspices of the College Level One (CL-1) Team of the NSF-supported National Institute for Science Education (NISE) at the University of Wisconsin-Madison. The CL-1 Team, including Fellows, met over the course of the following year to study in further detail the issues that were raised in the various workshop sessions[1]. The main product of their work is the Learning Through Technology (LT^2) Web site. The creation of the site and some of its content are described along with related developments.

Goals and Audience

The goal of the LT^2 Web site is to serve as a "one-stop" resource on the effective use of technology in college-level SMET classrooms. This goal was formulated based upon reviews of current web-based resources on the use of technology within SMET classrooms. The resulting Learning Through Technology (LT^2) site (http://www.wcer.wisc.edu/nise/CL1/ilt) includes both previously-existing resource materials plus a set of vignettes (quick looks at technology in the classroom) and case studies developed for the site.

The target audience of the LT^2 website is SMET educators who are interested in:

- learning about how to use technology in their classroom; and
- using pedagogical techniques that adhere to the Chickering and Gamson model of good practices.[2]

Strategy

The CL-1 team used the following guiding principles about technology to serve as a basis for development of the LT^2 site:

- Software and computers change at a rapid pace.
- Technology, by itself, is not inherently good or bad.
- The use of technology must improve the learning process, rather than be used for its own sake.
- Technology should be situated in a context that supports learning.

The CL-1 team also used guiding principles about faculty needs and use of web-based materials. These are that faculty:

- trust pedagogies and tools used by other faculty, especially those from their own field;

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[1] CL-I Team Members: Aaron Brower, Arthur Ellis, Kate Loftus Fahl, Anthony Jacob, Robert Mathieu; Fellows: Jean-Pierre Bayard, Steve Ehrmann, John Jungck, Flora McMartin, Susan Millar, Marco Molinaro

[2] Chickering and Gamson synthesized research on undergraduate education to produce a document called "Seven Principles for Good Practice in Undergraduate Education", *AAHE Bull* **39**(**7**), 3-7 (1987). These principles advocate the following: encouraging student-faculty contact; encouraging cooperation among students; encouraging active learning; giving prompt feedback; emphasizing time on task; communicating high expectations; and, respecting diverse talents and ways of learning.

- want concrete details (e.g., syllabus, handouts) of how technology is used in the classroom; and,
- appreciate an honest picture of both the good and the bad impacts of technology use.

These sets of principles framed the development of the LT^2 site. The CL-1 team chose to present vignettes and case studies that feature faculty who were already adapting—and in some cases creating—learning technologies that support learner-centered, inquiry-based environments, and who had credible evidence that their use of technology-based activities correlated with higher order cognitive skills and greater knowledge retention.

To ensure that the site meets the needs of a wide range of SMET educators, the examples presented are diverse with respect to institutional type (i.e., two-year colleges, four-year colleges, comprehensive universities and research institutions) and SMET disciplines. Moreover, the computer technologies used by the faculty who were interviewed vary in complexity from e-mail to high-performance computing.

Timeline for Website development

The process of designing the LT^2 site began at the TechEd 99 Workshop. During the 1999-2000 academic year, the Fellows frequently met at UW-Madison to plan the site, gather information, and write original material for the site. Using feedback obtained from an evaluator, they continuously refined the site design. During the 2000-2001 academic year, a subset of the team continued to develop the site with additional funding from the NSF's Division of Undergraduate Education (Education and Human Resources Directorate).

Organization of the LT^2 Web Site

The LT^2 Web site is organized into five main sections, which are briefly described below.

Technology in the classroom: quick looks – This section consists of brief, first-person accounts of the learning technology experiences of faculty, organized by discipline and type of institution. Visitors can sample, via Web links, the technologies that the faculty used, and, for further information, contact each faculty member via e-mail. Web visitors can, for example, explore how:

Rick Peifer, Assistant Director of the General Biology Program at the University of Minnesota, used visualization technologies to improve how students learn complex concepts, such as protein synthesis, that involve processes at the molecular level;

Frederick Moore, a physics professor at Whitman College, helped students use laboratory instrumentation with computer interfaces to test hypotheses about how a system is likely to behave under certain conditions;

Sam Donovan, a visiting professor at Beloit College in Wisconsin, used Biology Workbench from the National Center for Supercomputing Applications (NCSA) to access large databases via the Web; and, how

John Belcher, a physics professor at MIT, used 2-D and 3-D animations to teach his electromagnetism class.

Technology in the classroom: types of use – This section presents the same material as that found in "*quick looks*" (above), but is instead organized by the following key ways that faculty use computer technology ("*types of use*"):

1) **Modeling**. Conformational changes that occur within biological systems as a substrate and enzyme interact are common examples of modeling.

2) **Simulation**. One complex example would be a program that simulates an industrial chemical process, using an animation that shows valves, flow rates, and temperature, and that allows the user to change these parameters and observe the impact of these changes on the system.

3) **Visualization**. Examples include observing how the function $f(x) = x^2$ changes as the variable "x" changes, or how the DNA molecule appears in three dimensions.

4) **Computer and numerical analysis**. A computer can be used to determine and graph the instantaneous velocity and acceleration of a ball rolling down a hill, based on data obtained from instruments used to monitor the ball's motion.

5) **Locating and evaluating information**. This use of computer technology is illustrated by the use of systems or tools to retrieve desired information from large databases.

6) **Real-world data analysis**. An example of this application of computer technology is the use of climate data to predict regional or national weather patterns. Such applications can help to make classrooms seem more connected to the "real" world.

Hallway conversations about technology –This section offers opinions, advice, and insights from experienced learning technology users. The contents of this section were culled from the answers to questions that were posed to many faculty, and provide personal perspectives on technology use in post-secondary SMET education.

In-depth case studies of technology in use – This section of the site provides in-depth studies of learning technology innovations. Personal narratives of faculty and students cover many logistical, technological, interpersonal, economic, and political issues involved in adapting learning technologies for classroom use.

Links, articles, and more resources – This section of the site includes a classification of learning technologies that incorporates three main parameters: the nature of the learning task, the learner-centeredness of the software, and the degree of collaborative learning. There are also resources to help faculty evaluate the role of learning technologies in improving student learning, and links and articles that can help SMET instructors understand how and why learning technologies can improve student learning. Also presented are possible sources of funding, a glossary, and a list of experts from across the country.

For summary information about the scope of examples presented on the LT^2 Website (whether as vignettes from the "quick looks" at technology in the classroom sections, or as case studies), see Table 1.

Table 1. LT^2 Case Studies and "Quick Look" Vignettes

	Discipline	Institution Type	Name	Institution	Format
1	Astronomy	Research	Mathieu, Robert	University of Wisconsin-Madison	vignette
2	Biology	Research	Peifer, Rick	University of Minnesota-Twin Cities	vignette
3	Biology	Research	Poston, Muriel	Howard University	vignette
4	Biology	Research	Uhl, Gerald	University of Illinois at Champaign Urbana	case
5	Biology	Liberal Arts	Donovan, Samuel	Beloit College	vignette
6	Biology/Chemistry	Research	Weinhausen, Gabriele	University of California-San Diego	vignette
7	Chemistry/Biology	Two-year	Burton, Carol	Bellevue Community College	vignette
8	Chemistry	Liberal Arts	Longley, Betsy	University of St. Thomas	case
9	Chemistry	Research	Ellis and Lisensky	University of Wisconsin-Madison	vignette
10	Chemistry	Research	Middlecamp, Catherine	University of Wisconsin-Madison	vignette
11	Chemistry	Research	Turro, Nicholas	Columbia University	vignette
12	Chemistry	Two-year	Rusay, Ronald	Diablo Valley Community College	vignette
13	Earth Science	Comprehensive	Frost, Eric	San Diego State University	case
14	Engineering	Comprehensive	Mott, Robert	University of Dayton	vignette
15	Engineering	Comprehensive	Pendergrass, Nicholas	University of Massachusetts-Dartmouth	case
16	Engineering	Comprehensive	Zoghi, Manoochehr	University of Dayton	vignette
17	Engineering	Research	Burleson, Wayne	University of Massachusetts-Amherst	vignette
18	Engineering	Research	Miller, Gregory	University of Washington	vignette
19	Engineering	Research	Rogers, Chris	Tufts University	vignette
20	Engineering	Two-year	Anderegg, Barbara	Madison Area Technical College	vignette
21	Engineering	Two-year	Arbor, Alan	Lambton College	vignette
22	Engineering	Two-year	Lee, Frank	Bellevue Community College	vignette
23	Interdisc Science	Comprehensive	Wamser, Carl	Portland State University	case
24	Interdisc Science	Liberal Arts	Waller, William	University of Houston-Downtown	case
25	Interdisc Science	Research	Van der Pluijm, Ben	University of Michigan	case
26	Mathematics	Comprehensive	Kaput, James	University of Massachusetts-Dartmouth	vignette
27	Mathematics	Comprehensive	White, James	Stetson University	vignette
28	Mathematics	Research	King, James	University of Washington	vignette
29	Mathematics	Research	Olin, Robert	Virginia Polytechnic and State University	vignette
30	Mathematics	Two-year	Burzynski, Denny	West Valley College	vignette
31	Meteorology	Research	Ackerman, Steven	University of Wisconsin-Madison	vignette
32	Physics	Liberal Arts	Moore, Frederick	Whitman College	vignette
33	Physics	Research	Belcher, John	Massachusetts Institute of Technology	vignette
34	Physics	Research	Thornton, Ronald	Tufts University	vignette
35	Physics	Two-year	Hieggelke, Curtis	Joliet Junior College	case
36	Technology	Two-year	Mowery, Jeanette	Madison Area Technical College	case

Early formative feedback from site visitors indicates that the LT^2 site can benefit college SMET instructors who want to:

- see examples of how technology is used in classrooms like theirs;
- gain a deeper understanding of why other faculty have chosen to use technology;
- gain a better understanding of the benefits and drawbacks encountered by faculty as they used technology; and,
- find technology they can use within their own classrooms.

The LT^2 site's emphasis is on the context for the use of technology, rather than just the technology itself .

Evaluating technology in college SMET learning

As a Fellow of the Institute on Learning Technology, Ehrmann provided guidance on how to evaluate the role of technology in the improvement of college SMET learning. He presented characteristics of evaluations based on his experience and that of others, and identified issues that should be at the focus of evaluation. Ehrmann proposed the following:

- It is what students, faculty, and staff each choose to do with technology that matters most. Evaluations need to describe what users choose to do with the educational choices made available by technology, and why.

  Technology's role is to expand the range of choices facing learners. Computers, software and the Web play the same kind of role in education that paper does: all of them widen the range of choices available to faculty, staff and students. Just knowing that computers (or paper) are in use reveals virtually nothing about how outcomes might change, or why. It is the choices people make about how to use those technologies that matter. (Ehrmann, 1995)

- Patterns of learning principally determine programmatic outcomes and should be a focus of evaluation. It is likely that a student graduating from a program was shaped almost entirely by coherent patterns of learning that developed over multiple courses and experiences. For example, the engineer's ability to "think like an engineer" is usually determined by a set of related courses and extra-curricular experiences. If we want to understand and improve technology's influence on who graduates, and what those graduates can do, we need to study patterns of technology use that characterize their course of study.
- Evaluation can make a difference by making hidden trends, barriers and opportunities visible, and by the ways it can bring people together. To illustrate trend identification, imagine that an engineering program invests in CAD/CAM in order to emphasize design. A study conducted after several years with the new curriculum can evaluate the status of design work and determine whether the curriculum is still appropriate. By making a barrier visible, evaluation can set the stage for action. For example, suppose that faculty want students to use the Web and e-mail to collaborate on homework and team projects. A diagnostic evaluation could reveal that students might not be collaborating because they do not have adequate skills for using communication software or because they believe that teamwork is a

waste of time. A diagnostic evaluation can provide instructors with opportunities by, for example, accurately identifying the level of a class so that it proceeds at an appropriate pace. Evaluation can help improve instruction by bringing individuals together.

As a report from California State University, Sacramento suggests (http://www.tltgroup.org/resources/F_Eval_Cases/FacDev_CSUS.htm), when instructors begin to plan evaluations, they can immediately obtain insights into how to improve their courses.

- Evaluating the return on technology investment has multiple dimensions. There are four types of outcomes of technology investment that are linked to the learning process, and the outcome of each must be assessed differently.

  1) Gains in access can be measured in enrollment and retention figures and in the inclusion of distant learners, older learners, learners with disabilities, and learners with nontraditional values and learning styles.

  2) Gains in traditional learning goals might be illustrated by determining whether students learn the central limit theorem of calculus better with technology than they did before technology was used, using some appropriate test of mastery.

  3) Gains in new learning goals measure command of new content or skills, such as gains related to computer science, that could not have been taught before the appropriate technology was available; evaluation may require recognition of the extent to which new and traditional content or skills are coupled and might even make use of external expert reviewers.

  4) Gains in the efficiency of learning activities can be evaluated at the level of simple activities (e.g., calculators versus slide rules) and at the level of entire programs or services using approaches like "activity-based costing" that examine component activities and tasks (e.g., Ehrmann and Milam, 1999).

In addition to these four evaluation goals, it is noteworthy that another major reason that institutions invest in technology is to be seen as up-to-date and thus competitive.

Working from these evaluation themes and from the cases, interviews, and surveys developed through the LT^2 Institute, a set of items for surveys and interviews has been drafted and is available on the LT^2 Web site in the section *Links, articles, and more resources*. Some representative questions for students are presented, in which they are asked to make general statements about all the courses they have taken thus far in their major. For simplicity, questions use a limited scale (strongly agree, agree, neutral, disagree, strongly disagree, or believe the question is not applicable to their experience.)

The items listed below are coded as follows:
(A) Questions about the teaching-learning **A**ctivity (without reference to technology)
(T) Questions about the role of **T**echnology in carrying out that activity
(B) Questions about **B**arriers to the activity or to the use of technology for that activity

Sample (Draft) Items for a Student Survey Instrument:

- Many instructors ask us frequently to predict what will happen, then to observe what actually happens, then to explain what has happened. (A)
- When we used computer simulations, I often experimented with different settings or parameters and that helped me understand a concept or master a skill. (T)
- The faculty aren't satisfied if we just know how to do calculations. They want to know if we understand the fundamental ideas and how to use them for ourselves. (A)
- On-line quizzes helped me understand important concepts and skills, not just memorize them. (T)
- We used computers or other digital equipment to gather and analyze real world data. (T)
- I receive considerable help in this field in visualizing difficult ideas (for example, from animations or slides the faculty show, or from the ways we use computers in doing assignments and projects) (T)
- We are usually expected to find more than one answer to a problem or more than one route to an answer. (A)
- Many of my courses require me to work with other students on one or more projects that take us each more than ten hours of work to complete. (A)
- We are expected to use computers in order to work on more interesting or realistic projects than would have been possible if we could use only pencil and paper. (T)
- In most courses, doing calculations does not take much time because of the way we use calculators or computers. We are encouraged instead to think about strategies for solving the problem or carrying out the process. (T)
- I use my computer to communicate with working professionals in my field who are not at this institution. (T)
- I have no time to do anything but the minimum on an assignment. (B)
- Grading on a curve has made me reluctant to share what I know with other students. (B)
- The way we are tested emphasizes memorizing material, not thinking. (B)
- Some of the students in my courses do not know how to use the technology in the way that the faculty members expect. (B)

These items can be combined with others relating to the frequency with which activities occur, outcomes, and perceived linkages between activities and outcomes.

References

Ehrmann, S. C., (1995) *Asking the Right Questions: What Does Research Tell Us About Technology and Higher Learning?* in Change. The Magazine of Higher Learning, XXVII:2(March / April),pp.20-27.
http://www.learner.org/edtech/rscheval/rightquestion.html

Ehrmann, S. C. and Milam, J. (1999) *Flashlight Cost Analysis Handbook,* Washington D.C.: The TLT Group.

Related developments

In addition to the collection of technology examples explored by the LT^2 Institute, Brown has published a set of vignettes. [Brown, D. G. (2000). "Interactive Learning: *Vignettes from America's Most Wired Campuses*", Bolton, MA: Anker Publishing].

One of the principal themes of the Workshop was the need for common platforms. The Department of Defense has established three national Advanced Distributed Learning Collaborative Laboratories (ADL Co-Labs). The Academic ADL Co-Lab is administered by the University of Wisconsin System and the Wisconsin Technical College System and housed at the University of Wisconsin-Madison campus. It serves as the focal point for the nation's universities and colleges in promoting high quality content for distributed learning. Its mission is to serve as the communication link for academia, and to provide testing, evaluation and demonstrations of ADL-compliant tools to enhance teaching and learning. Creation of the ADL Co-Lab reflects "net-centric" learning and the need for common specifications for instructional software and for a framework for sharing content. The Sharable Content Object Reference Model (SCORM) that resulted from this approach is a set of specifications and guidelines that ensure accessibility, interoperability, adaptability, reusability, durability, and affordability. [http://adlnet.org]

In a similar vein, the digital library holds considerable promise for sharing high-quality SMET instructional materials. Information on the digital library can be obtained through http://www.smete.org/, a Core Integration project of the NSF National Science, Mathematics, Engineering, and Technology Education Digital Library (NSDL) that currently has about 20 partners, spanning digital libraries in several SMET disciplines, K-12 education, and industry.

Appendix

The appendix includes a list of resources for those interested in further study, a list of Workshop participants and their e-mail addresses, some comments from participants, and a glossary.

Resources for further study

Please see the following Web sites and related articles for more information on topics discussed at the Workshop. This list is not intended to be exhaustive, but is a "snapshot" of MPS-related sites. More Web references can be found in the Participant profiles of the Workshop Web site (www.wcer.wisc.edu/teched99).

Note: The Web sites included here were accessed June 2001.

Astronomy

- sunshine.chpc.utah.edu, the Astrophysics Science Project Integrating Research and Education (ASPIRE) Web site.
- www.haystack.mit.edu, the Haystack Observatory home page, has links to the Research Experience for Undergraduates (REU), Young Scholar, and other educational pages.
- www.gettysburg.edu/academics/physics/clea/CLEAhome.html. Project CLEA (Contemporary Laboratory Experiences in Astronomy) develops laboratory exercises that illustrate modern astronomical techniques using digital data and color images. They are suitable for high-school and college classes at all levels, but come with defaults set for use in introductory astronomy classes for non-science majors.

Biology

- bioquest.org/ the home page of the BioQUEST Curriculum Consortium at Beloit College.
- www.apnet.com/bioquest, the home page for the BioQUEST Library, an academic, peer-reviewed publication of electronic curricular materials.
- acube.org/bioscene.html, the on-line archive of Bioscene, the Journal of College Biology Teaching.
- www.beloit.edu/~biology/jungck.html, Art of Mathematical Biology Gallery — images of natural forms, exploring their mathematical bases.

Chemistry

- www.monmouth.edu/~tzielins, Physical chemistry case studies, along with the Mathcad Physical Chemistry documents, including exercises and additional data sources.
- jchemed.chem.wisc.edu/jcewww/columns/McadInChemMathcad applications to physical chemistry.
- jchemed.chem.wisc.edu/the on-line version of the "Journal of Chemical Education", containing a variety of useful resources, including novel experiments and exercises.
- wey238ab.ch.iup.edu/pcol/Event.htm, Physical Chemistry On-line, including experiments.
- TRUTH.WOFFORD.EDU/~whisnantdm/p_chem.htm, physical chemistry projects from a group of colleges.
- www.ched-ccce.org/index.html, home page of the Committee on Computers in Chemical Education (CCCE) of the ACS Division of Chemical Education, including links to Intercollegiate On-Line Chemistry Courses (OLCC) and on-line chemistry conferences (CONFCHEM).
- www.chem.ukans.edu/Tkuwana, link to the report of the NSF-funded workshops "Curricular Developments in the Analytical Sciences" (.pdf and .html copies available).
- www.almaden.ibm.com/st/msim, the IBM Kinetics Simulation Project page, where the Chemical Kinetics Simulator (CKS) program is available for downloading and licensing.
- www.iup.edu/~grlong/i1fac.htm, a collaborative on-line study in physical chemistry (G. Long et al., "The Iodine Spectrum: A new look and an old topic". *J. Chem. Educ.* 1999, *76*, 841-847).
- www.chem.wisc.edu/~concept, ConcepTest questions for use in all areas of undergraduate chemistry.

Cognitive science and perceptual learning

- A recommended general-audience article on conceptual change in physics is: diSessa, A. A. (1996), What do "just plain folk" know about physics? In D. R. Olson and N. Torrance (Eds.), The Handbook of Education and Human Development: New Models of Learning, Teaching, and Schooling. Oxford, UK: Blackwell Publishers, Ltd., 709-730.
- For a complete treatment of Andrea diSessa's discussion of Galileo's theorems and tick models, and their meaning for cognitive science, see www.soe.berkeley.edu/boxer/ papers.html. This URL displays the first two chapters of diSessa's book in

press, “Changing Minds: Computers, Learning and Literacy.” Cambridge, MA: MIT Press.

- Another broader volume of diSessa’s work is diSessa, A. A., Hoyles, C., Noss, R., with Edwards, L. (1995). Computers and Exploratory Learning. Berlin: Springer Verlag.
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- Hummel, J., & Kellman, P. J. (1998). Finding the Pope in the pizza: Abstract invariants and constraints in perceptual learning. Behavioral and Brain Sciences, 21(1), 58-59.
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General education issues

- “Reinventing Undergraduate Education: A Blueprint for America’s Research Universities,” The Carnegie Foundation for the Advancement of Teaching, 1998.
- www.ed.gov/offices/OPE/FIPSE. FIPSE is the Fund for the Improvement of Post Secondary Education.

General science and technology

- whyfiles.news.wisc.edu, a critically acclaimed Web site that explores the “science behind the news.”
- www.wsu.edu/druniverse. This site is similar to the whyfiles site (see above), with great questions from children. Informative and entertaining.
- books.nap.edu, the National Academy Press Web site, which includes many titles relevant to the Workshop.
- www4.nas.edu/cpsma/cstbweb.nsf, the home page of the Computer Science and Telecommunications Board of the National Academy of Science, with links to several reports of interest.
- books.nap.edu/catalog/6482.html, “Being Fluent with Information Technology,” Committee on Information Technology Literacy, National Research Council, 128 pages, 1999.
- www.nasa.gov, the NASA Web site. The links to NASA for Kids and to Educational Resources are especially useful.

- taz.cs.ubc.ca/swift, the site for SWIFT (Supporting Women in Information Technology), a research, action, and implementation project to increase the participation of women in Information Technology.

Materials science

- mrcemis.ms.nwu.edu/mrc/org/educational_outreach.html, the site of the Materials World Module (MWM) program, which provides high-school students with hands-on experience in the design, synthesis, and evaluation of materials.
- www.engr.sjsu.edu/WofMatE/, the "World of Materials."
- mrsec.wisc.edu/edetc, the education and outreach page of the Materials Research Science and Engineering Center for Nanostructured Materials and Interfaces. It includes demonstrations, experiments, and links to other materials science education sites.

Mathematics

- archives.math.utk.edu, the home page for the Math Archives, a collection of software, teaching materials, and Web links for mathematics.
- archives.math.utk.edu/visual.calculus, the site for Visual Calculus, a collection of modules that can be used in the study or teaching of calculus.
- taz.cs.ubc.ca/egems/home.html. E-GEMS (Electronic Games for Education in Math and Science) develops strategies and materials to integrate game-like computer activities with other forms of classroom learning. The site includes exercises and products for K-8 math learning.
- www.sci.wsu.edu/idea. IDEA (Internet Differential Equations Activities) is an interdisciplinary effort to provide students and teachers with computer-based activities for differential equations in a variety of disciplines.

Molecular science

- www.molsci.ucla.edu, the Molecular Science Project, which is developing server-based instructional materials and techniques covering the topics of the first two years of college instruction. Curricula, innovative Web-based writing assignments, and "learning units" are available at this site.

National laboratories

- www.emsl.pnl.gov:2080/docs/collab,/the Web site for the Environmental Molecular Sciences Laboratory (EMSL), the Department of Energy's new national scientific user facility in Richland, Washington.
- For details on the EMSL approach and experience, see "Technology and the Internet in Undergraduate Research", J. Myers, N. Chonacky, T. Dunning, E. Leber, CUR Quarterly, vol. 17(3), March, 1997, pp. 116-120.

Physics

- physics.dickinson.edu includes links to the Workshop Physics project, which has developed computer tools, exercises, and curricular materials at the college and high-school levels for introductory physics courses.
- www.Colorado.EDU/physics/2000. Physics 2000 is "an interactive journey through modern physics," with interactive graphics demonstrating basic concepts and experiments.
- jersey.uoregon.edu/vlab. This page includes a collection of interactive Java applets for use in physics, astronomy, and environmental science. There are also Java tools for students and an example Java exam interface.
- webphysics.iupui.edu/jitt/jitt.html, the Web site for JiTT (Just in Time Teaching), an effective tool in using the Web to impact student learning.
- galileo.harvard.edu, the page for Prof. Eric Mazur's project at Harvard, containing "class-tested, ready-to-use methods."

Science education

- www.clp.berkeley.edu, Computer as Learning Partner, at the School of Education at Berkeley "dedicated to informing and improving middle school science instruction." The site includes the Integrated Energy Curriculum, involving light, sound, and thermodynamics. Includes problems and lab exercises.
- www.nsf.gov/pubs/1998/nsf9882/nsf9882.txt, the Report from a 1996 NSF workshop entitled "Information Technology. Its Impact on Undergraduate Education in Science, Mathematics, Engineering and Technology."
- cilt.org, Center for Innovative Learning Technologies, a university consortium and a distributed center designed to serve as a national resource for stimulating research on innovative, technology-enabled solutions to critical problems in K-14 learning. They have produced reports and software for mathematics and science teaching.
- marcopolo.worldcom.com/ a site that provides no-cost, standards-based Internet content for the K-12 teacher and classroom, developed by the nation's content experts. On-line resources include panel-reviewed links to top sites in many disciplines and professionally developed lesson plans and classroom activities.
- http://wise.berkeley.edu , Web-based Integrated Science Environment. Designed to bring new technological resources into the classroom, this site includes the "deformed frogs" curriculum discussed at the Workshop (wise.berkeley.edu/WISE/pages/demos.php).
- www.kie.berkeley.edu, the Knowledge Integration Environment (KIE) Project, which pioneers educational uses of the Internet and World Wide Web for middle and high-school science instruction. Includes class projects.

- www.wcer.wisc.edu/nise/CL-1, Web site developed by the National Institute for Science Education (NISE). It is designed to introduce MPS instructors to assessment and collaborative learning methods.
- www.needs.org, Digital Library for the Engineering Education Community, providing World Wide Web access to digital learning resources since 1994.
- www.tltgroup.org/programs/flashlight.html, site of the Flashlight Program, which "helps institutions study the ways that technology can be used to improve education," including assessment and evaluation issues.
- scope.educ.washington.edu. The Science Controversies On-line: Partnerships in Education (SCOPE) Project is a research partnership whose primary focus is to design and test Web-based environments for on-line, knowledge-building communities centered around current scientific controversies.
- www-caes.mit.edu, the Center for Advanced Educational Services (CAES), which is the main MIT facility for technology-facilitated education, and the main source of MIT continuing professional education, often via distance learning.
- www.wgu.edu/wgu/index.html, Western Governors University page, with information about their competency-based courses and degrees.
- www.uen.org, the home page of the Utah Education Network (UEN), which electronically delivers classes from kindergarten through college level.
- pompeii.nap.edu/catalog/catalog.cfm?record_id=5952, Developing a Digital National Library for Undergraduate Science, Mathematics, Engineering and Technology Education: Report of a Workshop. Steering Committee for Developing a Digital National Library for Undergraduate Science, Mathematics, Engineering, and Technology Education, National Research Council, 136 pages, 1997.
- www.nap.edu/catalog/9584.html, Serving the Needs of Pre-College Science and Mathematics Education: Impact of a Digital National Library on Teacher Education and Practice. Proceedings from a National Research Council Workshop. Executive Committee, Mathematical Sciences Education Board, National Research Council, 44 pages, 1999.
- www.nap.edu/catalog/6453.html, "Transforming Undergraduate Education in Science, Mathematics, Engineering, and Technology," Committee on Undergraduate Science Education, National Research Council, 126 pages, 1999.
- www.pkal.org, the home page of Project Kaleidoscope, an informal national alliance of individuals, institutions, and organizations committed to strengthening undergraduate science, mathematics, engineering, and technology education.
- D.F. Barbe, H. Rabin, and E.M. Sybert, "Incubating Technology-Oriented Start-Ups," The Industrial Physicist, American Institute of Physics, June, 1998, pg. 47.
- Report by the Task Force on Chemical Education Research, Journal of Chemical Education, Vol. 71, Number 10, October, 1994, p. 850.

- www.nsf.gov/cgi-bin/getpub?nsf96139, "Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering and Technology." Washington, D.C.; National Science Foundation, 1996.
- books.nap.edu/catalog/5287.html, "Science Teaching Reconsidered: A Handbook," National Research Council, Washington, D.C. National Academy Press, 1997.
- www.pewtrusts.com, the home page of the Pew Charitable Trusts, which makes major educational grants.
- www.pbs.org/adultlearning/als, the home page for PBS's Adult Learning Service, including the Adult Learning Satellite Service (ALSS). It lists both teacher and student resources for a variety of science courses.
- www.cae.wisc.edu/~lead/, the site for the LEAD (Learning through Evaluation Adaptation and Dissemination) Center, producer of the FLAG assessment tools.
- amp.bc.inter.edu/ns4/index.htm. As part of the Alliance for Minority Participation (AMP), this page has links to a variety of SMET undergraduate educational materials.
- scienceview.berkeley.edu, the home page of ScienceVIEW, an educational multimedia research and production group within the Curriculum Research Division of the Lawrence Hall of Science.

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Participant comments

Rex Adelberger

"Working in a small college, I only have a small amount of time to invest in playing with new tools. As was obvious from this workshop, there are an amazing number of tools available to the educator these days, and they are multiplying rapidly. Why can't the folks who are paid (through grants, etc.) to play with the tools tell me which are the neatest and most interesting? This sort of advice from the pros would be most useful to folks in my circumstances. If someone came to me and said they had 10 days to learn some physics, and asked which parts should they read about and play with, I surely could tell them."

Jean-Pierre Bayard

"There are some real practical problems if we wish to seriously encourage non-research universities to participate in the process. The process should be structured so that innovative ideas are rewarded, not only the organizational infrastructure of the university. Funding agencies should consider establishing a streamlined application process for universities with no research traditions (so-called teaching universities). Without that, research universities will use, appropriately so, their research infrastructure to compete for these funds. Partnerships often require a full-time grant developing staff, and this is a tall order for most teaching universities. Perhaps having a pre-proposal (2-4 pages simply outlining the idea) process would make the field more even. I think this is something that should be addressed."

Anna Cavinato

"Somehow if we want to make sure that faculty do a good job at teaching, we need to change the ongoing philosophy that relegates instruction to a lesser role in promotion and tenure decisions. Although I personally work in a school where good teaching is definitely high priority and is highly rewarded, my impression from formal and informal discussions with many workshop participants is that it may be risky, particularly for younger faculty, to invest much of their time in curriculum development."

Frances Houle

"How to encourage business to become more involved in the used of technology in college SMET education:

- Make it prestigious – give awards.
- Provide external funding for release time for technical staff or, for example, to support a postdoctoral associate to interface between academia and the company.
- Hold workshops to develop ideas and partnerships.
- Provide focus. People don't have a lot of time but likely would respond to well-defined needs and opportunities."

Tristan Johnson

“The processes that we are trying to achieve require expertise from multiple areas. There are distinct roles that do cross over, but only slightly. What is so very important to the success of most technology initiatives is the collaboration of key experts. Another thing that was apparent was the close tie between technology and pedagogy. When we talked about using technology improvement, there was a definite interest to also improve the pedagogy. As I see it, the technology is a means to an end, but the pedagogy (learning environment) is a critical part of the success of the technology implementation. What is this tie?”

John Jungck

“My primary concern is a greater need for a collective approach, as opposed to individual teachers, classes, departments, institutions, or disciplines. My concern is that many faculty still do not see education problems in a shared perspective that enables systemic reform.”

Karen Levitan

“At the faculty level, collaboration and teamwork are not rewarded. Institutions need to change this. And they need to prepare faculty for teaming and project management. At the college and university level, these institutions need to partner to share the cost of developing courses, modules, distributed learning deliveries, etc., in order to gain economics of scale from a larger student population. Funding agencies should encourage this.”

Brian Tissue

“Information technology is like a new locomotive. It is powerful and noisy, but it will only take you where the old tracks go. The “old tracks” of universities go a long, long way, but they also include inflexible physical facilities, obsolete pedagogy, and a reward system that neglects the scholarship of teaching. If we want to improve education we must lay track.”

Maxine Willis

“It is important for the K-12 teaching community to be taught in MPS courses as they should teach. It’s hard to make these teachers change their ways if this is not what they have experienced. They feel the colleges are the experts, and if the colleges don’t do it that way, then why should they change? Teaching by example is very important in the process. There is a crisis in MPS in K-12, especially at the secondary level in terms of getting qualified faculty. The college courses cannot be just screening students for Ph.Ds, but need to encourage them to look at all kinds of options. Teaching middle school and high school can be a satisfying career with lots of rewards.”

Glossary

AAHE. American Association for Higher Education.

ASPIRE. Astrophysics Science Project Integrating Research and Education, a Web-based educational initiative at the University of Utah.

CAD. Computer Aided Design.

CAES. MIT's Center for Advanced Educational Services.

CAT. Classroom assessment technique.

CD-ROM. Compact disc with read-only memory.

CETP. NSF-supported collaboratives for Excellence in Teacher Preparation.

Chunking. In cognitive sciences, the ability to group pieces of information into usable blocks.

CILT. The Center for Innovative Learning Technologies.

CKS. Chemical Kinetics Simulator, a program that allows rapid and accurate simulations of many types of chemical reactions, available on the World Wide Web.

Computer literacy. The ability to use computers, usually PC applications.

CORE2000. EMSL's Collaborative Research Environment, a multi-platform environment available to users of UNIX, PC, and Macintosh computers.

Cybertutor. An interactive program developed at MIT to improve the homework experience of students and teachers.

Distance learning. The practice of teaching and learning using technologies that link remote sites.

Distributed learning. See *distance learning*.

DOE. The U.S. Department of Energy.

DUE. Division of Undergraduate Education, within the NSF Directorate for Education and Human Resources (EHR).

Educational technology. The systematic application of human and technological resources in teaching and learning.

E-GEMS. Electronic Games for Education in Math and Science, an interdisciplinary project studying computer games and activities for mathematics education in grades 4 to 8.

EHR. The NSF Directorate for Education and Human Resources.

EMSL. Environmental Molecular Sciences Laboratory, the Department of Energy's new national scientific user facility in Richland, Washington.

FIPSE. The Fund for the Improvement of Post Secondary Education.

FLAG. Field-Tested Learning Assessment Guide, a resource for developing assessment tools.

HUD. The U.S. Department of Housing and Urban Development.

IGERT. NSF-supported Integrative Graduate Education and Research Training program.

IT. Information technology, the confluence of telecommunication, video, and computing technologies that support diverse applications.

Java. A general-purpose, object-oriented programming language.

K-12. Kindergarten through 12th grade.

MPS. Mathematical and physical sciences.

NCSA. The National Center for Supercomputing Applications.

NEEDS. National Engineering Education Delivery System.

NISE. NSF-supported National Institute for Science Education.

NRC. National Research Council. Organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government.

NSF. National Science Foundation.

PC. Personal computer.

PIVoT. Physics Interactive Video Tutor project, a hypermedia, Web-based video course at MIT.

PLM. Perceptual learning module.

PNNL. Pacific Northwest National Laboratory.

REU. NSF-supported Research Experiences for Undergraduates, a program that gives college students opportunities to conduct research.

Scaffolded Knowledge Integration network. A synthesis of research findings from a broad range of cognitive traditions that suggests ways to design effective MPS instruction.

SCOPE. Science Controversies On-line: Partnerships in Education.

SMET or **SMETE**. Science, Mathematics, Engineering, and Technology education.

TLT. The Teaching, Learning and Technology group is a non-profit organization affiliated with AAHE. Its mission is to motivate and enable the improvement of teaching and learning with technology.

WCER. Wisconsin Center for Education Research.

WISE. Web-based Integrated Science Environment, based at the University of California, Berkeley.

WWW. The World Wide Web.