Information Technology In the Service of Student Learning

2001 PKAL Roundtable on the Future

ABOUT THE ROUNDTABLE

The 2001 PKAL Change Agent Roundtable, jointly sponsored by Project Kaleidoscope and Sigma Xi, The Scientific Research Society, was held March 2-4, 2001 at the ExxonMobil Corporate Headquarters, Irving, Texas.

The Roundtable brought together forty-four leading agents of change from all sectors of higher education, career stages and disciplinary backgrounds. The organizers and participants extend their heartfelt thanks to President Edward Ahnert, Program Officer Truman Bell and the staff of the Conference Center of the ExxonMobil Foundation for their hospitality in providing the excellent facilities and support enjoyed by all participants. The assistance of the following PKAL F21 members in preparing summary reports after each session is gratefully acknowledged: Nkechi Agwu, Zekeriya Aliyazicioglu, Ramesh Arasasingham, Mark Benvenuto, Terri Bonebright, Ivona Grzegorczyk, Tanya Furman, James Napolitano, and Tingxiu Wang.

Additional thanks go to organizing and editorial committee members: Frank Wattenberg and Robert Kolvoord.

INTRODUCTION

As part of its national series of activities focusing on the reform of undergraduate education in the sciences and mathematics, Project Kaleidoscope (PKAL) jointly sponsored the 2001 Change Agent Roundtable, *"How Can Technology Be Best Used to Enhance Undergraduate SME&T?,"* with Sigma Xi, The Scientific Research Society. This Occasional Paper is a collection of presentations and stories from Roundtable participants.

It is a good time to examine the best use of information technology to enhance undergraduate education. An explosive growth of technological advancements and information has been accompanied by a dramatic increase in hardware and software available for use in the classroom.

But the question remains, are we using it properly?

Because technology changes so rapidly, there are few occasions to examine the rationale for its use in the classroom, or the objectives that we hope to achieve through the use of information technology. Drawing on exemplary projects and models in the wise use of information technology, the PKAL/Sigma Xi Roundtable focused on *what works*. In presentations and small group sessions, participants explored the issues, challenges and opportunities for the informed use of IT in enhancing undergraduate STEM learning.

Formal and informal discussions throughout the Roundtable coalesced around several key questions. These questions might provide direction for broader discussions on the use of information technology, with ideas and insights from Roundtable participants serving as a catalyst for dialogue within departments, divisions and at the institutional level.

Project Kaleidoscope's approach to reform has been to get people wrestling with key questions that must be addressed by the community and to support the design and implementation of programmatic ideas that emerge from that wrestling. From the participants at the Information Technology Roundtable, a series of interesting questions surfaced. We present these questions here, together with some of the answers that emerged in the pre-Roundtable essays and in our discussions during the weekend.

We invite the PKAL community and other readers of this report to join us in continuing to explore these questions.

INTRODUCTION

The fundamental question woven throughout all Roundtable discussions was:

- How can information technologies serve contemporary goals for student learning?

Other questions were spun off from that basic question:

- How does the faculty responsibility to "teach content" change as information technologies are integrated into the learning experience of students?
- Can the use of information technologies help ensure institutional vitality?
- What are the future challenges and opportunities for information technology in the service of student learning?

On behalf of the PKAL organizing and editorial committee, we thank you for taking time to read this Occasional Paper and for having the courage to become involved in transforming undergraduate science and mathematics education. We hope this paper will be helpful as you respond to the challenges ahead.

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In a nation—indeed a global economy—increasingly based on information as its common currency, the provision of appropriate information technology in addition to well prepared teachers, instructors and facilitators of such powerful tools, must become a vital part of the entire educational continuum as we step into the next century.

In order to be effective, the use of technology in education must involve not only the provision of equipment such as computer hardware and software, but also the human aspects of essential content, engaging presentation, effective pedagogy, appropriate evaluation, and widespread dissemination. Communication and computing provide dynamic tools, placing nearly continuous demands on financial reserves and human resources as equipment and professional training are revised and upgraded.

–National Science Foundation, Report from the 1998 Workshop, "Information Technology: Its Impact on Undergraduate Education in Science, Mathematics, Engineering, and Technology"

A FOCUS ON STUDENT LEARNING

How can information technologies serve goals for student learning?

One must learn by doing the thing, for though you think you know it, you have no certainty until you try.

— Sophocles, 400 B.C.

SOME KEY QUESTIONS

- How are technologies redefining the learning space and redesigning the classroom experience for students?
- How can technologies bring students to appreciate complexity and to be comfortable thinking about nonlinear interactions? Can, in fact, the use of information technologies lead to deeper learning?
- Are there different learning styles (such as visual and oral) and if so, must these be included in the design of technology-intensive learning experiences?
- How can technologies facilitate the building of collaborative communities of learners?

A FOCUS ON STUDENT LEARNING

REFLECTIONS: CAMILLAN HUANG

John Dewey, the father of "experiential learning" and "learning by doing," has been called "the most important public intellectual of his day," and a philosopher with unprecedented impact on society and education.

Dewey proposed that learning should be a concrete experience. Students should be faced with the task of solving problems that are real to them. Teaching, therefore, should consist of applying the principles of problem solving, which he defined as follows: ...

There was a discussion over dinner at the Roundtable about why students were not as interested in a specific computer-simulated chemistry experiment as the instructor who designed it had hoped. I thought the reason was obvious. Special effects generated by the computer are not as stimulating to the current generation of students because for them it is a commonplace experience to interact with such innovative, hi-tech tools.

We have to know who our students are. We must ask them what they want, what excites them and what they like, what motivates them. We must be aware of their experiences, the social trends that shape them, and– in this context– the web sites that appeal to them. If these ways of thinking are captured as we shape technology rich learning environments, we will be able to reach out to the student and make learning relevant to their everyday lives.

The answer to these questions will vary, however, depending on educational level. Undergraduates do not have the same luxury of time as elementary and secondary students to play around and explore on the web. Undergraduates want directed learning and guided understanding, and we need to build the learning experiences accordingly.

How thus should the design be approached? Storytelling engages the student, and this should be one approach. A story is a personal account of something that did or could have happened; it is only natural for us to be compelled by a story. In our gastrointestinal module, the students explore what foods might be appropriate to eat before going out to a bar by following the storyline of two different college students. This is a very relevant topic and they have an incentive to learn for themselves and for their peers.

Technology can be used to enhance many traditional pedagogies, but to harness it best, it is essential to find out what our students need or want, rather than assuming we know what they need or want. Student-centric design is critical.

REFLECTIONS: CHRISTOPHER DEDE

Just as information technology has improved effectiveness in medicine, finance, manufacturing, and numerous other sectors of society, advanced computing and telecommunications have the potential to help all students and teachers learn complex concepts and skills. Research-based curriculum projects are developing technologies that enable online virtual communities of practice using advanced tools to solve real world problems. Simulations and visualization tools help students recognize patterns, reason qualitatively about physical processes, translate among frames of reference, and envision dynamic models.

Sophisticated computers and telecommunications have unique capabilities for enhancing learning. These include:

- centering the curriculum on “authentic” problems parallel to those adults face in real world settings
- involving students in virtual communities-of-practice, using advanced tools similar to those in today’s high-tech workplaces
- facilitating guided, reflective inquiry through extended projects that inculcate sophisticated concepts and skills and generate complex products
- utilizing modeling and visualization as powerful means of bridging between experience and abstraction
- enhancing students’ collaborative construction of meaning via different perspectives on shared experiences
- including pupils as partners in developing learning experiences and generating knowledge
- fostering success for all students through special measures to aid the disabled and the disenfranchised.

However, realizing these capabilities requires a complex implementation process that includes sustained, large-scale, simultaneous innovations in curriculum; pedagogy; assessment; professional development; administration; organizational structures; strategies for equity; and partnerships for learning among schools, businesses, homes, and community.

...They are first that the pupil have a genuine situation of experience- that there be a continuous activity in which he is interested for its own sake; secondly, that a genuine problem develop within the situation as a stimulus to thought; third, that he possess the information and make the observations needed to deal with it; fourth, that suggested solutions occur to him which he shall be responsible for developing in an orderly way; fifth, that he have opportunity and occasion to test his ideas by application, to make their meaning clear and to discover for himself their validity.

— K. Patricia Cross, Learning Is About Making Connections

WHAT ARE THE AFFORDANCES OF DIGITAL LEARNING?

AN ESSAY: NANCY BUTLER SONGER

My question is, "how do we begin the transformation from digital resources to digital learning?"

I argue that while many of us are beginning to understand some of the "affordances" of digital learning, we are not systematically realizing these in undergraduate STEM environments because of an overemphasis on the design of the technological resources (hardware and connectivity).

I propose what is needed is a broader discussion about digital learning that moves from an emphasis on powerful resources one on powerful learning. Unfortunately, even exemplary users of technologies and current policy documents gloss over this issue, seeming to imply that how one gets from powerful resources to powerful learning is a straightforward or clearly understood process. For example, a recent Department of Education report suggests that learning can be transformed merely by providing technological infrastructure and support:

> ...with sufficient access and support, teachers will be better able to help their students comprehend difficult-to-understand concepts and engage in learning, provide their students with access to information and resources, and better meet their student's individual needs.

A starting point for such a discussion is a recent report of the *CEO Forum on Education and Technology*, which identifies what learning can become when the creators and users of digital resources take advantage of the affordances of digital resources, that they can be:

- randomly accessed information
- relevant, up-to-date authentic information
- explored on many levels
- interactive and engaging
- manipulatable
- instantaneous
- creative.

Further, that digital resources can provide multiple representations of a given phenomena with transitions or links between these representations, as well as multiple and various simultaneous interactions with that phenomena, such as data manipulation and synchronized threaded discussions.

The authors of this report also suggest, when those designing and using digital content take advantage of these affordances, that learning becomes:

- problem and project-centered
- student-centered
- collaborative
- customized
- communicative
- productive
- lifelong, at anytime, from anywhere.

While many projects give substantial evidence of realizing these affordances, a fundamental shift in focus might improve our ability to realize more effectively the potential and power of digital learning. To date, many creators and users of digital learning, because of the overemphasis on hardware and connectivity, are forced to focus on training for basic technological skills and the availability (or lack) of resources to support that training.

How do we shift our thinking from hardware, networks, and the creation of "cool" web pages to a deep rethinking of the transformation of the learning that does occur– and that we want to occur– with the disciplines of science and mathematics through the use of information technologies.

I propose thinking that involves an examination of the following questions:

- ◆ What constitutes scientific reasoning in my discipline, in my area of science or mathematics?

- What kind of thinking do I want to foster in my students as they learn in my classrooms and labs?
- Which of the affordances identified by the *CEO Forum* might enhance the learning experiences of my students?
- What are the ways that my students could interact with tools (digital resources) most effectively?
- What new approaches or ways of thinking should I consider about how I shape, reshape or use digital resources;about how I fulfill my role as teacher; about how my students learn in order to use digital resources most effectively as a resource for scientific inquiry?
- What am I learning about the process of moving from an emphasis on creating digital learning resources to creating digital learning?

Let me illustrate how I have answered such questions from the perspective of my work with BioKIDS, an interdisciplinary research project to produce a digital learning resource in evolution and biodiversity, for both undergraduates and urban middle school students.

- *What constitutes scientific reasoning.......*

We envision a learning resource that would foster aspects of scientific inquiry as students explore controversies related to the concepts of diversity and adaptation. We wanted to support the ability of students to engage in scientifically-oriented questions to provide evidence either for or against these scientific controversies, to formulate explanations related to evidence and patterns of data, and to connect explanations to additional scientific knowledge, theories, and conjectures.

- *How do learners interact with our tool (digital resources).......*

The current tool is encyclopedic in nature, allowing users to search thousands of species accounts for particular kinds of information, such as what can be learned about the diet of an animal through an examination of its teeth. We discovered that the current encyclopedia resource largely promotes the learning of facts, not the exploration of questions, data interpretation, or the formulation of explanations as we had desired.

- *What transformations should be considered.......*

We are exploring transforming this encyclopedic tool to smaller sets of interactive 'species accounts' focused around a given controversy in order to more easily and more naturally foster the kind of thinking we envision. We will couple these accounts with Palm Pilot, student-collected species data from their local school grounds, and with threaded web boards for cross-region conversations with students and scientists.

- *What have I learned....*

We learned that the design of digital resources that are interactive and engaging, that use multiple representations of information, and that lead to customized and collaborative student-centered learning must begin with an in-depth rethinking of the content and of the learning goals. This must be done as a part of the design process, rather than after design is complete.

Thus, it is clear that if powerful learning is to occur in our project, biologists, educators and software designers must be working together as the digital resource is conceived, designed and used.

UNDERSTANDING DEEP CHANGES IN REPRESENTATIONAL INFRASTRUCTURES: BREAKING INSTITUTIONAL AND MIND-FORGED MANACLES

AN ESSAY: JAMES KAPUT

THE CO-EVOLUTION OF REPRESENTATIONAL INFRASTRUCTURES & SOCIAL SYSTEMS

Fundamental representational infrastructures such as writing systems, number systems, and algebra play a deep role in determining what and how people think, and what individuals are capable of doing. Hence their (the representational infrastructures) associated literacy communities and communities of practice and related social institutions are very sensitive to the learnability of such infrastructures and how they are physically implemented via such devices as the printing press and computers. Today's communities of practice and social systems such as education are greatly dependent upon, and in great measure defined by, the historically-received representational infrastructures with which they co-evolved.

Nowadays, you don't get a high school diploma without surviving algebra courses (which is at least indexically connected to learning the representational infrastructure of algebra), and you don't become an engineer without surviving the calculus sequence (which, again, perhaps remotely, suggests that you've learned something about that system of knowledge and representation). Importantly, these infrastructures evolved within the constraints of static, inert media and, with the partial exception of the now standard number system, they evolved to serve the needs of a small intellectual elite.

The close relationships between major representational infrastructures and social institutions were historically quite stable across the millennia because they co-evolved, just as do the constituents of any mature ecosystem. However, the dynamic and interactive computational medium enables the rapid evolution as well as the deliberate design of new representational infrastructures: spreadsheets, dynamic geometry, interactive diagrams, visually-editable graphical systems and state-space visualizers of dynamical systems. By adding new interactivity and hot links to traditional representational infrastructures as is reflected in any Computer Algebra System (CAS), such changes can be especially destabilizing because they change the means by which new systems of knowledge can be built. This was the case of writing, which provided the first extracortical means for creating and storing the products of human cognition, and which therefore made possible new kinds of feedback loops between knower and known. Another surge forward occurred with the development of operative algebra in the 16th and 17th centuries as western civilization attempted to create models of the physical world. This operative system and the hierarchical, placeholder system for numbers supported an entirely new level of computational and reasoning capability at the hands of a suitably trained human partner.

We are in the early stages of yet another surge of representational infrastructure development, rooted as were the others in mathematical activity - in this case the development of the idea of formalism and operations on formalisms coupled with new physical devices that could instantiate these. This idea has provided the ability to run extracortical processes (not merely records) autonomously of a human partner. In turn this has led to a new medium: the dynamic, interactive computational medium, within which one can create new representational infrastructures and new means for creating and sharing knowledge – embodying the combination of rapid computation, visualization and communication. Feedback loops are again changed, whereby we no longer need to interact with static, inert knowledge records, but can interact with dynamic and responsive representations and tools - so the central role of the book is replaced by the simulation. This marks yet another breakthrough in human representational capability. The impacts of this change will unfold unpredictably in coming generations as the means of building and sharing things have changed, reflected for example, in the Human Genome

Project or in a field such as artificial life. Yet, we have every reason to believe that the impact of these new representational infrastructures will be on the order of the invention of writing in the way humans shape their worlds, define themselves and their places in them, and live in them (plurals here are deliberate).

Historically, changes in representational infrastructures and changes in associated communities of practice (and literacy) as well as, social institutions were slow, measured in centuries or longer and, more importantly, on the same time-scale. But this consonance in time-scales no longer prevails, which creates new tensions and new opportunities, as changes in representations and their learnability are occurring on much shorter time-scales than the ambient social systems. However, discussions of technology in education largely reflect expectations defined by pre-existing social systems and the representational infrastructures with which they co-evolved. Hence we tend (with honorable exceptions!) to discuss doing old stuff better within slightly altered educational circumstances rather than doing better stuff within radically changed circumstances. At the worst, we worry about how to use technology to remediate K-12 educational failures (which is where the majority of post-secondary mathematics education resources are spent). Or we try to fix university calculus without changing anything else - surely some of us remember the Calculus Reform Movement.

TWO KINDS OF USES OF ELECTRONIC TECHNOLOGIES IN EDUCATION

There are two broadly drawn types of impacts of technology on education:

- Those that involve connectivity and all that changes in connectivity entail (e.g., in the forms of education, relations between education and the wider society or between constituents and levels of the education system), and
- Those that involve representational infrastructures and hence the nature of the knowledge and its learnability, including forms of interaction. (These obviously interact-as seen in any good applet.)

THREE LEVELS OF REPRESENTATIONAL INFRASTRUCTURE CHANGE

Change in representational infrastructures seems to have impact at three levels:

LEVEL 1

The knowledge produced in static, inert media can become knowable and learnable in new ways by changing the medium in which the traditional notation systems in which it is carried are instantiated - for example, creating hot-links among dynamically changeable graphs equations and tables in mathematics. Most traditional uses of technology in mathematics education, especially graphing calculators and computers using computer algebra systems, are of this level.

LEVEL 2

New representational infrastructures become possible that enable the epistemic reconstitution of previously constructed knowledge through, for example, the new types of visually editable graphs and immediate connections between functions and simulations and/or physical data of the type developed and studied in the SimCalc Project.

LEVEL 3

The construction of new systems of knowledge employing new representational infrastructures- for example, dynamical systems modeling of nonlinear phenomena, or multi-agent modeling of complex systems with emergent behavior, each of which has multiple forms of notations and relationships with phenomena. This is a shift in the nature of mathematics and science towards the use of computationally intensive iterative and visual methods. It will enable entirely new forms of dynamical modeling of nonlinear and complex systems previously beyond the reach of classical analytic methods - a dramatic enlargement of the mathematics of change & variation that will continue in the new century.

SIMCALC REPRESENTATIONAL INFRASTRUCTURE CHANGES

Below is summarized the core web of five representational innovations employed by the SimCalc Project, all of which require a computational medium for their realization. The fifth actually falls into Level 3.

1. *Definition and direct manipulation of graphically defined functions*, especially piecewise-defined functions, with or without algebraic descriptions. Included is “Snap-to-Grid” control, whereby the allowed values can be constrained as needed - to integers, for example, allowing a new balance between complexity and computational tractability whereby key relationships traditionally requiring difficult prerequisites can be explored using whole number arithmetic and simple geometry. This allows sufficient variation to model interesting situations, avoid the degeneracy of constant rates of change, while postponing (but not ignoring!) the messiness and conceptual challenges of continuous change.

2. *Direct connections between the above representational innovations and simulations* - especially motion simulations - to allow immediate construction and execution of a wide variety of variation phenomena, which puts phenomena at the center of the representation experience, reflecting the purposes for which traditional representations were designed initially, and enabling orders of magnitude tightening of the feedback loop between model and phenomenon.

3. *Direct, hot-linked connections between graphically editable functions and their derivatives or integrals.* Traditionally, connections between descriptions of rates of change (e.g., velocities) and accumulations (positions) are usually mediated through the algebraic symbol system as sequential procedures employing derivative and integral formulas - but need not be. In this way, the fundamental idea, expressed in the Fundamental Theorem of Calculus, is built into the representational infrastructure from the start, in a way analogous to how, for example, an immensely powerful hierarchical system for structuring numbers is built into the placeholder system and which democratized access to numerical computation.

4. *Importing physical motion-data via MBL/CBL and re-enacting it in simulations, and exporting function-generated data to drive physical phenomena LBM* (Line Becomes Motion), which involves driving physical phenomena, including cars on tracks, using functions defined via the above methods as well as algebraically. Hence there is a two-way connection between phenomena and mathematical notations.

5. *Use of hybrid physical/ cybernetic devices embodying dynamical systems,* whose inner workings are visible and open to examination and control with rich feedback, and whose quantitative behavior is symbolized with real-time graphs generated on a computer screen.

The result of using this array of functionality, particularly in combination and over an extended period of time, is a qualitative transformation in the mathematical experience of change and variation. However, short term, in less than a minute, using either rate or totals descriptions of the quantities involved, or even a mix of them, a student as early as sixth-eigth grade can construct and examine a variety of interesting change phenomena that relate to direct experience of daily phenomena. And in more extended investigations, newly intimate connections among physical, linguistic, kinesthetic, cognitive, and symbolic experience become possible.

Importantly, taken together, these are not merely a series of software functionalities and curriculum activities, but amount to a reconstitution of the key ideas. Hence we are not merely treating the underlying ideas of calculus in a new way, treating them as the focus of school mathematics beginning in the early grades and rooting them in children's everyday experience, especially their kinesthetic experience, but *we are reformulating them in an epistemic way*. We continue to address such familiar fundamentals as variable rates of changing quantities, the accumulation of those quantities, the connections between rates and accumulations, and approximations, but they are experienced in profoundly different ways and are related to each other in new ways.

These approaches are not intended to eliminate the need for eventual use of formal notations for some students, and perhaps some formal notations for all students. Rather, they are intended to provide a substantial mathematical experience for the 90% of students in the U.S. who do not have access to the Mathematics of Change & Variation (MCV), including the ideas underlying calculus, and provide a conceptual foundation for the 5-10% of the population who need to learn more formal calculus. Finally, these strategies are intended to lead into the mathematics of dynamical systems and its use in the nonlinear science that is now growing so dramatically.

In terms of our historical perspective, this current work is seen as part of a large transition towards a much more broadly learnable mathematics of quantitative reasoning, where both the representational infrastructure is changing as well as the material means by which those more learnable infrastructures can be made widely available.

"Could it be that these kinds of representational innovations constitute steps toward the development of a new alphabet for quantitative mathematics which might do for mathematical representation what the phonetic alphabet did for writing?"

> I found the idea proposed by James Kaput very interesting, that the use of technology would change the way we represented knowledge, and therefore, its learnability. I suppose, all the visualizations that we build into our technological tools are attempts to devise new representations of knowledge, and to speak in mixed metaphors, these representations could help our students "stand on the shoulders of giants" to "go farther than anyone has gone before." A lot of the knowledge that we expect everyone to learn today may be relegated to being optional in the future, freeing up space on a student's academic plate. It may be considered sufficient for most people to have only a qualitative understanding of certain topics (e.g., calculus), an understanding that will qualify them to be educated users. Those who plan to work in those areas would still be given the opportunity to study the topics more rigorously. Ultimately, this may be the solution to the ever-increasing amount of knowledge and its demand for inclusion in the undergraduate curriculum.
>
> -AMRUTH KUMAR-

A FOCUS ON STUDENT LEARNING

CONVERSATIONS & DISCUSSION POINTS

Christopher Dede: The difficulty in answering the question about different learning styles is that studies are not framed in that way and people end up looking at other studies, trying to extract evidence from which to address that question of whether there are different learning styles and, if so, how to accommodate them.

There is certainly a strong conventional wisdom in the research community -- partly case-study based, partly instinct, and partly significant research, that says if you use a variety of pedagogical approaches in your teaching, together with a variety of media, you get better results. This is the "lawn-sprinkler" approach; it is a pragmatic one. You are not trying to identify the learning style of each individual student and tailor your work– that is not feasible. You sprinkle things around and it works. At least I believe there is good evidence that supports this theory.

But, let me turn the question around. Most instructional decisions made, period, are not based on hard evidence, so I don't know why we should hold evidence in regard to learning styles to a higher standard than most of the other instructional design decisions we make. There is certainly as much common sense and empirical evidence to support using multiple pedagogies to reach different learning styles as there is for a variety of other things we routinely do in the instructional setting.

The more interesting question, I think, is, "can technologies provide new ways of supporting a range of pedagogies that serve a range of learning styles?"

Before this generation of technology that would have been a difficult question to answer, but we are seeing now that technologies are opening up a wider variety of opportunities for students to experience and learn the knowledge and skills we are trying to build.

Kirstie Bellman: In a sense, it seems as teachers we always enjoy using a variety of different presentational styles, and not only because of the worry about stereotyping a single student into a particular mode of learning.

Catherine Cotton: Yes, we also have an obligation to stretch our students, to build from their strengths and help them experience different ways of learning. In reality, when they leave our campus they will be operating in a multi-dimensional world.

CONVERSATIONS & DISCUSSION POINTS

Robert Kolvoord: There is a fair body of evidence, I believe, that says we have a growing group of visual learners, a group that STEM educators have not served well.

Thomas Banchoff: Talking about visual learners means something to me as a teacher of multilevel calculus. People ask, “if we start using technologies for purposes of graphing, will it mean that students will no longer learn how to draw graphs?” The answer is that they are not now learning how to draw graphs because the professors cannot do it. The thinking in mathematics for generations was that those who chose to pursue a PhD in mathematics were the abstract learners. Students realize that they will not be tested on something that their professors cannot do. So it is really quite true that there are groups of students who learn by doing and by analyzing visually and that they have not been given the opportunity in our classrooms nor have they been reinforced as good learners in that way.

Comment: Interactions in the classroom include the cross-conversations between students and instructors that help identify and address misconceptions. This is a time to get a feel of what students are understanding or not understanding, a time to give a student the feeling that s/he is having a one-on-one relationship with the faculty member, a time for them to say, “I don’t understand....” And technologies are a way for students to participate actively, particularly those who do not normally speak out. If we can get the students to interact more in the classroom, they are spending more time with the material and– hopefully– they will be getting better grades.

A FOCUS ON STUDENT LEARNING

SERVING GOALS FOR STUDENT LEARNING

Roundtable participants identified some ways in which the use of information technology can serve student learning goals:

TAKING RESPONSIBILITY FOR SHAPING THEIR OWN LEARNING

> *The opportunity to access sophisticated equipment not otherwise available to do these experiments on line, and to partake of real experimental results which can be modified by adjustments in the apparatus, motivates students to learn and demonstrates that scientific research can be fun.*
> - Lambertus Hesselink

In Hesselink's Cyberlab, students from all over the world have the opportunity to carry out real physical experiments. Although students do not gain experience with building an experimental apparatus, the remote laboratory does provide them with all the post-set-up experiences in data collection, analysis, and evaluation; For example, in the module on Fourier transforms for first and second-year physics students, the image to be analyzed can be one of a collection which the student can access with the aid of a robot, and each student can experiment with different filters and detector settings. Students write their own modules for controlling the experiment, leading to sophisticated, discovery-based learning.

CONNECTING TO THE REAL WORLD OF STUDENTS

Why does science frustrate learners? Learners are required to extract abstract concepts of scientific phenomena from textbooks and to visualize them as mental models. The delivery of science has remained unchanged for many years and learners still struggle with the same complex concepts. Camillan Huang is working to develop technology that can deliver information in a way that a textbook cannot. Her 'Virtual Labs' incorporates learner-centered content design with computer technologies to present engaging content. This learning environment creates a new standard of integrated visual teaching and active learning.

MAKING ACCESSIBLE 'SCIENCE FOR ALL'

Throughout the Roundtable, discussions returned to the issue of how information technologies could be used to attract and sustain student interest and perhaps motivate more students to persist in the study of mathematics and the various fields of science. It was also noted how leaders in undergraduate STEM needed to be clear about the "experiences with technology" of students of elementary, middle and high school age, and come to understand what this will ultimately mean for the higher education community.

BUILDING COMMUNITIES OF LEARNERS

Technology has both the danger of isolating people and the promise of enhancing interaction. One has only to look at how scientific research has constructed national and international communities of scholars to see the possibility, feasibility and value of such communities. Today all students as well as faculty can be exposed to new concepts of learning communities.

> *Much of the early use of the computer and Internet in classroom settings served to do ordinary tasks more efficiently – providing the course syllabus and readings, providing a communication link between faculty and students and among students, creating the means for more effective student research, etc. At an increasing rate, however, new software is emerging which allows students to take part in more engaging and effective learning. Our estimate is that over the next five or six years, the use of such software will become commonplace, truly transforming the way learning takes place in most settings – traditional classrooms on campus and virtual courses online.*
> - Frank Newman

TWO APPROACHES

MODIFY THE COURSE AS IT PROCEEDS BY USING STUDENT FEEDBACK

THOMAS BANCHOFF

Interactive learning existed before computers were ubiquitous. Faculty could obtain feedback from students in class, during office hours, and in other ways. But the ready availability of email correspondence between the instructor and members of the class has escalated the speed and breadth of this process, to the point where instructors can routinely modify what they do in class as a result of feedback received since the previous class.

In Tom Banchoff's honors linear algebra class of forty-five, freshmen assignments are turned in by email, and posted after the weekend. Tom and his undergraduate TA spend all day Monday reading the assignments due that morning, and emailing back and forth with the students via the course website. So before people come to class on Tuesday, everyone has read everyone else's comments. At the beginning of class, the class decides the difficult items that need to be covered.

> "*So, you ask, 'Why do I have class?' First of all we introduce all of the concepts in class. We have the discussion in class. After people have talked about what was difficult in the reading and we have a consensus, we can go over the reading in the class and talk about the stuff that was hard as opposed to the stuff that was easy. There is a lot to do in class. I have perfect attendance every time.*"

CONSIDERING LEARNING IN A HETEROGENEOUS CLASS

BRAD OSGOOD

A frequent complaint of faculty is the difficulty of teaching to a heterogeneously-prepared class. The traditional solution, providing "remedial" work to the less well prepared and advanced work to the better prepared, is immensely aided by computer technology which allows students to access online modules and work on them at their own pace, with opportunity for email.

Brad Osgood is developing "courselets," – short, focused, one or two lecture-sized segments with supporting materials – for use as supplements or prerequisites to full courses or as stand-alone units for self-study. "Courselets" provide prerequisite material for students coming from different backgrounds. They can be particularly effective in bridging the gap between the disciplines for people who want to get up to speed on interdisciplinary research and study.

—So far the changes wrought by educational technologies have been largely incremental. But these technologies also create the possibility of radical change in higher education. Communication technologies can dissociate learning from location. “Virtual universities” are taking shape that link students and faculty electronically, and the potential growth of such institutions is unlimited. Already, undergraduates are participating in interactive discussions from their homes, from offices, from satellite campuses, or from other learning centers.

These technologies also can extend research experiences to many more people in many more places. Faculty and students alike would have access to the frontiers of science, mathematics, engineering, and technology both as observers and participants.

These more radical uses of educational technologies raise a number of difficult issues. Some question whether the dynamism of the teacher-student link will be lost if this link occurs electronically. Students value the human element in their education and will not willingly relinquish that element. Educational technologies also may not support all types of learning styles, and centrally dispersed learning may sacrifice the local adaptations that capture student attention.

—From Analysis to Action, Report of a Convocation,
National Academy Press , 1996.

A FOCUS ON CONTENT & PEDAGOGY

What do content and teaching have to do with learning?

People fluent with information technology (FIT persons) are able to express themselves creatively, to reformulate knowledge and to synthesize new information. Fluency with information technology entails a process of lifelong learning in which individuals continually apply what they know to adapt and acquire more knowledge to be more effective at applying information technology to their work and personal lives.

—Being Fluent with Information Technology, National Academy Press, 1999.

SOME KEY QUESTIONS

- What are the ways that technologies can help contextualize learning and help learners start from what is already known to explore what is not known?
- How can technologies help teachers do a better job of setting priorities for presenting material within a course and for recognizing when key concepts have been learned?
- How does attention to learning rather than to content coverage fit into this discussion? Is coverage the enemy of comprehension?
- What if, as a result of growth and rapid changes in content, the particular content taught becomes unimportant and teaching focuses instead on higher level thinking skills?

THOUGHTS ON TECHNOLOGY

AN ESSAY: TIMOTHY KILLEEN

We, as a national community of educators, have learned something about how information technology can be used to improve the educational experience. Yet, with future bandwidth and computational improvements further gains can be made, ultimately having a profound impact on the scientific literacy of our citizens and in fulfilling the promise to parents of an education truly enriched by the research environment for their children.

At the University of Michigan we conducted a successful eight-year experiment with a truly interdisciplinary course sequence in global change, integrating materials from natural and social sciences and the humanities. Our interdisciplinary course development team involved professors from eight departments and five schools who met weekly for over five years with a team of graduate students, postdocs and evaluation experts. Through the extensive use of information technology: web based materials, dynamical modeling tools, interactive data analysis tools, evaluation instruments, tailored distance learning modules, etc., the course sequence became the most "interesting to students" of any introductory science-based course on campus. Independent evaluations conducted by the School of Education showed that alumni of the course had a greater propensity for taking advanced courses and going on to graduate school.

To give you just a flavor: after six weeks of class, students with very little or no advanced math background were using dynamical modeling tools to study global warming scenarios of their own devising for Earth and Venus - and assessing the likelihood of a future ice age by analyzing and manipulating data from disparate sources, including ice core and other paleoclimate records, isotopes in the ocean, atmospheric carbon dioxide and methane trends, Milankovitch cycles describing changes in the earth's orbit around the sun, etc. All data were pulled from the web, inserted into dynamical modeling and graphical analysis packages and studied in small-enrollment lab sections. A few weeks later the students were conducting a modeling study of how fish populations in the Outer Banks respond to regulatory action of different types - and later still - quantitatively studying the impact of World Bank loans on human population mobility due to dam building in the Far East.

Now the three-course global change sequence is the basis for a brand new interdisciplinary minor degree at the university - one that students complete in their first two years. The minor provides a new model for general education - it puts interdisciplinarity before disciplinarity (some referees have great problems with that!); it gives students access to numerous professors from multiple departments early on before declaring majors. It also gives students a more profound appreciation for the bi-directional relationship between humankind and the planet. In that sense, it's not "pre-Med", but more like "Pre-Life."

It is not a trivial matter to experiment profoundly with the use of IT in university curricula; just getting this on the books originally took two years! However, such new models of general education are springing up in most research universities and are being evaluated for effectiveness in an exciting national reform movement, all spurred forward by IT innovations.

My second point really speaks to the essential contributions of the research university for scientific progress in high priority areas. Once again, I'd like to speak very briefly to the area of my own research interests, but I think the comments have greater generality.

The overarching purpose of earth system science is to develop the knowledge basis for predicting and adapting to future changes in the coupled physical, chemical, geological, biological, and social state of the earth and assessing the risks associated with such change. I would argue that the most natural engine for such an interdisciplinary research agenda is the research university and that the only way to take this on is using extensive IT tools. No think tank has the disciplinary range, no company can have the long-term motivation or resources to address such a set of nested challenges alone. Yet, as we all know, there is a clear societal imperative for such study. I could list many impending changes, but let's just focus on one. During this century, humankind will essentially become an urban species, with over four out of every five people living in such settings. The implications of this for atmospheric chemistry, for energy policy, for transportation, for surface hydrology, etc. etc. are enormous and require deep interdisciplinary study - including the efforts of the arts and humanities whose role it is to describe and celebrate the human condition.

So, how can such studies be carried out? Since these are very complex systems, integrated teams of mathematicians, economists, geoscientists, computer scientists, artists and humanists will be needed. Significant knowledge-generation, dissemination and curation capabilities will also be needed.

In the next five-ten years, the data rate of information describing the earth's state coming from satellites will increase by more than three orders of magnitude. We are not ready for this. The coupled models of the earth system are now truly community artifacts - not owned (or even understood) by single individuals, but rather by the broad community of practice. For example, at the National Center for Atmospheric Research (NCAR) the Community Climate System Model (CCSM) is being co-developed by over twenty universities and its governance structure involves thirteen separate working groups.

My point here is simply this - the scientific and intellectual challenges posed by the earth system sciences and the human dimensions of global change simply require a full-court press of information technology capabilities, as well as the harnessing of the interdisciplinary expertise base developed and sustained in the research university.

A FOCUS ON CONTENT & PEDAGOGY

CONVERSATIONS & DISCUSSION POINTS

Tanya Furman: I had expected discussions would be more futuristic, and I think that's because we have recognized that technology is no silver bullet to what we're trying to accomplish in regard to student learning. Instead we have turned again and again to the point that technology is forcing, or enabling, us to address the fundamental issues of pedagogy. A good educational experience includes active learning; it includes real world problems. This learning can benefit from asynchronous learning; it can involve peer learning, and it must involve participation of all students with enthusiastic effort. Designing technology-based resources that do not do all of this is a waste of time and resources.

We must remember that one reason technology can be so successful is that there is such an up front effort needed in faculty effort. Before the semester starts, you have to really ask yourself, "Why am I doing this, and what am I trying to accomplish?" in a very different way than if you are just going to go through a book and write down the chapter titles and come up with some grand pontifications on every topic the night before. Access to technology is forcing faculty to get our act together before we start this semester. That can then lead us to the greatest use of the tool of technology tool through pedagogy. Faculty members are not just content providers.

Frank Newman: Tanya, isn't it one of the implications of what you're saying that to the degree that the faculty member sees him or herself as a content provider period, and ignores the question of pedagogy and student contact and everything else, it's a failure.

Tanya Furman: Absolutely. Psychological or not.

Amruth Kumar: In academia, progress is made only by volunteers. Faculty cannot be directed to use technology in their courses, they can only be inspired to do so. However, the buy-in for technology has to be top-down: from the dean and onward down to the individual teachers.

CONVERSATIONS & DISCUSSION POINTS

Frank Hughes: What people like my group are trying to do is build you a new tool. Right now you've got PowerPoint and Word and all those things, and you're just augmenting with a new set of tools that allow you to either create your own content or buy a whole cloth from the street.

Tom Banchoff: I am somewhat scared by this discussion. The fact is we've had "content" around for a long time. It's called textbooks, and through them master teachers are providing us with material that's supposed to make us into good teachers. And if you can't do that, then having technology isn't going to make you good either. Faculty do not make up the content by ourselves. We mediate it through textbooks that we use. And unless you teach everything straight yourself, you're using a textbook. If you're using a textbook, you're helping the students to interact with it. Technology can provide new material, and you can help the students interact with that, but if you're not good at helping them interact with a textbook, you're not probably going to be terribly good at helping them interact with technology: it's an enhanced textbook. At the same time, the technology can help if it's done well.

Frank Newman: I take exception to that. Take the forklift experience as described by Frank Hughes. We can give the operator the forklift instruction book that says study these procedures. That's very different than driving that thing up and falling over.

Tom Banchoff: I agree that there are technology "things" that make textbooks almost irrelevant, because they are so much better. But we're not talking about that most of the time. Most of the time, what we are doing by using technologies is not too much different from what we do using textbooks. Faculty who do well with textbooks can do well with technology. People who are not doing well are not miraculously going to be doing well because they have now the tool of technology.

Doyle Daves: Let's try another tack about faculty and technology and content. One of the things our discussion implies is some reduction in local control. Most of us teach in our own classrooms just how we want to teach. Now we know that in large, multi-professor groups, like introductory chemistry, physics, or math it is essential to coordinate with colleagues, so there is some continuity in exams and other important things. But when faculty start to use technologies and web assisted instruction, we will be bound by what is available to a degree that I think is different– this is both for faculty as teachers and students as learners.

FORKLIFT STORY

The power of immersing a student inside the study subject was dramatically demonstrated by Frank Hughes, Hernandez Engineering - HEI Training Services. His software positions the computer user as the driver and operator of a forklift. This software is provided to buyers of forklifts as an instruction manual to enhance safe use, e.g., by not driving the vehicle off the high end of a ramp.

www.tietronix.com

CONVERSATIONS & DISCUSSION POINTS

Bob Kolvoord: I'd like to offer a personal observation. Perhaps 80%-90% of what we do, in large part, we could do with unaltered, off-the-shelf materials. But faculty feel the need to customize the content and thus we spend 90% of our time on making that 10% or 15% of the changes. There may be some real significant opportunities here with emerging technology-based materials to change the way we use our time. But it will take faculty being a little more willing to abandon the feeling that we have to make it absolutely our own, that it's not okay to use something that somebody else created and designed.

Tanya Furman: When we're talking about efficient use of time, you're right, but there is this important process of personal investment in the material that you're making. And if it takes me ten hours to feel that I'm comfortable with it, whether I change it or not, that's a process I need to go through before I could employ some in my classroom and feel like I can answer all the student questions that will come up.

A FOCUS ON THE FUTURE

What are the future challenges and opportunities for information technology in the service of student learning?

"...ensuring that all Americans have access to technology is the civil rights challenge of this millennium. We will not meet this challenge until all of our children are as interested in becoming Michael Dell as they are in becoming Michael Jordan – when they would rather have the latest laptops than the latest hightops."

–William E. Kennard, Chairman of the Federal Communications Commission, Howard University 2000 Commencement Address

SOME KEY QUESTIONS

- How do faculty responsibly change as information technologies are integrated into the learning experience of students?
- How can an institution use information technologies to build on its peculiar distinctiveness to make a more attractive learning community for its students and faculty?
- What will be the effect of the increasing use of information technologies on social interactions among students and faculty, and in achieving the goal of greater student diversity?
- How can information technology aid us in achieving the goal of bringing quality STEM education to all students?
- What might our community look like in 2012 if we all took this seriously?

POLICY FOR HIGHER EDUCATION IN A CHANGING WORLD

AN ESSAY: FRANK NEWMAN

We have seen a rapid growth in the awareness of academic leaders of the potential power of technology. Technology is not an end in itself. Rather it is a tool to enhance teaching and learning. It is a tool, however, that allows the process of learning to take place in more effective and compelling ways ‘in ways that increasingly will not be possible to accomplish without the use of technology. As technology continues to improve and as the ability to use it wisely spreads, the use of the traditional modes of teaching will be less and less practical.

When the conversation in higher education turns to the subject of technology, there is a tendency to jump, instinctively, to one aspect—the capacity for virtual online education, or education at a distance over the Internet. However, as important as the capacity to educate at a distance is, the impact that digital technology is beginning to have on pedagogy—including the pedagogy of the traditional classroom—is, in the long run, of far greater significance. While the growth of virtual education has been rapid, the change in the traditional classroom is, by comparison, moving more slowly, dependent as it is on acceptance by individual faculty. The change is moving more slowly than virtual education, and more slowly than the impact of technology in many fields (such as banking or telecommunications) but still far more rapidly than change typically takes in higher education.

Much of the early use of the computer and internet in traditional classroom settings served to do ordinary tasks more efficiently—providing the course syllabus and readings, providing a communication link between faculty and students and among students, creating the means for more effective student research, etc. At an increasing rate, however, new software is emerging which allows students to take part in more engaging and effective learning that is computer mediated. Our estimate is that over the next five or six years, the use of such software will become commonplace, truly transforming the way learning takes place in most settings—traditional classrooms on campus and virtual courses online.

What gives technology for learning its power? The opportunity ahead lies in the capacity to use digital technology to transform learning in ways that capitalize on what we have known for a long time about powerful pedagogy—that students learn more, more profoundly, and remember over a far longer period when they are actively engaged in a self-driven learning activity rather than when they are engaged only passively, sitting and listening.

Despite all the evidence to this effect, a recent study shows that we remain heavily engaged in lecturing. Ninety-six percent of students reported “extensive lecturing” was the prevalent teaching technique they encountered, but only 21.4% of students found lecturing was “very important” in their coursework. Technology has the capacity to help accomplish in a straightforward, manageable way those modes of teaching that have been recognized as far more effective than the standard classroom mode. Without the aid of technology, they are seen as too difficult and too time consuming for the teacher and for those being taught.

Each of these improvements in learning could be gained, at least in part, without the application of digital technology. To do so, however, would take so much faculty — and student — time and effort. For example, one of the advantages of virtual laboratories in a field such as chemistry is that every student can have a hands-on experience. In an introductory chemistry class of 400 or 500 students, this takes an exorbitant amount of laboratory equipment and staff time, so that sophisticated laboratory experience is not practical. While actual laboratory experience is essential, virtual laboratory time allows more efficient and effective use of laboratory facilities. In addition, the growing availability of modules allows a faculty member to have students do hands-on exercises (e.g. using a virtual infrared spectrometer to analyze a sample or changing the chemical parameters of an experiment) that substantially enrich an otherwise abstract and generalized class.

Beyond all of these advantages, technology has one other great capacity—the ability to make the process inherently more interesting and even exciting. One need only look at the evolution of computer games to recognize the potential for engaging student attention. As the inexorable improvement of digital technology continues, and as our understanding of how to deploy it deepens, there will be further gains in capacity, reliability, and ease of use as well as reductions in cost. Soon it will be impossible, even with great effort, to achieve the same learning results without the use of technology.

In looking ahead, it would be wise for every institution of higher education to consider six points:

- Digital technology has already begun to change how students learn in every setting—traditional classrooms, online courses, elementary and secondary schools, skill training centers. Every day, new developments are announced making technology more effective in helping students learn, simpler to use, more reliable and less costly.

- As the capacity and use of technology continue to advance, the traditional classroom and the online course will look more alike to the student. Each will use technology to enhance learning. Each will encourage active learning and frequent communication with the faculty member and other students. Each will utilize faculty as mentors and guides rather than as the source of information. More and more learning will involve both classroom and online.

- The debate over technology has moved teaching to the center of the university's concerns from a distinctly peripheral position. This will force a review of the incentives for faculty performance.

- For universities and colleges to be effective at teaching will now require mastery of technology—including its skilled use in traditional classrooms. Those institutions with faculty skilled in the use of technology to improve learning will be seen as more dynamic and effective than their less engaged competitors. Therefore, institutions and faculty that view themselves as excellent at teaching now need to excel at the use of technology if they are to stay as leaders. This raises the question: "How should the institution support faculty as they make this transition?"

- To be effective at learning will require students as well as faculty to master technology. Every new wave of students arrives at the campus door with greater, but still uneven, mastery of technology and with changed expectations. This raises two questions: "What is the institution's responsibility to support students with infrastructure and help in mastering digital learning? How must higher education cope with the digital divide?"

- As technology's impact on pedagogy becomes more profound, every university and college will need to develop a strategy for its use.

A FOCUS ON THE FUTURE: FACULTY

REFLECTIONS: IVONA GRZEGORCZYK

Technology has become an important instrument in education. Computer-based technologies hold great promises both for increasing access to knowledge and as a means of promoting learning. The public imagination has been captured by the capacity of information technologies to centralize and organize large bodies of knowledge; people are excited by the prospect of information networks, such as the Internet, linking students around the globe into communities of learners.

—How People Learn: Brain, Mind, Experience and School, National Research Council National Academy Press, 1999.

It is clear that obstacles created by educational technology are substantial and so - the joy of teaching and learning is deteriorating! While there is a vast variety of new technology-based projects and curricula, and while technology-based teaching is exponentially developing – at different levels, different places, different fields, in different instructional media and hardware bases, even at different websites – there is a complete lack of a unified educational approach of the teaching community towards this development. There is no defined final product that meets the expectations of teachers and learners. What's more, the expectations themselves are not completely developed or verbalized. We do not have yet a common language to describe what we want (are activities, probletes and courslets the same ideas or different?). We spend too much time on designing hardware-dependent classroom resources rather than on defining and then developing a technological environment that will aid our teaching.

We all agree that the sophisticated technology of the 21st century will have unique capabilities for enhancing teaching and learning. It is time for experts from various educational fields to start the tedious task of designing a common software-engineering model for the teaching environment for the new century that could be harmoniously developed by teams of educators and technical specialists. It is time to define the current and future uses for the proposed software products, to decide on a vision for further development and possible connections with existing components. We should decide on what we want to happen, not what we alone can make happen in our classrooms - and ask the industry for help. "I touch here and I inspire my students to learn."

REFLECTIONS: WILLIAM S. MAKI

One of the dictionary senses of pedagogy is the "science of teaching." All too often, in my experience, we scientists act as if we don't believe it. We seem to dissociate our practice of research and rules of evidence in laboratories and our views of evaluation and rules of evidence with respect to what works in teaching and learning. For example, scientists at the PKAL Roundtable understand the importance of addressing the misconceptions that students bring to science classes (presumably using empirical evidence). But these same scientists passionately believe in "learning styles" and the need to match learning styles with particular teaching styles and the particulars of technological learning tools. The catch is that there is little or no evidence that learning styles interact with teaching styles to optimize student learning.

So I ask: "How can we get faculty in the sciences to generalize the scientific habits of mind from the laboratory to the classroom? How do we get the design criteria of 'common sense and intuition' (to quote a well-known educator) replaced with design criteria based on experimental research and behavioral observation?"

If we can't answer those questions our educational technology innovations will remain on shaky foundation and we have not much hope, beyond evolution, of knowing *what works*. The stakes are high; evolution can be a very cruel teacher.

Just as important as questions about learning and the developmental appropriateness of the products for children are issues that affect those who will use them as tools to promote learning; namely, teachers. In thinking about technology, the framework of creating learning environments that are learner, knowledge, assessment, and community centered is also useful. There are many ways that technology can be used to help create such environments, both for teachers and for the students whom they teach. Many issues arise in considering how to educate teachers to use new technologies effectively. What do they need to know about learning processes? About the technology? What kinds of training are most effective for helping teachers use high-quality instructional programs? What is the best way to use technology to facilitate teacher learning?

—How People Learn: Brain, Mind, Experience and School, National Research Council National Academy Press, 1999.

CONVERSATIONS & DISCUSSION POINTS

Comment: If the curriculum design people provide us specific instructions and the content is included in the materials, which is conceivable, what's the role of the faculty member? When we think about faculty, we tend to either think of ourselves as only content experts or curriculum creators. We rarely articulate the extremely important role we play in mentoring and facilitating learning.

Frank Newman: As this revolution in regard to the use of technology takes place, many faculty who are primarily content providers are in for a terrible time, because their personal identity is built around conveying content. And more than that, this new role is much harder, more demanding on faculty, than being merely a content provider.

Tanya Furman: But it's more rewarding. It's the creative process, like you're doing your own research for the creative process, and that's what we need to convey here.

Comment: This is probably the reason why not too many faculty are into using the new technology, because most faculty are trained in their discipline, not in teaching. Their pedagogy, how they teach, is an afterthought to thinking about what they teach.

A FOCUS ON THE FUTURE: FACULTY

REFLECTIONS: TERRI BONEBRIGHT

Faculty attitudes toward technology must change.

With the correct use of technologies, the instructor can be a facilitator rather than an information provider. Careful attention needs to be paid to behavioral components of the interactions of students with one another and with the instructor. Doing assignments and other activities online has an impact on interactions, and faculty need to be aware of the advantages as well as the disadvantages here.

Faculty must consider that the assessment of student learning must work in parallel to the assessment of the uses of technology to determine if learning is enhanced. Further, the usefulness of specific technologies to achieve learning goals set of specific courses and disciplines must also be measured.

There will need to be appropriate training so that faculty do not have to become "techies;" so they can focus on the impact on learning rather than on the functioning of the technologies. Faculty should have easy access to a technology support infrastructure, and to working groups on their campus that bring faculty together to address needs of a particular discipline.

To make the best use of information technologies, faculty must:

- focus on learning, not on coverage of material, on developing habits of mind and higher thinking skills rather on strict acquisition of information
- set priorities for what students should learn
- make accommodation for different learning styles
- have the support of senior administrators
- have easy access to the right technologies in class roomand lab, and 24/7
- have easy access to best practices in their discipline, and to effective tools for assessing the impact of technologies on student learning.

Other changes, beyond faculty attitudes, must occur. The quality of digital resources must be improved. The reward structures must recognize the contribution– to research/ education/ service– of faculty involved in creating, using, and assessing digital resources.

A FOCUS ON THE FUTURE: COMMUNITY

CONVERSATION & DISCUSSION POINTS

Frank Newman: I want to raise the question of community. What we want is two kinds of communities: one an intellectual community and the other a social one. Something that has arisen during this weekend is that technology offers both a promise and a danger. The fear is that it will end up isolating people, with students sitting in front of computer terminals, rather than being actively engaged in any kind of social dimension. Yet, we've also mentioned repeatedly that when technology is used wisely, it can enhance interaction. So it seems to me that a central part of what we've been discussing is that if we're going to do this, we have to do it right, and that this means we have to build communities: virtual, mixed, and/or traditional communities.

The key point to recognize is that technology can humanize things or dehumanize things, it can build or destroy community.

Mark Benvenuto: Let me make a different point about community and interaction. Not all students crave face time; we have to pay attention to students at different levels, with different learning styles. I try to teach a significant number of freshman, and not always honors courses. I find new students feel a certain amount of intimidation about coming to see the professor in his or her lab often, or any time other than in class. Somehow technologies can help here.

Frank Newman: Yes, part of our job is to create the relationship with students that they crave, but are afraid to seek. I'm sure there are many people in this room that are probably very good with students, but students often tell me, "I'm so glad to get a professor I can talk to." They want that contact, but they're leery. The big question is how to use technology as a tool to increase interaction, increase community.

The other day at Brown we were talking about what is happening in the library, where they have built clusters of computers, and they are always swamped. Students use them round the clock, because they're doing more team activities in class, and they love it. They love to work together, and they're all sitting at the computers and debating back and forth. They tell us they see this as a real social opportunity. It becomes a social interaction between people who might not have interacted otherwise and the ability to build friendships based on intellectual activities, rather than simply partying together.

A FOCUS ON THE FUTURE: COMMUNITY

THREE APPROACHES

A REGIONAL COMMUNITY

WILLIAM E. MOORE

For the past five years we have attempted to transform the traditional practice of distance education from one in which one university provides technology-driven learning opportunities for a collection of learners to a format in which several universities are both the providers and beneficiaries of a distance education initiative. Our first attempt at initiating this project was conducted in 1996 by the Science and Engineering Alliance. This ten-year old consortium consists of four HBCU's (Southern University, Alabama A&M University, Jackson State University and Prairie View A&M University) and Lawrence Livermore National Laboratory. Although research collaboration was a primary item on the Alliance's agenda, in the early 1990's we began to place increasing emphasis on collaborative instruction and its effectiveness.

When we surveyed the distance education spectrum, we found no cases in which a group of institutions offered a common course that would be taught by instructors from four institutions and would be taken by students from the same four universities By using a combination of formats which included face-to-face instruction one day per week, we thought we could provide a smooth transition from the authoritative lecture to technology based instruction and at the same time placate those technology-resistant faculties on our respective campuses. This model showed some tremendous potential, but it had some glitches associated with videoconferencing hookups and campus logistics. We were able to fill these holes over a three year period with Power Point support materials coupled with audio conferencing and video taping.

A GLOBAL COMMUNITY

JACK WILSON

A lot of institutions have a desire to extend their reach globally. The MIT/Microsoft Singapore Project, a fifty million dollar project, part of MIT, is a classic example of that. Some use projects of this type as kind of marketing their programs. But it's another thing if you are in a rural liberal arts college. How can you provide a global experience for your students? Sure, you can do traditional things like junior year abroad. You can have language programs. You can have international students. But there is still much more you can do. Using distance education, we actually put Rensselaer Polytechnic Institute (RPI) physics students in class with Chinese students in China, with whom they have to make joint presentations and work as teams.

A FOCUS ON THE FUTURE: COMMUNITY

THREE APPROACHES

A CAMPUS WIDE COMMUNITY

GERALDINE TWITTY

Howard University restructured its Environmental Studies program. The fall semester focuses on Individuals and the Environment; the spring semester addresses Communities and the Environment. The ultimate aim of the sequence is to establish a "Green Community" - a community of individuals from diverse backgrounds who work together toward establishing a sustainable environment that involves both the University and the neighboring community.

The syllabus, lecture notes, and assignments are online using Blackboard.com. The team is currently developing web-enhanced materials and opportunities that support inquiry-based, interactive, and investigative experiences.

This semester, the learning experience finds students engaged in organizing a campus recycling program:

Part I. Campus Recycling Audit

Each student has assumed responsibility for a particular aspect of the first phase. The audit includes research on [1] local regulatory statues governing recycling, [2] campus procurement and management practices, [3] waste flow analysis and [4] comparative aspects of recycling among area university campuses. Information flow among the students/faculty is implemented through email. Networks of potential allies are being established via web based activities and enhanced by invited lecturers. Environmental case studies are assigned for relevance and use in assessment.

Part II. Establishing Short and Long Term Goals

A working plan will be formulated along with cost-time analysis. Coordination of goals with key players in all avenues of the campus will be achieved through continuous technological information flow. Among the significant components of the program will be [1] the integration of strategic projects with the Howard University Environmental Science organization and [2] the development of an educational outreach initiative to the greater community.

Part III. Launching the Program: EarthDay 2001

A media blitz will announce the initiation of the program. Students will prepare briefs for interviews and press releases. Power point presentations of each student effort are scheduled during regular class.

This exercise offers opportunities for expanding the parameters of electronic technology while enhancing the active learning process and transforming the community into a sustainable Green Space.

CONVERSATIONS & DISCUSSION POINTS

Comment: The wise use of technology can enable dramatic improvements in undergraduate STEM only if best practices are established, adopted and disseminated throughout the community.

Tanya Furman: The Roundtable provided a focused discussion on the wise uses of technology to address the common problems that we all face in teaching science within a broad community. We've returned repeatedly to the notion - or the recognition - that technology is not a silver bullet. Technology is forcing us - or enabling us - to return to and address the fundamental issues of pedagogy. Designing technology-based resources that don't achieve our learning goals is a waste of time.

Bob Kolvoord: I want to ask about the issue of scaling. How can we take the sophisticated tools described by Dede, Kaput and Songer, which were developed for modest sized groups, across two million K-12 teachers, 100,000 higher education faculty? Or do we just keep doing small scale experiments that work really nicely, and we are very excited, and we go to the next small scale experiment?

Doyle Daves: Songer told us that she's got things running with 15,000 students at one time in many sites. Hesselink's remote operated lab is available now at twenty-nine universities in several continents. In a very short time we're going to hear people talking about another order of magnitude, meaning over 100,000 students affected by innovations that are technologically meditated.

Nancy Butler Songer: I have been working with this scale issue for several years and my first thought every time it comes up is that it is the exactly wrong way for us to be thinking about it. The main reason why I don't like the word scaling is because I think it has the implication of more is better and mass production equals good stuff . If we know anything about human systems in education, we know of course that's not really true. So, you not only have to have learning goals be the driving force behind the design of activities but you have to have resources. The resources have to be flexible to foster both simple kinds of questioning at the level of a fourth and fifth grader, and to allow entry level university students using the same resources to ask more sophisticated, higher level questions. So we've built the program in a way that everyone does certain parts but then there are a whole lot of other pieces that are flexible that allow you to do much more sophisticated things or much less sophisticated things depending on the audiences' interests and preparation. It's a whole new way to think about

ADDITIONAL CHALLENGES

- Transformation of resources (hardware, networks, class websites, online lecture notes, syllabi, etc.) to the learning we want.
- Information technology is progressing exponentially, while people change slowly.
- The important trends will be globalization, mass customization, studio classrooms, and fully wired campuses.
- Globalization will be achieved not just by marketing programs overseas, but by bringing global experiences to students, having an international student body, and running exchange programs.

SCANNER EXPERIENCE

Earlier in the conference Frank Newman illustrated how a technological innovation can develop: the scanners used in supermarkets were introduced to increase the speed of check-out. If a teller knew the prices,she (or he) could enter them by hand about as fast. But then it was realized that the data from scanning could provide an instantly updated inventory, but this advance could only be effective if all tellers scanned. Soon all purchasing/profit calculations, etc. were linked to this computerized system.

what scale means and why mass production of these very complicated learning environments is never ever going to work.

Bob Kolvoord: Let me use the word sharing, then, instead of scaling. If you have a quality experience that you want to share, how do you share more broadly, given that there is only one of you and however many staff you have?

Nancy Butler Songer: I think the answer is “community, you build” communities, because clearly you can’t possibly facilitate the kind of a mentoring and sharing opportunity that we do all by yourself. So we never think our job is done when we create resources. We also work on building communities, on fostering them, on helping people to help each other, and then we can get out of the way.

Nkechi Agwu: The lesson learned from the supermarket scanner experience is that what was once a luxury used to support a small number of services is now ubiquitous and essential. The whole supermarket business now revolves around this technology. Academic institutions are at this same point of no return.

In our rush to embrace the technological innovations of this century, we need to tread cautiously so that our creations for ensuring the success of all students in STEM education do not become mechanisms for perpetuating social ills, and end up alienating the very students we are trying to educate. This calls for sociological, psychological and medical research on using new information technologies for education, and a review of the history of equivalent systems so that we do not repeat the mistakes of the past.

NOTEBOOK COMPUTERS: THE KEYSTONE IN THE TECHNOLOGY ARCH?

AN ESSAY: FRANK WATTENBERG

Technology used well and technology used consistently has the power to help us achieve long-standing goals of undergraduate education. It can enrich, unify, and integrate the undergraduate experience and bridge the boundaries between the undergraduate years and those that precede and follow them.

Realizing the transformational potential of technology requires four things:

- A clear vision and strong leadership with well articulated goals at the national, institutional, and departmental levels
- New educational materials and resources
- Faculty professional development
- Technology itself - hardware, software, and networks.

To date our use of technology has been sporadic at best, and its impact generally disappointing. In fact, we have been through several generations in technology with only marginal and isolated impact on education precisely because we have not put together all four of the required elements. A clear, well-articulated vision backed up by strong and consistent leadership is particularly important because the other three elements must work together as a whole.

A VISION FOR TECHNOLOGY IN UNDERGRADUATE EDUCATION

First and foremost, technology is a force-multiplier. Technology cannot replace traditional learning. What it can do is multiply the effect of traditional learning. Students should master and use technology routinely in the same way that we use technology as professionals.

The key verb is "master." Students need to develop a sense of confidence and ownership in their technological tools. The key adverb is "routinely." Students need to use technology consistently and routinely throughout their academic and professional careers. Jim Kaput's article points out the extent to which technology can change our ways of representing and manipulating ideas. This kind of fundamental change requires consistent not episodic use.

Technology has the power to help students integrate their learning across time and subject. Timothy Killeen speaks eloquently in his essay on the importance of multidisciplinary approaches to the most significant problems we face as a civilization.

Technology has the power to enrich learning. This is the area where we have made the most progress. Virtual learning environments like those discussed by Frank Hughes; remotely accessible, research quality laboratory equipment like that discussed by Bert Hesselink; and widely available calculator- and microcomputer-based hands-on laboratory equipment, are already enriching students' experiences.

Powerful multifactor simulations are today being applied to important public policy debates, e.g., global warming, and the impact of World Bank loans on population mobility. These debates can be brought into the undergraduate curriculum in a real-world context. The National Science Foundation's National STEME[1] Digital Library (NSDL) project has the potential to make a large variety of primary resources and other educational resources of high scientific and pedagogical quality widely available at very low cost.

Technology also has the power to connect people. Here again, we have made very substantial progress. Threaded web-based discussions among students at different study sites (discussed by Nancy Butler Songer) and distance-learning courses across two continents (described by Jack Wilson) are connecting students across the world.

NOTEBOOK COMPUTERS: THE KEYSTONE IN THE TECHNOLOGY ARCH?

At these times" says Dumbledore, indicating the stone basin, "I use the Pensieve. One simply siphons the excess thoughts from one's mind, pours them into a basin, and examines them at one's leisure. It becomes easier to spot patterns and links, you understand, when they are in this form.

–J. K. Rowling, *Harry Potter and the Goblet of Fire, 2000.*

HARDWARE AND SOFTWARE

Pervasive computing, made possible by powerful portable notebook computers, is particularly well suited to the vision described above. It can further the goals of unifying education and of developing a sense of ownership and mastery of technology.

J. K. Rowling's *Harry Potter* has caught the imagination of youth (and adults) around the world. Harry often finds himself in places where he should not be. On one such occasion he finds himself in Dumbledore's office and discovers Dumbledore's Pensieve.

Dumbledore's Pensieve is a good metaphor for one facet of the promise of pervasive computing. It is a personal log, notebook, or portfolio. By making regular entries in his Pensieve, Dumbledore not only has a multimedia-rich record to aid his memory but he is able to integrate his individual memories, spotting patterns, and making connections. Although most notebook computers lack the "odd carvings, runes, and symbols" of the Pensieve, the Pensieve lacks tools like spreadsheets and computer algebra systems. In addition, Dumbledore makes no mention of a broadband Pensieve connection to the Internet, MathDL and the NSDL. More importantly, the Pensieve is not very portable and students at Hogwart's are not issued their own Pensieves with a standard suite of memories and tools. There is no mention of students using Pensieves on exams.

The vision of the notebook computer as a high-tech Pensieve promises to help students make connections across subject and time. Carrying a notebook computer from one classroom to another can be a physical manifestation of carrying ideas, knowledge, tools, skills, and questions from one classroom to another. But this requires action at the institutional level. The integrative power of pervasive computing cannot be realized one course or one subject at a time.

Notebook-based textbooks and other educational materials can be tightly integrated with the Pensieve. For example, students in a Mathematics class will add their own live notes using a computer algebra system to their notebook-based textbooks. They will establish hyperlinks to applications in other subjects including, for example, physics and economics. They will keep track of major themes by building a section of their Pensieve devoted to these themes. These thematic sections will be built at several levels - at the course level, at the subject level, and across subjects.

Students interested in a particular country might develop a thematic section for that country. Such a section might include notes on its literature and language from a language class, a population model developed in a mathematics class, the country's role in history with contributions from courses in its own history and from courses in other history courses, photographs and a log from a summer visit, notes from reading the newspaper or novels, and many other sources.

In short, the notebook computer can help students develop a sense of ownership in their learning and integrate their learning in physically realizable ways. However, notebook computers by themselves will not transform undergraduate education. The key is how we use them or, more precisely, how our students use them. Perhaps the most important practical step will be making these computers an integral part of exams. Our assessment of student learning must evolve in step with the evolution of learning itself. If we expect students to use technology as an intellectual force multiplier and we exploit that use to transform the curriculum then students must be able to use technology when their learning is being assessed. Otherwise, our progress will be thwarted by the WYTIWYG[2] imperative.

PROFESSIONAL DEVELOPMENT

I am particularly fortunate to be teaching mathematics at an institution, the United States Military Academy (USMA), whose mission is particularly well articulated and understood. At USMA, we look at each cadet's development in a holistic way over the period of fourty-seven months of undergraduate study. In addition, we spend a lot of time and energy on our own professional development, individually and as a faculty. New faculty members begin in the summer with an intensive six-week faculty development workshop. We have faculty development workshops throughout the year and faculty often visit each other's classes. During the year instructors in multi-section classes meet weekly and we write "after action reports" after each major graded event and for each course every semester.

When I describe this collection of faculty development activities to friends at other colleges and universities, the usual response is "we could never do anything like that at my institution." The real question should be "Why aren't we investing similarly in our faculty as professional educators?" We need to bring the same sense of pride and professionalism to teaching as we do to research. We need to work in teams and to build on each other's work and on a base of research on learning. We need to keep current on research on learning in the same way that we keep current in our disciplinary research areas.

We also need to strengthen the links between high school and college and between college and the workplace. We cannot blame K-12 education for our woes when it is we who are educating K-12 teachers and we who often are ignorant of changes in K-12 education.

All of this is always important, but today the rapid pace of technological change multiplies its importance many-fold. Because we need to elevate the importance of professional development and look at professional development in a multidisciplinary setting which encompasses each student's entire experience from freshman through senior, leadership and vision at the institutional level is critical.

NOTEBOOK COMPUTERS: THE KEYSTONE IN THE TECHNOLOGY ARCH?

LEADERSHIP AND VISION

Our educational goals are long-standing and well understood. Technology has the potential to help us achieve many of those goals but success requires both vision and leadership. The bullets below outline some of the policies that will help us dramatically improve learning in science, technology, engineering, and mathematics - and, indeed, in other subjects as well.

- Technology should be a force multiplier.
- Emphasize the synergies between technology and traditional approaches. In mathematics, for example, computer algebra systems should not replace traditional algebraic skills but should multiply them.
- Students should master a few general-purpose tools and they should use them throughout their academic careers.
- Technology should be required on major graded events and those events should change to reflect the increased power in students' hands.
- Technology should be allowed and even required in "downstream" courses.

This final policy recommendation is particularly important in mathematics. Technology allows us to work with more significant and complex applications by using sophisticated computer-based numerical and graphical techniques. In some cases this has reduced the importance of the formal techniques that dominated mathematics classes less than twenty years ago. Downstream courses in both mathematics and other disciplines can exploit the power of these new methods only if they allow and encourage the use of technology.

- Technology should be used to help unify students' education across time and subject.
- Wherever possible students should use common software in multiple courses.
- Students should be required to use their knowledge and skills from one course in other courses. Pervasive computing should be a vehicle for pervasive exchange of ideas and skills.
- Multidisciplinary faculty development efforts must be given the highest institutional priority. This must be backed up by real dollars and an eagerness to change.
- Multidisciplinary curriculum development and teaching must be given the highest institutional priority and be backed up by real dollars and substantive organizational change.

The overarching imperative for leadership is establishing a climate of change. The following definition of life from the *Encyclopedia Brittanica* is instructive.

> *The state of a material complex or individual characterized by the capacity to perform certain functional activities, including metabolism, growth, reproduction, and some form of responsiveness and adaptation. Life is further characterized by the presence of complex transformations of organic molecules and by the organization of such molecules into the successively larger units of protoplasm, cells, organs, and organisms.*

Life is characterized by change and adaptation and by organization into successively larger units. Because our best educational institutions are living organisms they will be able to thrive and take advantage of the potential of new technology.

ADDITIONAL RESOURCES ON THE INFORMATION TECHNOLOGY ROUNDTABLE CAN BE FOUND AT:

http://www.pkal.org/template2.cfm?c_id=339

SONGER PAPER RESOURCES

"Realizing the Learning in Digital Learning" can be found at:

http://www.pkal.org/template2.cfm?c_id=337

www.onesky.umich.edu

www.ceoforum.org

NEWMAN PAPER RESOURCES

"Policy for Higher Education in a Changing World" can be found in the Technology–Intensive Learning section of the PKAL website: www.pkal.org

http://www.futuresproject.org/

WATTENBERG PAPER RESOURCES

"Notebook Computers: The Keystone in the Technology Arch?" can be found in the Technology–Intensive Learning section of the PKAL website: www.pkal.org

[1] Science, Technology, Engineering, and Mathematics Education.

[2] What you test is what you get.

KAPUT PAPER RESOURCES

"Understanding Deep Changes in Representational Infrastructures: Breaking Institutional and Mind-Forged Manacles" can be found at:

http://www.pkal.org/template2.cfm?_id=338

www.simcalc.umassd.edu/NewWebsite/curriculum.html

Cross-platform software, Java MathWorlds for desktop computers can be viewed and downloaded at: http://www.simcalc.umassd.edu and parallel software for hand-helds can be examined and downloaded from: http://www.simcalc.com

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ABOUT PKAL

Project Kaleidoscope (PKAL) is an informal national alliance working to build strong learning environments for undergraduate students in mathematics, engineering and the various fields of science. We believe this occurs where:

- Learning is collaborative and steeped in investigation from the very first courses for all students through capstone courses for majors in mathematics and the various fields of science

- Faculty are committed equally to undergraduate teaching and to their own research.

- All students are expected to succeed

- There is active and visible institutional support for such a community with a shared vision of what works.

ABOUT SIGMA XI

Founded in 1886, Sigma Xi, The Scientific Research Society, is a nonprofit membership society of nearly 75,000 scientists and engineers who were elected to the Society because of their research achievements or potential. Sigma Xi has more than 500 chapters at universities and colleges, government laboratories and industry research centers. In addition to publishing *American Scientist*, Sigma Xi awards grants annually to promising young researchers, holds forums on critical issues at the intersection of science and society and sponsors a variety of programs supporting honor in science and engineering, science education, science policy and the public understanding of science. Membership in Sigma Xi is by invitation.

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