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REALIZING THE EDUCATIONAL PROMISE OF TECHNOLOGY

Universal Design with Technology

Universal Design for Learning will transform math education.

BY PAUL HORWITZ AND ROBERT TINKER

If you're a parent, you know that your child is unique. Your child thinks and learns in different ways than your neighbor, niece, or friend's child. But it's just those differences—the things that make your child and every child special—that can make it difficult for educators. How can your child's teacher reach the diversity of children in her classroom, some of whom may have physical or learning disabilities as well as different learning styles and preferences? And if the teacher uses technology to help her teach, how can the technology adapt to the varying needs of all those children? The answer is Universal Design.

In 1990, the Americans with Disabilities Act was signed into law. That act prompted a rethinking of architectural design to give disabled citizens greater access to public buildings as well as commercial facilities and transportation. At first this seemed to benefit only one group, but people soon came to realize that the changes engendered by the new law had made everyone's lives better—parents with strollers, people laden with packages, as well as ordinary commuters with no special needs. The concept of designing technology for a broad range of personal needs and abilities is known as Universal Design.

In educational technology, it means designing software and hardware that everyone can access and learn from. Universal Design for Learning (UDL) draws upon principles of universal design that are now widely accepted in architectural and product development, and applies these principles to the needs of teaching and learning. UDL is based on four tenets, described by the *Center for Applied Special Technology*:

- Rather than constituting a separate category, students with disabilities fall along a continuum of learner differences.
- Teacher adjustments for learner differences should occur for all students, not just those with perceived disabilities.
- Curriculum materials should be varied and diverse, and should include digital and online resources rather than centering on a single textbook.
- Instead of "remediating" students so that they can learn from a set curriculum, curriculum should be made flexible to accommodate learner differences.

continued on page 4

Inside

Throwing Away the Technological Advantage

BY ROBERT TINKER

Technology, which has transformed business and government, has not realized its **educational promise.**

The United States is letting its educational system decay. As the world gets "flatter," not only are call centers and light manufacturing being outsourced, so too are jobs that require advanced education: medical diagnostics, advertising, and even research. If the nation expects to compete in this flat world, it needs education that is deep and strong. It cannot afford to continue to be far behind Singapore, Taiwan, Korea, Hong Kong, Japan, Hungary,[1] or most of Europe.[2]

Current national policy will not significantly improve education. It is based on trying to extract better performance through coercion, while withdrawing support for innovation and improvement that could result in fundamental, lasting gains. This is nowhere more apparent than in support for educational technology.

Even though it is a leader in technology, this nation is failing to apply technologies that could generate huge improvements in learning. Technology will not be solely responsible for improving education, but it could be a key enabling force. It offers exciting *new* prospects for long-term educational gains. The articles in this issue give a taste of some of the transformative innovations that are possible.

In spite of the promise of technology, and the natural advantage the U.S. has in technological innovation, technologies are relatively underutilized in education. Compared to the personal computers of the 1980s, today's computers are millions of times more powerful, but educational applications have hardly changed. Technology, which has transformed business and government, has not realized its educational promise.

Educational technology utilization in schools is stalled for many reasons, many of which can be traced to the structure of American education: highly decentralized decision-making, stretched budgets, unfunded mandates, distrust of technology, and backlash from the too-plentiful examples of poor uses of technology. While these historical and cultural barriers to better use of technology will not soon change, federal leadership and funding for educational technology can be changed.

The most important federal role in education is to foster innovations that might have significant national impact. Federal agencies should focus on innovations that are too expensive, require too long to develop, and are too speculative for states, schools, and business to develop. If these innovations prove their worth, they will impact every student in the nation. There should be funding for all stages of innovation, from research-based development to small-scale testing and revision, then large-scale testing, and ultimately national dissemination. Funding should be available in stages, anticipating the loss of innovations that do not pass each level. Funding strategies should anticipate that the process requires a decade or more.

Surprisingly, in spite of its obvious educational promise, there is essentially no federal funding of any of these steps for educational improvement that depend on innovative technology. The National Science Foundation is uniquely qualified to be the primary sponsor of the nation's innovations in science, technology, and mathematics. Yet, the federal budget currently under consideration slashes NSF education funding by over $100M, or about 12% of its current level.

Now that federal funds for innovations in educational technology have dried up, we are coasting on the technology investments of one and two decades ago. Many technology-based innovations are simply not being explored. As a result, we are throwing away a rich resource that could be making huge contributions to improve education, particularly in science, technology, engineering, and math. Unprecedented computational and communication resources could allow educators to teach more, earlier, more deeply and thoroughly, with richer connections between subjects and the real world. We need a national effort to harness these capacities, turn them into innovative approaches, study their value, and ensure that the best are used widely.

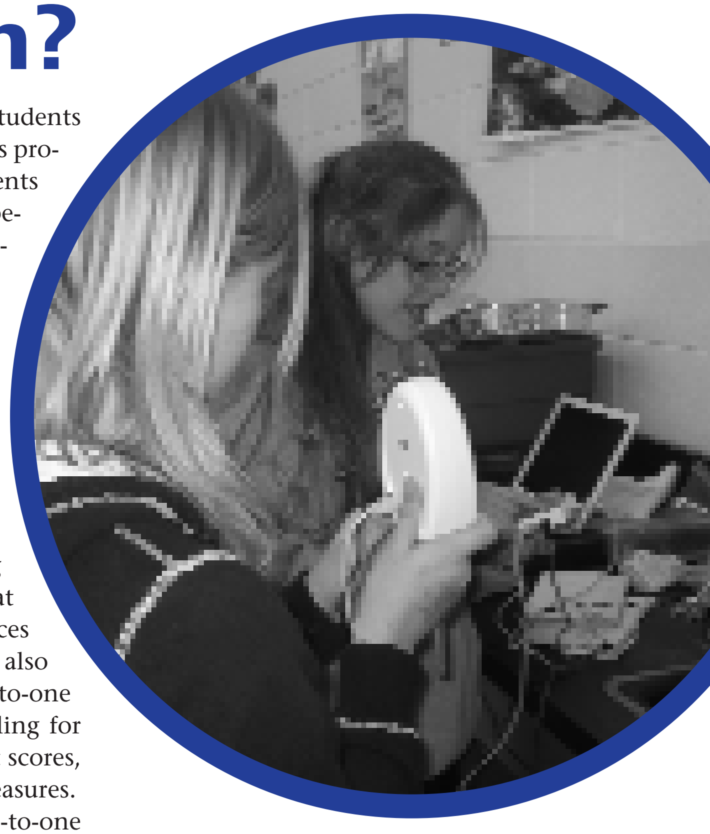
Robert Tinker *(bob@concord.org) is President of the Concord Consortium.*

1 Science scores of eighth graders in the TIMSS 2003 study, see ***http://nces.ed.gov/timss/***

2 PISA 2003 results, see ***http://www.pisa.oecd.org/***

Will Ubiquitous Computing Improve Education?

BY ANDY ZUCKER



"For more than 100 years, Maine has always been in the bottom third of states—in prosperity, income, education, and opportunity for our kids. In my 30 years of working on Maine economic issues, no idea has had as much potential for leapfrogging the other states and putting Maine in a position of national leadership as this one—giving our students portable, Internet-ready computers as a basic tool for learning."

–Former Governor Angus King, who spearheaded the Maine Learning Technology Initiative

In 2002, Maine began the world's largest school laptop program, providing Apple iBooks with wireless Internet connections to 34,000 grade 7 and 8 public school students and teachers. Massachusetts, Michigan, New Hampshire, New Mexico, Texas, and Vermont have pilot laptop programs, and dozens of schools and districts in other states support one-to-one computing.

Hundreds of thousands of K-12 students in the U.S. are using individual laptop or handheld computing devices. With the cost of computers continuing to fall, it is only a matter of time before personal, networked computing devices are used in school by millions of students.

While not all one-to-one programs are the same, many sites, including Maine, report that students are more engaged in school, demonstrate greater independence and more self-directed learning, and improve in a variety of skills, such as writing. Providing computers to all students also equalizes access to these tools for families of different economic backgrounds. Teachers and students in one-to-one classrooms have ready access to a wide range of software, electronic documents, animations, online assessments, the Internet, and other resources for teaching and learning. Teachers often report greater interaction with their students and their colleagues. Computers provide unique benefits to students with disabilities, and many special education teachers are especially enthusiastic.

Despite these promising reports, skeptics have lots to say. They claim it is too costly and difficult to provide all students with computers. They fear that without assistance, many teachers will not know how to skillfully integrate computers into teaching and learning. They warn that some students will use the devices inappropriately. Policy-makers also want better evidence that one-to-one computing will improve schooling for students, in terms of higher test scores, increased job skills, or other measures.

Whether the benefits of one-to-one computing are worth the costs may depend in part on transforming other aspects of the education system, for example by linking both curricula and assessments to digital resources. Nonetheless, some decision makers are committed to ubiquitous computing.

Maine is expanding its program into high schools and Massachusetts Commissioner of Education David Driscoll says of the state's new one-to-one pilot program in the Berkshires, "This really is an opportunity to truly change the way teaching and learning occurs in our classrooms.... [T]his should be statewide."

We already know much about how to implement ubiquitous computing and about its potential to improve education. For example, *Lessons learned about providing laptops for all students* identifies supports needed to implement effective one-to-one programs. Yet, because these programs are new, there is still much to be learned, and several major research studies are under way, including a large-scale randomized experiment in Maine, studying the effects of teacher professional development to use software applets in teaching middle school mathematics. As the Ubiquitous Computing Evaluation Consortium co-director, I am optimistic about the results and look forward to the study findings.

LINKS ***Ubiquitous Computing***

- **Lessons learned about providing laptops for all students.**
  http://www.neirtec.org/laptop
- **Information about one-to-one programs and related research.**
  http://ubiqcomputing.org
- **Information about the study in Maine.**
  http://www.mistm-maine.us

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Universal Design—*from page 1*

UDL is exciting because it represents a convergence of thinking about the best uses of technology. UDL calls for multiple means of representation, multiple means of expression, and multiple means of engagement. Universal design goes hand in hand with technology because computer-based materials are the most practical way to provide the needed flexibility.

There is a considerable body of research in human cognition that provides experimental evidence for designs that UDL can utilize. One of the strongest findings involves using visual and audio outputs in parallel. While this is obviously useful for students with severe vision or hearing challenges, research has found that this benefits everyone. Another finding is that screen design needs to be highly stimulating for some students while others need a relatively "calm" and simple design. These and similar factors can be preferences that are set by teachers or students, or they can appear as options always available to the learner.

As the UDL revolution takes hold, students who are currently marginalized in traditional classrooms will soon find tools that suit their unique abilities. Schools and vendors will discover educational methods and materials that are flexible and powerful enough to help all students, regardless of their ability. And the revolution has already begun. *Thinking Reader*,™ developed by CAST and distributed by Tom Snyder Productions, is a highly successful reading program based on UDL.

But even as UDL is helping to transform technology for reading, mathematics education lags behind. The research results that gave rise to UDL make general statements about human cognition and perception, and are not specific to a single area of learning. But those findings have yet to be applied toward the creation of mathematical educational products that can meet the widely varying needs of students with different learning styles and strengths.

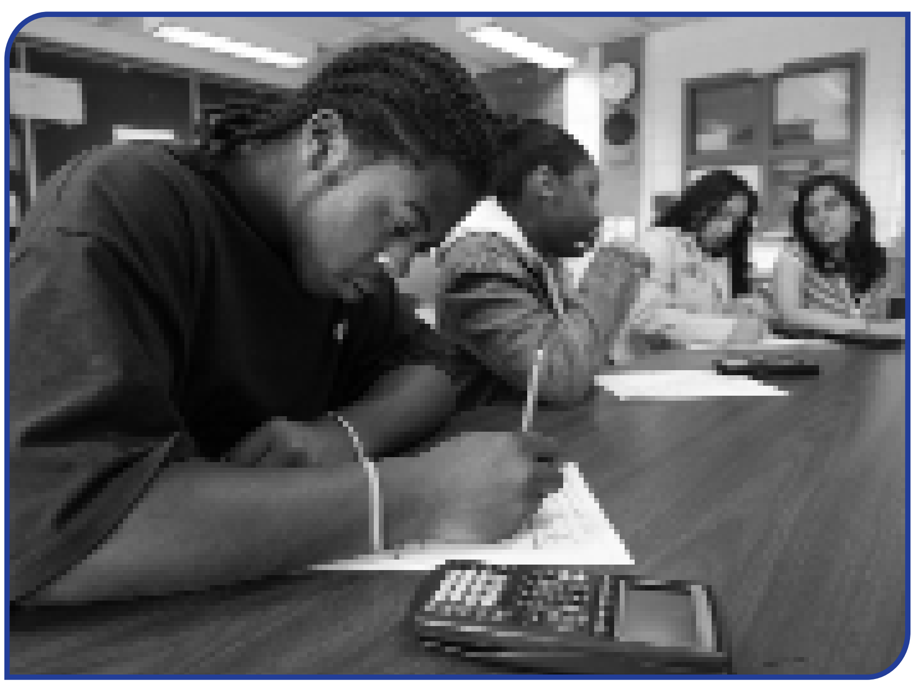
The Concord Consortium is dedicated to making such educational innovations available. We are currently planning a suite of web-based algebra interactives based on UDL. We will begin with "Talking Graphs," which will use graphing data to generate text and verbal descriptions of important features of the graph (e.g., axes, overall shape of the graph, and location of maximum and minimum values). The software will be designed so that students or their teachers can adjust the screen complexity and display options, and generate visual, aural, and haptic (touch) output. Algebra students, including the low-vision seventh-grade student and the remedial nine-grade student, will benefit from the opportunity to make math meaningful.

> Universal design goes **hand in hand with technology** because computer-based materials are the most practical way to provide the needed **flexibility.** Our goal is to make software with multiple options to support **mathematical problem description** and problem solving.

UDL Math

A central feature of UDL is its ability to adapt to students with different perceptual and cognitive needs. Our goal is to make software with multiple options to support mathematical problem description and problem solving.

Screen Display Options. A customizable set of screen display options (e.g., high and low contrast, as well as shades for the color blind; text size and font choice; and speed of motions on the screen) will allow the teacher or student to customize the display to match each student's learning preferences. We will also alter the surface complexity of the problems we present. For instance, with students whose number sense is weak, we will start by restricting variables to positive integral values. Later, students can control the variables and determine for themselves what happens when the



There is a need for flexible tools to teach math to young people, especially those with disabilities. With software based on principles of Universal Design, students are able to access course materials in ways that are flexible and customizable.

variables take on fractional, decimal, or negative values.

Audio Options. Each object in Talking Graphs will be able to describe itself in words while highlighting whatever feature is being described. The description will have various levels of complexity, and will be sensitive to the context of the particular problem. For example, a position-versus-time graph that represents the motion of a vehicle will highlight a horizontal portion and explain, "This line segment represents the time when the car was stopped at a traffic light." In one mode, this explanation will include an animation panel showing the actual situation. Because some students find it difficult to concentrate with several simultaneous visual stimuli, sound effects will be available. In this case, imagine hearing the car motor rev faster and faster, as an upward sloping section of the graph is highlighted, or hearing brakes squeal when the graph moves precipitously downward.

Alternative Representations. We will present five different representations of information—text, graphs, tables, algebraic expressions, and animations. Each will be manipulable and when one is altered, all others will react accordingly. The representations will not be present on the screen at the same time. On the contrary, one of our strategies for gauging students' comprehension will be to hide one representation and ask the student to manipulate it by controlling a different representation. This ability to adopt different representations, to alternate among them, and to allow students to choose the representations they prefer, is one of the major advantages of computers over static textbooks, and a critical design feature of UDL.

Scaffolding Options. The degree and kind of help available to different students can be scaffolded, from high to low intervention; scaffolding is one of the primary ways software can be customized and aligned with a UDL approach. At the beginning level, we will show students how to set up a problem, and walk them through its solution, pointing out that many problems can be solved in multiple, equally valid ways. Subsequent levels will offer a choice of actions for students or a tutorial on how to solve problems of its general type, followed by questions designed to help the student map the general solution to the specific one. Other levels will monitor student actions and offer hints, either automatically or in response to a request. For some, the software will not intervene until the student either solves the problem or gives up. At that time the software will produce a report describing the student's actions with suggestions for improvement.

Feedback to Teachers. The data obtained by monitoring the students' problem-solving strategies will be analyzed in real time and reported back to the teacher at the end of each student's session. Because such analysis is timely and fine-grained, the teacher will be able to identify students with particular learning difficulties as soon as those difficulties become apparent, rather than having to wait for test scores that come too late and are insufficiently diagnostic.

One size doesn't fit all. With the invention of the printing press it became possible to produce textbooks that would transform education from a luxury available only to the elite to a commodity accessible to everyone. This was decidedly a major advance, but the price we paid for it was a uniformity of curriculum and pedagogical approach that cannot reflect the diversity of the human mind and spirit. The advent of the computer gives us the power to return to the days when education could be tailored to the needs and abilities of individual students, while still making it widely available. By applying UDL principles to the important area of math education, the Concord Consortium is taking a small but significant step toward that goal.

LINKS *Universal Design*

- **Center for Applied Special Technology**
  http://www.cast.org
- **Thinking Reader™**
  http://www.tomsnyder.com

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Reaching Teachers Worldwide

BY ALVARO GALVIS

Developed and developing countries alike struggle with improving the quality of teacher preparation and teacher professional development. One thing is certain in education worldwide: teacher impact on student learning makes a critical difference. However, many areas of the world face special challenges attracting and retaining good teachers and providing appropriate resources for students. For instance, in rural areas and in low-income communities, it is difficult to recruit certified teachers and to provide students with multiple resources for learning. This twin set of problems is most severe in areas where there is armed conflict or a major health concern. The AIDS epidemic in rural Africa, for example, has virtually destroyed education; many untrained teachers head up classrooms. Worse still, these teachers face barriers that hinder their continuing professional development.

> The Internet provides opportunities for students in **developing countries** to interact with educational resources and with **distant students and teachers.**

But there is good news. Information and communication technologies (ICT) have opened new avenues for teaching and learning. The Internet provides opportunities for students in developing countries to interact both with a wide variety of educational resources and with distant students and teachers. The Concord Consortium has pioneered the educational uses of ICT. For a decade we have researched the essential elements to ensure success when technology is introduced in classrooms. Hardware and software alone are not enough. More important are good teaching and quality learning resources. Our efforts have, therefore, focused on developing research-based materials and high-quality teacher professional development.

CAPTIC project in Peru

The Concord Consortium is part of *dot-EDU,* an alliance for education funded by the U.S. Agency for International Development (USAID). The dot-EDU strategic alliance is a worldwide effort to enhance education in friendly countries through the use of ICT. USAID-Peru and the Peruvian Ministry of Education invited dot-EDU to create and pilot a model for professional development of rural elementary teachers that would enhance their students' learning. In response, the Concord Consortium partnered with EDC and *Programa Huascarán*—a national program in Peru that provides ICT infrastructure and advice for educational institutions—to create *CAPTIC* (a Spanish acronym for ICT-based learning communities).

During the pilot, we faced huge organizational and technological issues that are common in many developing countries. For instance, while the Peruvian Ministry of Education determines which competencies must be achieved at each grade level and outlines ways of achieving these competencies, it does not prescribe national curricula. Educational regions in Peru are thus autonomous from an administrative perspective. Each region has its own funds to provide free basic educational services at public schools and regional educational authorities appoint teachers at public schools. However, teacher preparation is not part of this regional administration; rather, teacher colleges are ruled and sponsored by the Ministry of Education. The creation of a network of ICT-based learning communities was, therefore, not an easy task, requiring careful coordination with different groups and authorities.

Technology readiness was also a major issue. While all of the institutions participating in the Programa Huascarán theoretically had working computers and Internet access, this was not the reality. At the beginning of the pilot, only four of the fifteen computer labs were fully operational; at the end, twelve were prepared. The original design of the project assumed that online interaction was possible between all institutions, but while computers were available everywhere, connection to the Internet was not. The project thus reimbursed participants for fees they spent for Internet connections at local cyber-cafés.

Networked communities of practice

The CAPTIC project tested an ICT-based network of communities of practice in Peru. The center of this network was at Programa Huascarán, which hosted the virtual space for interaction between project participants. A full-time national coordinator of the network was in charge of ensuring technological support from Huascarán and of leading the implementation of CAPTIC. Four regional bases, one at each of the participating rural teacher colleges, co-facilitated the in-service training of elementary teachers. Each local group was focused on creating and nurturing communities of learners composed of students and teachers who co-construct knowledge around inter-curricular and locally relevant educational problems. Twelve rural elementary schools in four regions, each with four or five participating teachers, took part in the project.

The teachers focused on two key educational ideas, both of them implemented in face-to-face and online learning environments: genuine dialogues between teachers and students, and CLIC-based projects. (CLIC is a Spanish acronym for Creative, Ludic (playful), Interactive, and Collaborative.)

Regional facilitators videotaped sessions of participating teachers' classes at the beginning, middle, and end of the school year. Teachers reviewed their own videos, selected episodes to study with colleagues, and participated in a local community of practice. The facilitator helped teachers build trust and develop expertise in reflecting and commenting on their classroom experiences. Videotapes revealed that at the beginning of the project, interactions between teachers and students were mostly didactic (focused on getting the expected answers from students); at the end, many teachers sustained genuine conversations with their students. When teachers took part in an online seminar about building online learning communities, they reported learning additional strategies for fostering pragmatic dialogue in their classrooms.

Teachers also participated in two workshops where they discovered CLIC pedagogy. Teachers were immersed in playful problem-based experiences. Problems were designed to require interdependency between groups as well as a variety of educational resources. After the first workshop, teachers created local collaborative projects that focused on school-based educational needs. Following the second CLIC workshop, teachers created global collaborative projects, focusing on a grade-specific educational need. The global projects were implemented across sites using information and computer technologies to manage the interaction between distant groups.

Through their involvement in ICT-supported reflective practice, teachers reported professional growth. The integration of educational media around problem-centered activities gave ICT another important role. Teachers and students participating in local and global collaborative projects found that this learning expands the borders of the classroom and allows them to go beyond the traditional role of transmitting or receiving knowledge.

Because teachers discussed local practices, face-to-face interaction was necessary. The Internet was essential for managing the interaction among teachers at different schools and among their students. Facilitation of the process was blended, with both face-to-face and online seminars and workshops. In the future, the hope is to move more quickly towards Internet interactions.

Local and distributed collaborative, inquiry-based projects helped students to develop basic competencies.

Teacher professional development provided by CAPTIC used both online and onsite discussions among teachers.

A look into the future

Is the Peru experience expandable and sustainable? Could it be used in different settings with similar problems and opportunities? We think so. The Ministry of Education in Peru is preparing for a second round, with only minimum intervention on our part. A similar initiative is being launched in Colombia, in partnership with the Colombian Ministry of Education and the dot-EDU program.

We hope to refine the process, methods, and tools in order to share this experience with many other countries that need to reach teachers and students in underprivileged areas. Online activities will increasingly become the dominant mode of interaction among teachers and students who participate in problem-based collaborative projects. But video case-based teacher professional development may still require some face-to-face interaction, at least initially, in order to create the local conditions in which educational innovations can prosper.

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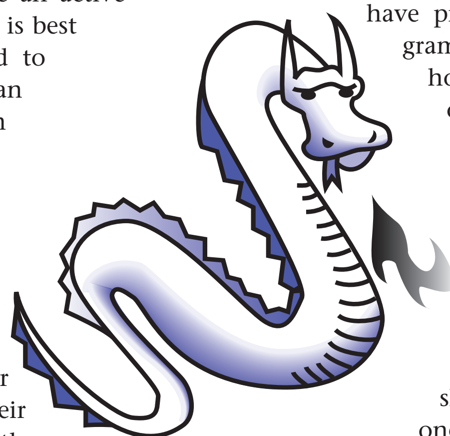
LINKS *Reaching Teachers*

- Concord Consortium online professional development projects include **Seeing Math™** *http://seeingmath.concord.org* and **Technology Enhanced Elementary and Middle School Science** *http://teemss2.concord.org*
- For a successful virtual school model, see **Virtual High School** *http://govhs.org*
- **dot-EDU** *http://www.dot-edu.org*
- **Programa Huascarán** *http://www.huascaran.edu.pe*
- **CAPTIC** *http://www.huascaran.edu.pe/WebCaptic*

Performance Assessment:
Science Knowledge in Action

BY PAUL HORWITZ

Computers are beginning to change the way we teach students; soon they will revolutionize the way we assess those students' understanding. Why? Because computers are an active medium and student understanding is best measured when it is being applied to active situations. Print materials can explain things to you; computers can guide you to learn by trial and error. Printed tests can ask you questions; computers can pose complex challenges and offer you alternative ways to achieve a goal. We can infer a great deal by observing how students rise to the challenge, what use they make of the tools at their disposal, how they react when their first idea doesn't pan out, and how they interpret their results.



No matter how well designed a test is, it is difficult to determine whether someone really understands a concept and can apply that understanding in a practical situation simply by asking a series of questions. The very act of answering questions on a test puts one into a special mindset, calls up specific associations, and prepares one to think about a situation in a particular way. For example, if we are teaching genetics, we will want to know whether our students know how dominant and recessive traits are inherited. Do they understand how the appearance of an organism is related to the specific forms of the genes it carries? Do they know that every sexual organism inherits half its genes from its mother and half from its father? If we simply ask those questions outright, however, many students will answer them correctly, even though most might be incapable of using their "school knowledge" in a practical context. The Horns Dilemma computer activity, developed by the *Modeling Across the Curriculum* project, tests students' knowledge of genetics and also assesses their ability to apply that knowledge. Here's how it works.

Dragons illustrate the problem

We start by describing a real-world situation involving a genetic disease that results from the inheritance of two copies of a relatively rare recessive allele. The story involves a young girl named Sara who has cystic fibrosis. The students are told that this disease is genetically inherited and that it is caused by only one gene. They are also told that neither of Sara's parents, nor any of her siblings or relatives, has any hint of the disease. How can this be? The students are left to ponder that question as we switch to a seemingly unrelated one involving the not-so-real world of dragons.

One of the traits of the dragon species, as we have programmed our BioLogica™ program, is the possession or absence of horns, with horns being dominant over hornlessness. Specifically, the horns trait is governed by a single gene that comes in two varieties, or alleles: the dominant "H" and recessive "h." A dragon with two recessive "h" alleles has no horns; any other combination of alleles (HH, Hh, or hH) will result in a dragon that has horns. We show the student two dragons—one male and one female—both with horns, and we ask whether it is possible for them to have a baby that has no horns. Initially, the genes of these dragons are not visible. Unless the student uses a special "chromosome tool," she can only see the dragons' physical traits and there is no way for her to tell whether these particular dragons can have a hornless baby.

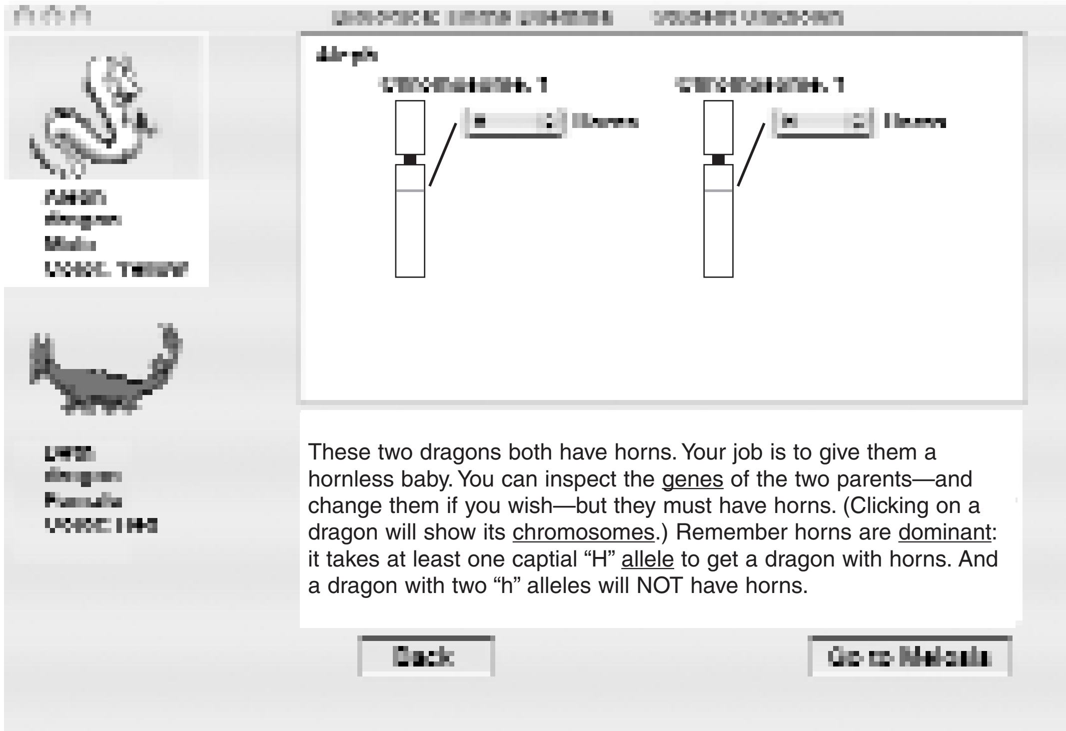
In fact, one of the two dragons has two "H" alleles, making it impossible for this pair to have a hornless baby. (For them to have a baby with no horns, each parent dragon would have to have one "H" and one "h" so that each could donate a recessive "h" to the offspring.) Through the magic of computer simulation, the student can do more than just look at the dragons' chromosomes, she can alter them if she chooses, as long as each parent still has horns. And to achieve the goal of creating a hornless baby dragon, she will have to do just that—changing an "H" to an "h" to give both parents a recessive allele.

Monitoring student actions

For assessment purposes, we now have two actions to monitor, each of which bears significantly on the student's understanding: if she fails to look at the genes of the parent dragons, she is probably not thinking

LINKS ***Performance Assessment***

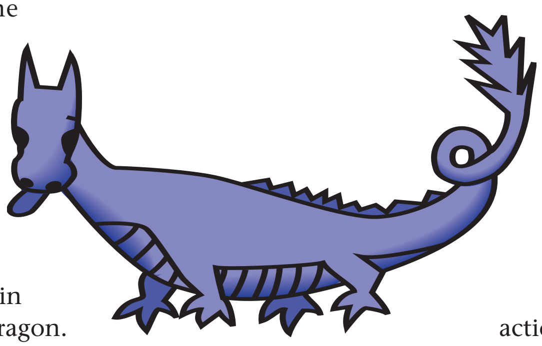
Modeling Across the Curriculum
http://mac.concord.org



The crux of the Horns Dilemma activity. Note that Aleph, the father dragon, is selected, thus it is his chromosomes that we see. Since he has two dominant "H" alleles, he cannot have a hornless (hh) baby, and it will be necessary for the student to change one of his horns genes in order to solve the problem. The text makes it clear that this "genetic engineering" is allowed, but stops short of suggesting that the student do it. It is a reasonable inference, therefore, that students who go on to try to make a hornless offspring without altering the father's genes do not really understand how a recessive trait can be inherited from parents who do not exhibit it.

"genotypically," but considering only the outward appearance of the dragons. On the other hand, if she looks at the genes, but does not change them, it is a reasonable inference that she does not realize the importance of each parent carrying that recessive allele. Because the activity is run on a computer, we can easily monitor which choices the student makes—by recording mouse clicks or paths along the branching story line.

In later stages of the activity the student runs meiosis on each parent and fertilizes the resulting gametes to produce an offspring. If that offspring has horns the computer will offer minimal guidance, in the form of hints that become more and more explicit until the student succeeds in making a hornless baby dragon. Thus, the level of aid required becomes yet another useful indicator of the student's preparedness for the task.



But how do we know, in the end, whether the student has connected the manipulation of the dragon model to the real world of genetics? Once the hornless baby has been created, the computer returns to the story of Sara, and asks a series of questions, including the critical one: what does the hornless dragon activity have to do with Sara's cystic fibrosis? The student who realizes that hornlessness in dragons and cystic fibrosis in humans are both passed on the same way—through the inheritance of two copies of a recessive allele—has integrated "book learning" with a real-life situation, and is on the way to thinking and behaving like a geneticist.

Assessments of this kind, in which one infers the state of students' knowledge and understanding from their problem-solving actions, are called "performance assessments," and much of our current research is devoted to learning how to design them well. We are figuring out what kind of challenges to pose, how to provide timely feedback without being intrusive, what data to collect, and how to analyze that data. We still have a lot to learn before we can realize the full potential of our technology, but preliminary results hold much promise for science, technology, and vocational education. More good news: the technology for capturing student actions and measuring student understanding continues to improve. Our data collection and analysis software is now robust, powerful, and widely available. Over 260 schools have registered to use our modeling software and many of these have registered their students with us, enabling us to collect performance assessment data and generate reports for them. Let us know if you'd like reports for your students, too. Our modeling software is available for biology, physics, and chemistry.

Paul Horwitz *(paul@concord.org) directs the Modeling Center at the Concord Consortium.*

Freeing Educational Applications

BY ROBERT TINKER

You should think about using open source software in education. For starters, the price is right—it's *free*. And some of it is quite good. Misconceptions about open source educational software abound, however, and they need to be cleared up:

Free means junk. Not necessarily. Just like commercial software, there is a lot of open source junk and vaporware. But there are some gems, too, described below. Indeed, sometimes, there is such a thing as a free lunch.

Open source software only runs on a Linux box. Wrong. Most recent open source software is written in Java, which will run on current Windows, Macintosh, and Linux computers, without requiring downloads. Other open source software is available as applets that run in almost any browser.

We hope to be part of this exciting development by committing our software team to **generating open source applications,** and by stimulating interest in the use of OS applications. You can help, too, by using this software, sharing it, and **telling your friends** and representatives in government **how great it is.**

Open source software may be free now, but what about later? If it's open source now, it will always be open source. The open source copyright forbids anyone from withdrawing open source software and making people pay for it. That said, you may want to pay someone who bundles open source software into a convenient package, but there will always be a free option.

Open source software will crash and burn. Not likely. Open source software tends to be better than commercial software when lots of people are involved in maintaining it. This hasn't happened yet for most interesting educational applications, but if enough people begin using open source educational applications, it will.

Only geeks use open source software. No way. All the software described in this article can be downloaded and run by most users with some (but not advanced!) technology experience, just like other educational applications.

If it's free, it must be open source. Not necessarily. Developers sometimes make early versions of their software free to get you hooked, and then begin charging later. Check the licensing to be sure it's copyrighted under one of the open source licenses, like the GNU General Public License.

Right now, open source (OS) educational software is "pre-takeoff." Not many are aware of it, there is not much high-quality software, it is scattered, people confuse it with open source system software releases like Red Hat and Fedora, and there is no real community of programmers supporting the code base. But that will change soon, and we hope to be part of this exciting development by committing our talented software team to generating excellent open source applications, and by stimulating interest in the use of OS applications.

You can help, too, by using this software, sharing it, and telling your friends and representatives in government how great it is. Some of the open source applications you should know about are described below. Be sure to let us know about other open source software you're using.

The software tools and models showcased here were designed specifically for education in a particular discipline area or topic. Most of these are in mathematics and science, because the National Science Foundation has funded almost all this software. No comparable source of funding exists for educational software.

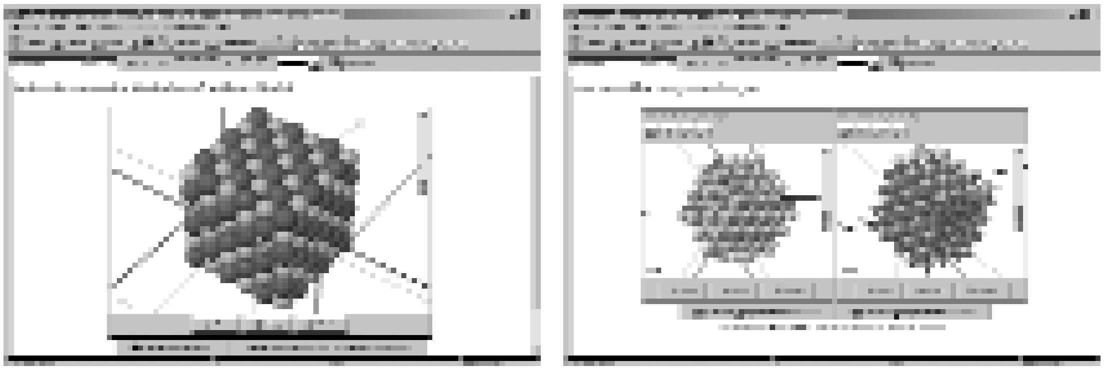
Mathematics

Seeing Math Interactives. The Seeing Math project has developed a series of interactive software that clarify key mathematical ideas for teachers and students of algebra. Five packages are currently available that allow students to explore various aspects of linear and quadratic functions. *http://seeingmath.concord.org/resources.html*

Shodor Software. This is a collection of over 60 Java applets for all levels of math, with student activities. *http://www.shodor.org/interactivate/activities/tools.html*

StarLogo is a special kind of model-building programming language like Logo. It is hard to categorize, because it can be used to create interesting models of systems in mathematics, science, and social science.

The Molecular Workbench software provides a variety of 2D and 3D molecular dynamics engines and an authoring system to create models and activities based on these engines.
Left: A simulation for an NaCl crystal, with the 3D graphics rendered with Jmol.
Right: Molecular dynamics simulations of two intermetallic compounds (Au_3Cu and Cu_3Au).



These models all involve giving simple rules to an "agent," and when there are lots of these agents, the system as a whole sometimes has some unexpected "emergent" behavior. *http://education.mit.edu/starlogo*

Science

BioLogica is a multi-level model of classical genetics that is often known as "Dragon Genetics" because it allows students to explore the mythical genetics of dragons as a way of discovering all the major forms of inheritance. The software is available as a series of guided explorations, or as an open-ended tool called GenScope. *http://molo.concord.org/database/activities/30.html*

Dynamica provides guided exploration of two-dimensional kinematics and dynamics. It can trace its roots to ThinkerTools, which once ran only on a Commodore 64. Request a demonstration account at *http://mac.concord.org/portal/registration/register.php?action=demo*. You will then be given a username and password that will give you access to a "Software" button on the left-hand panel. Look for physics software.

Molecular Workbench is a model of atoms and their interactions that can be used to explore many properties of atomic and molecular systems in biology, chemistry, and physics. A database of over 100 student activities based mostly on the Molecular Workbench can be found at *http://molo.concord.org*

Open Source Physics is a collection of Java applets related to a text by Harvey Gold. *http://www.opensourcephysics.org*

PhET. The Physics Education Technology (PhET) project at the University of Colorado produces fun, interactive simulations of physical phenomena that make bridges to the real world. A collection of 40 Java applications for introductory physics is available. *http://www.colorado.edu/physics/phet*

Additional OS applications for educators

GIMP is an open source photo editing software.
http://www.gimp.org

GRASS is a geographic information system package.
http://grass.baylor.edu

ImageJ is a Java image analysis package.
http://rsb.info.nih.gov/ij

J-mol 3D visualization tool is particularly helpful for seeing large biological molecules.
http://jmol.sourceforge.net

.LRN is a platform for online courses, a possible replacement for Blackboard or other proprietary course management systems.
http://dotlrn.org

VideoPaper Builder makes it easy to make and share video case studies that can be used in teacher professional development.
http://vpb.concord.org

WISE is a Web-based environment for easily authoring and delivering learning activities made from linked steps.
http://wise.berkeley.edu

Other

Participatory Simulations developed at MIT for handhelds, use Palm computers to embed people inside simulations. Interactions between players in the game are mediated by beaming. Current systems model genetics, logic, ecology, and infection. *http://education.mit.edu/pda/index.htm*

Sustainable Education Software. Three packages help students think about environmental scenarios, communities, and their "ecological footprint."*http://www.concord.org/research/sustainable.html*

Squeak is a "media authoring tool," which allows you to create your own media to share and play with others. A modern implementation of Smalltalk, it is great for kids and serious programmers alike. *http://www.squeakland.org*

Robert Tinker *(bob@concord.org) is President of the Concord Consortium.*

Any Computer, Any Interface, Any Curriculum

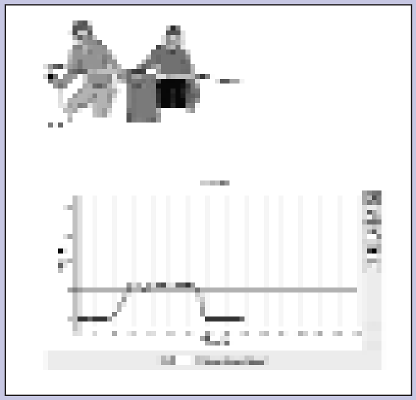
BY CAROLYN STAUDT

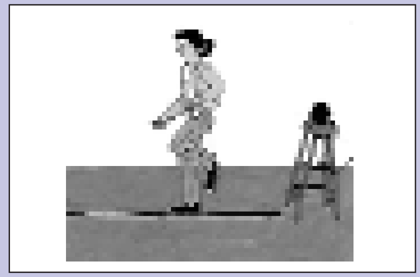
Fifth-grade science was different last year for Mrs. Rivera. Each year her students build terrariums and grow "fast plants" in them. Last year, for the first time, her students monitored the humidity, temperature, and pH sensors inside their terrariums while they studied the growth of their fast plants. As a result of this extensive data collection, students graphed and analyzed the differences between terrariums, which sparked further questions and experimentation. Mrs. Rivera had purchased sensors that functioned on desktop computers in the local computer lab. Little did she know that her school district would soon adopt a specific kit-based, standards-based curriculum for science that encouraged students to study various environments—inside and outside the classroom—in urban and field settings, around streams and rivers, and within homes.

Although she was thrilled with the new curriculum, Mrs. Rivera was faced with a dilemma: the school did not have portable computers. She would need to teach her science lessons without contextual experimentation, or find the funds to purchase a portable computing platform, such as laptops or handheld computers. Unfortunately, after she purchased the new portable computing devices, Mrs. Rivera realized that the sensor software the school had previously purchased was not compatible with the new platform. She now had portable computer devices that could support real-world inquiry, but no way to collect valuable data.

Participating vendors include:

- **CoachLabs**
- **DataHarvest**
- **Fourier-Systems**
- **PASCO**
- **Texas Instruments**
- **Vernier Software & Technology**





Above:* Setting Up a Walking Track from *Understanding Motion.
Left:* Collecting data with a force probe from *Levers and Machines.

Science teaching with sensor vendors has always been awkward due to the number of platforms, sensors, and software packages that are available within a school building. It is not uncommon to find schools with cabinets filled with sensors from multiple vendors that are no longer used. What if standards-based materials were developed using cross-platform software that could be interfaced by many different sensor vendors? *Technology Enhanced Elementary and Middle School Science* (TEEMSS) does just that.

Since our founding, the Concord Consortium has researched the impact of computer-based education to create and disseminate valuable, proven, and easily implemented technology-based science learning materials and associated teacher professional development. In 1999, our Mobile Inquiry Technology project used portable devices like the Apple eMate and eProbe sensors from Knowledge Revolution to allow students to collect data in and outside the classroom. As technology evolves, hardware and software become extinct: the eMate and eProbe are no longer produced or supported. To hedge our bets for longevity and reach as many classroom teachers and students as possible, our TEEMSS project develops materials that are cross-platform; they run on Windows, Macintosh, PocketPC, and Palm operating systems. Additionally, we use sensors from six of the major vendors to eliminate any concerns that a particular vendor's requirements would preclude a school's participation in the project.

With the recent No Child Left Behind Act and the need for broad content coverage, it is difficult for science teachers to find the time to provide their students with inquiry-based, hands-on activities. It's even more difficult to add technology to the mix. The TEEMSS project is positioned to change that. Our interactive materials target the *National Science Education Standards* (NSES) and the *National Council of Teachers of Mathematics* (NCTM) standards, and are focused on incorporating relevant materials into the existing curriculum.

Recognizing that using sensors and model simulations can be daunting to an elementary or middle school teacher, TEEMSS offers an online professional development course to assist teachers in becoming comfortable with integrating technology in the classroom. The five-week course encourages a discourse among the teachers as they work through the same activities their students will later use. Jennifer Reynolds (Lathrop, MO, Middle School) recently wrote online, "Wow!

This makes me feel overwhelmed and excited at the same time! I am a first-year teacher and I had no idea that all of this technology was available for classroom use. I think the first time I ever saw a teacher use any technology outside of PowerPoint was in 12th grade when my Biology teacher did gel electrophoresis. I thought that was the coolest at the time and I am really thrilled to be able to offer my students a glimpse of scientific technology much earlier in life."

Nine units have been developed for grades 3-8 based on the inquiry, physical science, and life science NSES standards. Six additional units will be developed this summer in earth/space and technology/engineering. Activities encourage students to predict, describe, and design. Each unit has embedded assessments, graphing tools, and technical hints for using the sensors and the software. Embedded assessments allow students to answer questions and justify their answers. For instance, following a multiple-choice question, students might respond to an open-ended statement like "Why do you think this would be true?"

What is so unique about the TEEMSS instructional materials is not only their ease of use, but also their ability to record and report student progress. Because students log in to a web portal to use the materials, their work is recorded. When teachers log in, they can view reports on the assessments and student work. The portal offers entry points for each particular brand of sensor, so technical help is focused and appropriate.

TEEMSS materials are "backward" designed. We started by identifying the essential understanding that we wanted students to have at the completion of each unit. Then we created questions that could be revisited throughout the unit to engage students in evolving dialogue and debate. By identifying the goals and objectives from the start, we could embed meaningful assessments. Rachel Tennison (Bolivar, MO, Intermediate School) says, "I am very impressed with the instructional units. The labs consist of essential questions to get the students instantly thinking. I love the box for the students to type their answers in because it is so similar to the state standardized tests. The use of sensors with these instructional units will definitely enhance the inquiry process in my classroom."

The TEEMSS project, funded by the National Science Foundation, includes a strong research component. In addition to evaluating project components, including materials, teacher training, and classroom implementation, we are also measuring student learning of the targeted standards. Seventy teachers from Missouri are using tests that have been developed in collaboration with our external evaluators at _SRI International_.

Technology Enhanced Elementary and Middle School Science (TEEMSS)

Standard	Grades 3-4	Grades 5-6	Grades 7-8
Inquiry	**Sound** Explore sound and vibration **sensor:** computer model	**Water and air temperature** Mix fluids and measure temperature changes **sensor:** temperature	**Air pressure** Explore soda bottles, balloons, and lungs **sensor:** gas pressure
Physical Science	**Electricity** Explore light bulbs, batteries, and wires **sensor:** voltage	**Levers and machines** Design and test your own compound machine **sensor:** force	**Motion** Graph, describe, and imitate motion **sensor:** motion
Life Science	**Sensing** Compare two ways of observing your environment **sensors:** temperature, light	**Monitoring a living plant** Place a living tree branch in a plastic bag **sensors:** relative humidity, light	**Adaptation** Explore population, selection pressure, and adaptation **sensor:** computer model

Exploiting Technology

Of twenty-two NSF-funded science curricula for grades 3-8 featured on the EDC Dissemination Center[1], not one exploits the greatest strengths of sensors and models for student exploration, communication, or student assessment. While many developers of science instructional materials believe that integrating sensors and/or models with their activities could help student understanding, they are unwilling to take this step. With limited resources, they would have to select a single vendor and doing so would limit the reach of their materials. By developing for (most) any computer and sensor, TEEMSS has an authoring and deployment system that can change this dynamic and effectively integrate sensors, models, and embedded assessment with science instructional materials. The potential for improving elementary and middle school science is enormous.

LINKS *Any Computer...*

- **TEEMSS**
  http://teemss2.concord.org
- **National Science Education Standards**
  http://www.nap.edu/readingroom/books/nses/html/overview.html
- **National Council of Mathematics**
  http://www.nctm.org
- **SRI International**
  http://www.sri.com

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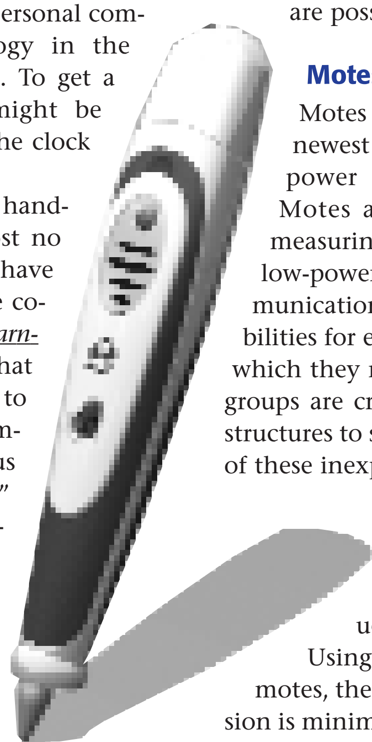
[1] See ***http://www2.edc.org/cse/work/k12dissem/materials.asp***

Future Technology in Unexpected Places

BY ROBERT TINKER AND STEPHEN BANNASCH

Today, educational technology is synonymous with computers, usually the personal computer. Educational technology in the future may be very different. To get a perspective of where we might be going, let's start by turning the clock back a decade.



It's hard to realize that in 1995, handheld computers were rare and almost no one had considered that they might have any educational value. That year, we co-founded the *Center for Innovative Learning Technologies* (CILT) and decided that one theme of the Center would be to create an educational role for palm-sized computers (see "Will Ubiquitous Computing Improve Education?," page 3). We created a sample application, held a software contest, built prototype probeware and eventually goaded Palm into funding a major research program: the *Palm Education Pioneers* grants. As a direct result of early CILT activity, handheld computers are now increasingly used in education. In the next decade it is possible that even more unlikely technologies will find an educational role. Motes, smart pens, and digital cameras are possible candidates.

Motes

Motes (short for "remotes") are some of the newest and smallest advances in extremely low-power wireless networking and computing. Motes are tiny circuits that have sensors for measuring the environment around them and low-power wireless network capabilities for communications. In addition, motes have output capabilities for electronically controlling larger devices in which they may be embedded. A number of research groups are creating the hardware and software infrastructures to support wirelessly interconnected swarms of these inexpensive tiny computers.

Data traveling in a wireless mesh network is routed from one mote to a nearby mote where it is re-transmitted to the next mote. This process continues until the data reach their destination. Using only enough power to reach the closest motes, the energy needed for wireless data transmission is minimized. By integrating the micro-controller, wireless network, sensors, and I/O onto a single inte-

Alejandra and the Pine Trees

A fictional scenario imagining the educational uses of motes.

Alejandra woke up and looked out the window. Frost covered the grass. After getting dressed, she grabbed her backpack and bounded downstairs. As Alejandra headed out the door, her dad called out, "Where are you going in such a hurry?"

"I'm just checking my data."

The crisp morning air bit at her nose and cheeks as Alejandra went outside. She walked over to the first mote she had placed in the field yesterday. Fishing through her backpack, Alejandra found her handheld computer and tapped on the screen. The computer turned on with the DataMote program just as she had left it. Within a couple of seconds, the icons representing the 10 datamotes she had placed around the yard began to fill up, indicating that the temperature, humidity, barometric pressure, and light data they had been collecting overnight was being loaded onto her handheld.

The closest mote showed a temperature of -4.2 degrees C. Before retrieving the mote, Alejandra snapped a picture with her handheld. As she took the picture of the frost on the field, the datamotes each flashed a bright infrared light. When the computer had taken a picture, it had also marked the position of the tiny infrared flashes. After a moment, the image on the screen shifted and Alejandra was looking at a view of the data superimposed on a satellite picture.

Alejandra walked to the next location. She oriented herself in the same direction as yesterday's picture, and tapped on her screen to open the image. She moved carefully until the objects in the image were in similar orientations and she snapped a second picture. After a few additional pictures, Alejandra had all the image data she needed for a 3D scene, so she collected the datamotes and went inside.

While she ate breakfast with her family, she showed her dad the 3D view of the field and the superimposed overnight temperature data.

"I'm not sure why, but there's no frost under the pine trees. And it didn't get as cold as it did in the open field," Alejandra said.

"Maybe the pine trees are acting like a blanket. See what you can figure out at school when you compare your data with the other kids."

grated circuit, motes can be as small as 1 cm square and 1 mm thick. A team at Berkeley coined the term Smart Dust to describe their vision of this miniscule sensing and communications platform.

Innovations in software will be necessary to create practical applications on networks of motes. Motes should be able to find other nearby motes and set up a communications mesh, even as they are being moved. Software should be able to run in parallel on many tiny computers, so that even if each one has limited capacity, a thousand hundred of them would have tremendous power. Berkeley has developed an open source operating system, TinyOS, that can support distributed motes.

Military, health, agriculture and a variety of commercial product applications for motes are currently in development. Educational applications are also possible, such as the scenario in the sidebar (p. 14).

Today, motes have practical applications—from non-intrusive habitat monitoring at Great Duck Island to measuring water usage in multi-unit housing complexes. The water monitoring system, created by H2Options, Inc., is designed to enable apartment managers to plan and schedule maintenance to maximize water conservation.

Other Unexpected Technologies

What could be more ubiquitous than a pen? Purses, backpacks, and briefcases everywhere carry one or more. A complete computer could be put in a pen, together with voice recognition, and the kind of motion sensing that is used in an optical mouse. The FLY pentop computer from LeapFrog (see image, p. 14) is the first educational application of these technologies. Due out in the fall, the pen is able to translate foreign languages, do math calculations, provide spelling prompts, and more.

The digital camera is a consumer success, but underutilized in education. Perhaps that is because we think of cameras as taking pictures. Instead, we should think of them as collecting data that can be processed. We have a prototype system consisting of a $30 Web camera and software that can track the motion of a colored ball. Alberti's Window markets a two-camera system that can track a ball in three dimensions.

But this only scratches the surface of what a camera can do. Software could let students automate all kinds of data collection tasks. A smart camera could grab a picture of every bird visiting a feeder, or every car at a busy intersection, or every fish migrating through a weir. The software could estimate the kind of bird, the speed of the car, or the weight of the fish.

> In the next decade it is possible that even **more unlikely technologies** will find an educational role. **Motes, smart pens, and digital cameras** are possible candidates.

There is a kind of liquid crystal used in place of thermometers that changes color as it is heated. Use a camera to log the color and convert it to temperature. The liquid crystal could be on anything: an incubating egg, rotating shaft, or a test tube holding a reaction. All kinds of chemical indicators could be logged with a camera to measure pH, glucose levels, or trace pollutants.

It is hard to imagine all the educational possibilities when smart motes, pens, badges, GPS, eyeglass displays, cameras, phones, and music players are combined in various ways and able to network wirelessly. Data, information, and collaborators will be much more easily available. The challenge for educators is how to turn all these resources into meaningful and efficient learning opportunities.

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LINKS *Future Technology in Unexpected Places*

- **Palm Education Pioneers**
  http://www.palmgrants.sri.com/findings.html
- To find out **more about motes,** an expanded version of this article with more technical information is available here:
  https://confluence.concord.org/display/CCTR/Motes+and+Smartdust
- **Center for Innovative Learning Technologies**
  http://www.cilt.org
- **LeapFrog**
  http://www.leapfrog.com
- **Alberti's Window**
  http://www.albertiswindow.com

The following projects are doing exciting work in the field of motes.

- **Center for Embedded Networked Sensing**
  http://www.cens.ucla.edu
- **Network and Embedded Systems Laboratory**
  http://nesl.ee.ucla.edu
- **Great Duck Island**
  http://www.greatduckisland.net
- **H2Options, Inc.**
  http://www.h2options.com
- **Smart Kindergarten**
  http://nesl.ee.ucla.edu/projects/smartkg/default.htm

NEWS at Concord Consortium

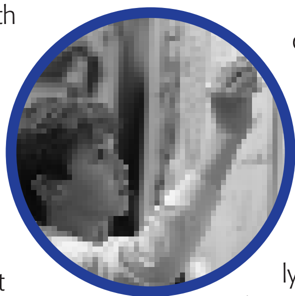
VideoPaper Builder3
vpb.concord.org

The newest version of our free VideoPaper Builder (VPB) software will be ready for release this summer. Sign up now at the Concord Consortium website to receive an email notification when it's ready to download. A VideoPaper is a multimedia document that combines digital video with subtitles, hypertext, and images. VPB3 is easy-to-use and includes an improved graphic interface with powerful editors for text, captions, and navigation structure. VPB3 software runs on Macintosh OSX and Windows operating systems and generates HTML code that synchronizes video to text and to images. VideoPapers can be viewed with any Java-enabled browser.

Classroom teachers are currently using VideoPaper Builder to document their teaching and present a video case study to their peers for comments and feedback in a supportive community. In this case, text might include commentary or background information about the setting of the video (the context of the teacher's lesson, for example), while still images enhance the video by displaying close-ups or related content (for instance, saved images of student work).

Seeing Math Courses
seeingmath.concord.org

The Concord Consortium has developed two series of online professional development courses that equip elementary and secondary mathematics teachers for greater success in the classroom; they are now available from our partners. The Seeing Math™ Elementary and Seeing Math™ Secondary series of web-based courses address crucial but often overlooked issues in successfully teaching math, through the unique integration of interactive software, video, and moderated online and face-to-face discussions.



Seeing Math Elementary offers eleven courses that integrate web-based learning with face-to-face interaction. Nine courses focus on concepts from the NCTM standards that are typically difficult to teach or to learn, such as fractions, division with remainders, calculating the area of a triangle, pre-algebra, or using data to make predictions. Two courses—one on questioning and one on formative assessment—address the use of effective teaching strategies. These courses are available through Teachscape **(teachscape.com)**.

Seeing Math Secondary courses focus on key algebra topics. The core concepts explored in each facilitated online course correspond to areas addressed by popular algebra textbooks and align with standards established by many states and by NCTM. A blend of activities, discussion, video, and interactive software help teachers develop content mastery and instructional insight in linear and quadratic functions, and proportional reasoning. Six courses are currently available though PBS TeacherLine **(teacherline.pbs.org)**. Four additional courses will be released in the fall.

MOLO Database
molo.concord.org/database

The Molecular Logic project is dedicated to improving the ability of all students to understand fundamental biological phenomena in terms of the interactions of atoms and molecules. The project aims to do this by enhancing science courses with guided explorations of powerful atomic and molecular computational models using our Molecular Workbench software.

The Molecular Logic Database includes over 100 activities and is designed to provide teachers and students with easy access to our model-based activities. Activities include links to concepts, standards, and textbooks.

@Concord

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