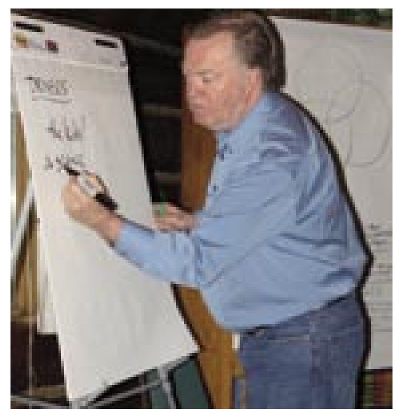
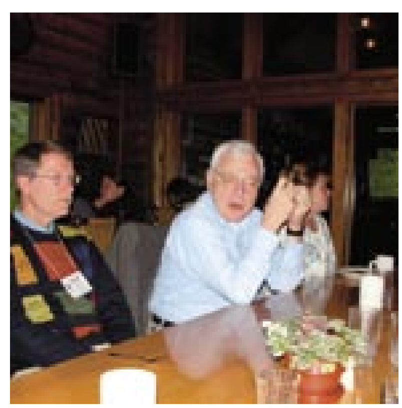
A New Digital Divide

Emerging Technologies and America's Classrooms





Lone Mountain Retreat

October **2004**

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BIG SKY INSTITUTE
For Science & Natural History

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Computers, cell phones, and telecommunications have changed the world significantly over the past few decades. The way 21st century science is conducted has changed dramatically as well, with technology now more deeply embedded in both the process of doing science and the analysis and communication of results. At the same time, the availability of portable and affordable technologies has provided new opportunities for improving science education, as students are exposed to a wide range of technology-based learning opportunities at home and at school.

Regardless of their eventual career paths, all students require a strong foundation in both science and technology if they are to be successful in tomorrow's workplace. If students are not better prepared to excel in dynamic work environments that are collaborative, technological, highly diverse, global in nature, and constantly changing, the nation's economic future will be put at risk. And yet, despite new educational standards and widespread testing, the United States still lacks a national commitment to improving education through the application of technology-related science content and active-learning pedagogies. As a result, while some students have the benefit of computers and telecommunications in their classrooms, most American students still learn in technology-poor schools that are not all that different from those their parents attended.

In the summer of 2004, with support from the National Science Foundation, the National Science Teachers Association (NSTA) and the Big Sky Institute (BSI) convened a retreat for leading teachers, academics, and technologists at the Lone Mountain Ranch in Big Sky, Montana. Their charge was two-fold: First, to examine what is known about applying technology to ensure that all students have a better understanding of the core concepts of science along with hands-on experiences with the methods of scientific inquiry, and second, to explore how more affordable and portable *technologies can be identified earlier in the research and development process, and be more successfully integrated into K–12 curricula.*

While the meeting did not produce definitive answers to all questions, participants concluded that the nation needs to move technological innovations closer to education at every step of its research and development to improve the teaching and learning of science. This national commitment to science and technology education will help ensure that all students have the skills they need to succeed in the 21st century workplace. To fail to respond, participants agreed, will put the nation's economic future at risk.

Gerry Wheeler
Executive Director
National Science Teachers Association

Lisa Graumlich
Director
Big Sky Institute
Montana State University

A New Digital Divide

Emerging Technologies and America's Classrooms

In the summer of 2004, technology and education innovators and visionaries convened in Big Sky, Montana, to explore the challenges affecting the introduction of technology to improve the teaching and learning of science. In particular, they explored what educational leaders know about applying technology to improve the quality of science education for all students, and what leaders need to know to ensure that emerging technologies are more successfully integrated into K–12 classrooms and more effectively applied in out-of-classroom inquiries.

The participants, representing K–12 schools, the academy, and the private sector, examined these two questions from various perspectives and considered various applications and opportunities. The pace of the discussions was brisk, and the scope wide-ranging, covering everything from the use of handheld computers by elementary students to collect, share, and analyze data in the field, to more visionary discussions about the future of science education and technology, where smaller and more sophisticated sensors and environmental probes will make it increasingly possible for students of all ages to participate in authentic research and large-scale data analysis.

Drawing on their diverse backgrounds and viewpoints, participants uncovered an unexpected trend. In addition to the widely discussed digital divide that separates the rich from the poor, and inner city and rural schools from their more affluent and technology-rich suburban counterparts, the nation faces newer and just as alarming divides. First, new and emerging information technologies, which help shape the future of science and discovery, are making their way into the K–12 curriculum in a belated or "back door" fashion, if at all. Technologies that are developed for business applications are being adapted, at best, in a makeshift fashion for educational use. In addition, small-scale, portable technologies—ideal for educational applications—are being developed to meet the needs of international markets while the needs of American students and schools fail to be a high priority.

"Technology has changed our society significantly over the last 50 years. We look to educators to help us define how technology should be used and to help guide the development of new and emerging technologies."

Chuck Thacker
Researcher
Media Research Group
Microsoft Corporation

"Outside the school environment, students are using technology in powerful ways, often resulting in very powerful learning. Educators need to learn how to bring that outside learning back into the classroom."

CHRIS DEDE
Professor
Learning Technologies
Harvard University

"Hardware availability and price no longer pose significant barriers to the introduction of computers into the classroom. It's what should be done with technology to improve science teaching and learning that now poses the greatest challenge."

WENDY RAMAGE HAWKINS
President
Intel Education Foundation

For the United States to maintain its leadership position in the new information-based world economy, new and emerging technologies must be defined and championed by the American research and education community, not solely by large-scale global markets. Additionally, emerging technologies with science education potential must be made available to students and teachers much earlier in the research and development cycle. Of all the issues discussed during the meeting, participants unanimously agreed that the nation must respond to this new digital divide to ensure that the U.S. continues to lead in science and technology and American workers continue to compete.

Although the following report does not provide definitive answers to all of the questions raised during the retreat, it does reflect the areas of common concern expressed by participants. They responded to specific questions about the development and application of technology in the classroom, and discussed the need for better integration of education, technology, and 21st century science. Based on what is known today, participants agreed that universal access to task-appropriate technologies, coupled with teacher preparation and professional development designed to enhance science and technology teaching and learning, should become a national priority.

Technology enables students to learn inquiry-based science and conduct authentic research that replicates (and even contributes to) the work of scientists. However, more research into specific educational applications needs to document the best content and pedagogies in the classrooms of today to ensure that the path is cleared for new and emerging technologies for the classroom applications of tomorrow.

Based on their collective insights and concerns, participants developed a series of recommendations for the National Science Teacher Association and others in the educational community; government agencies such as the National Science Foundation and the Department of Education; and congressional leaders and other public policy makers. The group also agreed that their discussions were the first of many needed between educators, scientists, and technology developers to ensure a lasting interconnection between 21st century science, emerging technologies, and the needs of science education.

Science Education For Today

Innovative educators around the country have demonstrated that technology can enhance the learning of science by putting the tools of scientific inquiry into the hands of students. As more educators and researchers explore ways to apply handheld computers, cell phones, and other new and/or emerging technologies in smart contexts, students have real-world opportunities to work on complex problems, contend with statistical variation and complexity, and model outcomes that result from small changes in assumptions and/or data. In American schools today, however, there are not enough tools for the teachers and students who could use them, not enough insight into how to integrate technology more effectively to improve the teaching and learning of 21^{st} century science, and not enough national commitment to ensure that technology integration into the K–12 curriculum becomes a priority.

Today's students are fascinated by the diverse activities technology enables, as evidenced by the ubiquity of cell phones, text messaging, and MP3 players, and by the hours students spend solving complex problems in virtual-gaming environments. Students quickly learn the abbreviated text messaging needed for e-mail exchanges on their cell phones, and they practice complex video games for hours on end to demonstrate their mastery to their friends. Students are ready and able to integrate new and innovative tools and methods into their learning of science, both in and out of formal classrooms. But once they sit at their desks, most students are expected to leave the 21^{st} century behind and re-enter the world of 19^{th} century education.

Educators have noted that, when students have access to technology, most quickly learn how to analyze and validate information, and build resources that work for them. In addition, anecdotal evidence and studies done to date indicate that integrating technology into the curriculum improves student understanding and involvement with 21^{st} century science and increases student standardized test scores. Educators point to many reasons for these improvements. For one thing, technology enables students to model more complex problems, and students have more time to work with data at a higher level, encouraging them to develop their critical-thinking and problem-solving skills.

With small, handheld computers connected to various measurement devices and probes, students of all ages can collect, analyze, and compare data in real time, providing real-world learning opportunities, while

"Classrooms are still using 19th century methods to teach 21st century science, leaving students vastly underprepared for the modern world and workplace."

Gene Frantz
Principal Fellow
Texas Instruments

"Technology can be a great educational and social equalizer, particularly when all students have one-to-one access so that they can work with it at home."

Richard Beckwith
Senior Researcher
Intel Corporation

"Teachers need to know how to use and teach with technology before they can instruct their students. Teacher quality is, therefore, as important as access to technology."

JEFF LUKENS
Biology Teacher
Roosevelt High School
Sioux Falls, SD

"If new technologies are more fully integrated into the teaching of science, the kinds of questions scientists investigate might resonate with students, leading more of them to consider science as a career."

LISA GRAUMLICH
Director
Big Sky Institute
Montana State University

experiencing first hand the process of science and discovery. Students can share data and analyses with students in other locations, broadening their investigations, and even design and conduct student-driven, large-scale data collection and research. To be successful in these learning environments, students must concurrently develop interpersonal and self-directional skills; oral and written communication skills; critical thinking and problem-solving skills—the very same skills needed to succeed in a rapidly changing workplace and to make informed decisions in a democratic society.

Students can't learn to effectively integrate technology into their learning of science, however, without quality instruction and curricula. Thus, teacher quality and preparation are both critical for the success of any teaching strategy that integrates science and technology. Teachers must learn how to apply technology, and how to more effectively integrate it into their curriculum. For example, because handheld computers are used in various scientific studies, and closely mimic more traditional computing capabilities with which teachers are familiar, teachers tend to be more comfortable adapting them for classroom use. On the other hand, if small remote environmental sensors are developed and tested in agricultural and other less familiar applications, teachers might find it harder at first to imagine how to apply them in the classroom.

Technology must be more closely aligned with science and other education standards to improve learning. Most participants agreed that because science knowledge changes so rapidly, science textbooks are almost always out of date. Likewise, the first generation science education standards are too broad and shallow to meet the needs of 21st century students. Rather, students need to be introduced to basic science concepts and systems approaches, so that they can develop the necessary skills to stay abreast of changes in science, and to apply core concepts in diverse learning environments.

Participants agreed that technology can help in this regard. Using technology, students can have hands-on experience with the methods of 21st century science, including hypothesis development, experimental design, and system approaches, all of which can be difficult to teach in the abstract. In other words, using technology, students can participate in the scientific enterprise, rather than simply be introduced to it in the classroom or read about it in a textbook. Technology can also make science more accessible and, therefore, has the potential to make scientific inquiry more relevant to students' lives.

Science Education For Tomorrow

From environmental biotechnology, to materials science and manufacturing, to genomics and proteomics, the world of science has changed significantly in recent years and continues to evolve even more rapidly as technology opens new avenues of discovery. These new breakthroughs and scientific and technological innovations stimulate the economy, improve the quality of health care, and create much-needed 21st century jobs.

Technology is now so deeply embedded in the discovery and practice of new science that it functions much like the test tube or beaker of the past. Therefore, to fully participate in scientific inquiry and stay abreast of scientific advances, students must have access to today's technology from their very first introduction to science. Educators must seriously consider how to best prepare students for a global, knowledge-based society because the skill mix and knowledge base needed for all students to succeed are significantly different than they were even a few years ago, and are changing rapidly. Unfortunately, while individual teachers and/or schools have responded, the nation as a whole has not risen to the challenge, leaving large numbers of students underprepared or not prepared at all.

These new skills are being defined largely by new and emerging technologies, and may provide educational levers to overcome other educational deficiencies. But to accomplish this, students must have access to tomorrow's technology as it becomes available to ensure that their education reflects current scientific knowledge. This is not to suggest that all students must have their own scanning electron microscope or be fully conversant with all scientific advances, but it does require that teachers and students alike have access to the technologies needed to teach and learn science as it is practiced today and will likely be practiced in the future. Retreat participants agreed that the nation is failing both its students and its economic future in this regard.

To compound the problem, the educational community lacks a general consensus about what is needed in the classroom to positively affect teaching and learning. Lacking a well-defined educational market for technology, software developers focus instead on meeting the needs of the business and research communities, with software being adapted and/or patched together for classroom use. And while some educational software has been

"Learning science and scientific methods at an early age can directly impact an entire generation's ability to contribute to the nation's long-term economic development and global competitiveness. If we fail with our students, our nation will fail."

Gerry Wheeler
Executive Director
NSTA

developed for handhelds (e.g., calculators, reference materials, classroom scheduling, and concept mapping) and useful probes and sensors can be attached for data collection, for the most part, the needs of business still dominate the software developed for handheld computers.

What is true for American students is not always the case for students in other parts of the world. The more centralized educational programs of Russia, China, and India provide lucrative markets, and technology companies around the world are beginning to respond to their needs. In addition, many Asian educational leaders have bypassed the need to hardwire schools, opting instead for universal wireless access. As a result, many emerging markets have better connectivity, access, and control of new technologies than their U.S. counterparts because they are able to drive the next generation of hand-held wireless technologies.

"Changing technology priorities will not be easy, because it requires a culture that values investments in education. The current U.S. education market does not provide enough of an economic engine on its own to promote technologies."

MICHAEL HANNAFIN
Director
Learning & Performance Support Lab
University of Georgia

Retreat participants, representing education, research, and technology companies, offered differing opinions about the best way to ensure that America students are not left behind. Some noted that a handful of communities already have, or are considering providing, wireless access to all schools, businesses, and homes as part of a basic utility package. All agreed that as these trends continue, improved educational access to existing technologies will follow. Others noted that as more students gain routine access to technology and distributed learning, the role textbooks play in curriculum development will be minimized, with science curricula becoming available electronically and downloaded for a fee, much like students now download individual songs for their MP3 players. Such a modular format will allow teachers to pick and choose the materials their students need to be introduced to core science concepts, as well as provide inquiry-based science and technology explorations.

The more pressing question of how to eliminate or at least minimize the growing gap between technology development and classroom applications was more difficult to address. Some suggested that technology developers need to work with teachers in their classrooms to better understand how current technology enhances teaching and learning, and then develop new applications in cooperation with teachers and their students. Others suggested that teachers and their technology-savvy students need to spend time with technologists in their milieu to better understand the research and development process so that they might be a source of new innovations. All agreed that students who enter science and technology careers will be severely handicapped if they continue to lack basic access to technology in K–12 schools.

To ensure that all students have access to quality science education requires a national commitment to technology in education, and a long-term investment in both educational technologies and educational research. To this end, the group developed several broad recommendations designed to raise awareness of the potential problems the nation faces because of the new digital divides, and to help focus the efforts of all those with an interest in the future of American education and the competitiveness of America's industry and workforce. A synthesis of these recommendations follows.

"What's needed is strong, systemic leadership that will focus our attention on new methods of developing learning communities and applying ubiquitous computing."

BARRY ADAMS
Director
Strategic Alliances
Apple Computers

TECHNOLOGY AND SCIENCE EDUCATION

The nature and content of science are changing, teaching and learning strategies are changing, and students themselves are changing, bringing different skills and diverse backgrounds and experiences into the classroom all within a changing technological environment. To stay abreast of these changes, teachers must have access to professional development opportunities and students of all ages must develop skills and have access to the tools they need to search out and apply new knowledge and build on what they know. However, all agreed that access to hardware and software is not enough. The following set of conditions is needed for students to succeed and for technology to improve the teaching and learning of science and other disciplines:

1. ACCESS. Students must have access to task-appropriate technologies and be able to link that technology to the Internet and their teachers and peers in real time.

2. CURRICULA. Twenty-first century curricula must organically integrate technology in much the same way that 19th century curricula integrated pencil and paper. Few of today's employees can participate in the workforce without familiarity with technology, and yet few students receive a solid grounding in technology. Science curricula in particular must integrate basic science concepts, processes, and technology.

3. TEACHER PREPARATION. Participants agreed that professional development is one of the biggest barriers preventing the effective introduction of technology into the classroom to improve teaching and learning. Like their students, teachers need opportunities to learn new technologies and effective applications to better prepare their students Because technology and science evolve so rapidly, rigorous professional development programs should be readily available to teachers throughout their careers.

Recommended Actions

Because so little has been collected in one place about what works and why, retreat participants identified a pressing need to compile currently available research on introducing new, more affordable technology in various teaching and learning environments, as well as the kinds of partnerships, if any, that were responsible for initiating the projects (e.g., partnerships formed with the private sector, universities, government agencies, and/or K–12 schools). This should be produced as a comprehensive literature review, with the help of in-service teachers, academic leaders, and technology companies with a commitment to science education, perhaps as the result of another, larger meeting as a follow-up to the Lone Mountain Retreat.

Based on this review, a new research agenda should be defined to better clarify the next generation of technology applications and their ties to teaching and learning 21st century science. This should include, but not be limited to, a new systemic initiative funded by the National Science Foundation and/or the U.S. Department of Education to test various technology-based classroom learning strategies and science education and technology partnerships among universities, K–12 schools, and technology companies willing to work closely with teachers and their students. Results of these strategies and partnerships should be rigorously evaluated and disseminated widely.

Once more science-based research on technology in the classroom becomes available, the nation must develop new technology benchmarks mapped to all educational standards to ensure that technology is integrated in all teaching and learning and that students have, at minimum, access to one computer of their own. Professional scientific organizations must insist that science education, if it is to truly reflect their respective disciplines, must include substantial use of computational tools. In addition, the National Science Teachers Association and the NSTA Institute should integrate technology into all of its professional development activities.

Policy makers must make a long-term commitment to, and develop a 21st century vision for, technology education for all students. There must be a national priority to invest in that vision, to ensure that large markets abroad are not driving the development of new educational technologies and to enable American technology companies to develop products to meet new science and other educational needs.

Technology companies need to make a commitment to work with in-service teachers and their students on the development of inquiry-based, task-appropriate classroom technologies. Working with technology developers, classrooms could serve as both alpha and beta test centers, with success stories shared with other schools.

K–12 teachers, academics, and technologists need to meet on a more regular basis to discuss ideas and educational innovations, and to stay abreast of cutting-edge technologies. NSTA should convene annual or biannual meetings to ensure that these three groups continue to have opportunities to discuss new technologies, and to advance the nation's scientific enterprise through the education of students of all ages.

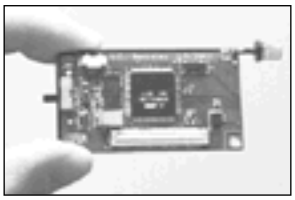
4. APPROPRIATE ASSESSMENTS. Teachers and parents need to know what works and why to ensure that technology is employed to its best advantage in and out of the classroom. Assessments need to be aligned to the technologies integrated into the curriculum, and not artificially established from outside.

5. SUPPORT FROM SCHOOL BOARDS AND ADMINISTRATIONS. Integrating technology into K–12 teaching and learning requires a long-term commitment to evaluate and upgrade available technologies to ensure that both teachers and students are staying abreast of current technologies.

6. SUPPORT FROM COMMUNITIES. A commitment to 21st century education requires the support of all members of society, from parents to employers to public policy makers. Communities need to make a long-term financial commitment to the future of their students and to their own economic well being.

New Technologies

MOTES



Intel Corporation

One of the more exciting prospects for doing authentic research is the advent of even smaller computerized sensors, or “motes,” that can monitor and share environmental data across space and time. According to Richard Beckwith, a senior researcher for Intel currently working with plant physiologists to monitor and identify “nano-climates” that can affect crop variation and productivity, this small-scale computing is already changing the way scientists conduct research in the field. Micro weather and monitoring stations, which consist of a small, computerized sensor, a battery, and a radio device, collect and send data for up to one year on two AA batteries. These wireless data collection networks have been applied to everything from monitoring volcanic activity to measuring soil moisture to even gauging the structural integrity of bridges.

Beckwith predicted that within five years, computerized sensors will be available for $5.00 and used to establish large-scale environmental research projects in which sets of computers, all working together, share their processing power as well as their data. Because this is exactly the kind of research project students do well, Beckwith envisioned a time in the very near future when students will design large-scale motes-monitoring programs and share their data in real time with their peers and with government agencies and professional researchers.

MUVEES

http:muve.gse.harvard.edu/muvees2003

The Multi-User Virtual Environment Experimental Simulator or MUVEES, developed by Chris Dede and his colleagues at the Harvard Graduate School of Education, creates a virtual late 19th century American city that features a river, different terrain, residential areas, industries, and institutions, such as a school and a hospital. Faced with a question (e.g., Why are certain residents getting sick, while others are not?), The program challenges teams of middle school students to investigate and attempt to solve problems by exploring the city’s virtual landscape, taking environmental samples, asking questions of city residents and officials, posing different hypotheses to explain complex problems, and comparing their evidence with other teams.

Teachers provide structure and guidance at certain points as students work through the curriculum, but otherwise students explore the virtual environment with their teams. Students maintain lab notebooks that help guide their explorations, and prompt the collection of data and data analysis. At the end of the learning sequence, student teams produce a final report, documenting their findings. These written documents, coupled with a "cognitive trail" that is recorded as students advance through the program, are used for assessment.

As they participate in the curriculum, students learn methods of 21st century scientific thinking (e.g., hypothesis development, experimental design, and systems thinking) and learn and apply standards-based content in biology and ecology. Students also improve their understanding of history and their reading, writing, and computer skills.

As Dede noted during the presentation of the MUVEE program, several questions need to be answered when applying technology to improve science learning. For example, is it practical in the classroom? Is it powerful in terms of learning, especially in reaching the lower third of students who are often uninterested and/or unmotivated to learn even basic science principles? And what types of learning are most affected by the use of video-like games, as opposed to more traditional approaches of teaching and learning?

Although Dede stressed the importance of more research in applying these types of gaming environments to improve teaching and learning of 21st century science, he did note that 1000 urban middle school students have tested the MUVEES program and that, to date, the curriculum has proven to be extremely successful in engaging all students, including those low-achievement students with little expressed interest in school. These students in particular have shown increased understanding of important science concepts and have demonstrated an improved interest in learning. High-achievement students have also been engaged by this unique learning environment, according to Dede. Additionally, absentee rates for the participating students appeared to go down, and students became interested and engaged in the program, regardless of the level of the support and encouragement they received from their teachers.

HANDHELD COMPUTERS

Palm pilots and other small personal digital assistants (PDAs) with their address books, calendars, and to-do lists were once the sole domain of the business market and the busy executive. But innovative educators are taking advantage of these small computers to use them as portable word processors, graphing calculators, scientific probes, cameras, and mini-workstations for students to share ideas, compare notes, and collaborate on reports. Newer devices can even be attached to global-positioning systems (GPS) to enable students to pinpoint their location and map their data. Because they are low cost, schools can provide a handheld computer for every student, while providing laptop or full-sized computers at the back of the classroom for those situations where handhelds are not task-appropriate.

Janine Kopera's third grade students routinely use PDAs for various tasks. For example, at the end of a lesson plan on plants and insects, Kopera's students map the relationships between sunlight, plants, aphids, and ladybugs using PiCoMap, a concept-mapping tool on their PDAs that documents student understanding of core concepts. Kopera then used these maps as assessment tools to ensure that all students understood the core concepts before moving on to the next science unit.

In a South Carolina middle school, students use a drawing and animation program for handheld computers called Sketchy to help them understand the metamorphosis of a caterpillar into a butterfly. On Day One, each student draws a picture of his or her own characterization of the caterpillar that is crawling around in a cage. On Day Two, each student taps the duplicate button to create a copy of their picture from the day before, and then changes the picture to reflect the changes in the caterpillar. Each day, students create a new frame that depicts the changes from the day before, stopping when the butterfly breaks out of the cocoon. Sketchy then animates the frames allowing students to replay their characterization of the metamorphosis process. Instead of watching a simulation, the students have created their own simulation and can compare their simulations with the others in the classroom, noting their similarities and differences.

The mobility and communications capabilities of handhelds can also support entirely new learning experiences. Drawing on the early work at MIT's Media Lab, the University of Michigan's HI-CE Center developed a participatory simulation, Cooties, to help students understand how communicable diseases are spread. In a group of six students, one of the handhelds is set up to be “sick” unbeknownst to the students, who beam germ-laden or germ-free messages to one another. As messages pass from student to student, all six handhelds eventually become infected. Students then need to develop a method to determine who infected their computer. In addition to the question of communicable diseases, participatory simulations like this one provide learning opportunities to explore concepts in other disciplines (e.g., economics, biology, and even technology).

As students gain hands-on experiences with data collection, analysis, and reporting, teachers can introduce more sophisticated learning experiences like the “environmental detective” program developed by Eric Klopfer at MIT. As described by Chris Dede, students use handheld computers to explore the MIT campus, which has just experienced a virtual chemical spill. Using GPS to identify specific locations, students drill virtual wells, take virtual water samples, and conduct virtual interviews, with the goal of producing a report with recommendations for MIT’s president. This guided inquiry learning provides students with opportunities to experience science and engineering problem solving and decision making, and provides a better understanding of what is involved with assessing risk.

Stationary personal computers too often tie students to a desk, are available only for limited periods of time, and limit one-to-one interactions. When students use their own small handheld computers, they can work as teams, interact freely with one another and their teacher, and “beam” information, questions, and notes to one another. And, using different probes and sensors attached to the handhelds, students can collect real-time data and discuss their hypotheses while still working in the field. Most schools are finding that students can also take their handheld computers and portable keyboards home without fear of them being lost or stolen, in essence closing the digital divide between those who have access to technology at home and those who do not.

These new applications allow students to bypass more mundane tasks, like information gathering that computers can now perform routinely, and focus instead on analyzing data, comparing conclusions, and incorporating various perspectives. By developing the skills needed to apply technologies, students of all ages can experience for themselves the joys of discovery while learning the methods of 21st century science.

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