Log On Education

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Science in the Palms of Their Hands

In the beginning, there are children and the learning experiences we want them to have. Now, let's bring in technology as the means for enabling those learning experiences.

If we're serious about having children use technology in K–12 classrooms, then we need to convince the gatekeepers of those classrooms as to the worth of the technology. Doing so requires that we speak in the language of the teachers' profession: first identify the learning experiences and their outcomes, along with why those are desired, and then speak about how to enable those activities via technology. It's a feature, not a bug, that teachers require this sort of argumentation. Teachers are protecting our children from gratuitous, trendy and ultimately empty, experiences.

Here's what the National Research Council says: "Inquiry into authentic questions generated from student experiences is the central strategy for teaching science."

By "authentic questions" the NRC does not mean questions at the end of a textbook chapter, but rather questions generated by students. The concern, the interest, and the motivation must come from the children; it is their questions. Now, teachers can surely help a child generate a question; an untutored 11-year-old's question is something like "How many planets are there?" or "How big is the earth." With help from a teacher, these students move beyond closed questions to more open-ended, content-rich questions such as "How do earthquakes stop?" and "How did scientists discover sprites?"

By "inquiry" the NRC does not mean the idealized scientific method that no one actually follows so linearly—make a hypothesis, for instance, and collect data. Moreover, an inquiry is not a hands-on, canned lab activity. For example, measuring the speed and acceleration of a cart on an inclined plane. Rather, an inquiry extends over weeks of time, where measuring the cart's speed, say, is only one of a set of activities, where collaboration with adults (teachers and domain experts) is integral, and where the inquiry revolves around an authentic, student-generated question.

Now for the technology. Inasmuch as computational tools are used by scientists in their investigations, computational tools, appropriately redesigned with learners in mind, must be used by students in their investigations. What follows is a set of short reports from colleagues on computational tools, based on handheld devices, that enable children to collect data outside the classroom, enabling children to conduct investigations they were not able to before. No better argument in support of technology could possibly be mounted.

First, Wayne Grant reports on his company's efforts at attaching standard science probes to 3Com's PalmPilot. Next, Bob Tinker, one

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of the inventors of microcomputer-based laboratories—probeware—describes a new generation of smart probes. Jeremy Roschelle and Michael Mills envision how handhelds can be used educationally. Finally, Mitchell Resnick and colleagues describe an effort where children build their own computationally based sensors and effectors. The evidence is clear: children find stationary probeware exciting and productive. Now that children can take this technology onto the playground, and into their houses, they can connect the things they see, hear, and feel outside the classroom to ideas they can scientifically examine.

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NEXT-GENERATION MICROCOMPUTER-BASED LAB

Wayne Grant, ImagiWorks, Inc.

Dave, a 16-year-old high school student, was mildly intrigued when he plugged the pH sensor into an interface connected to his desktop computer in the science lab. He watched the pH graph change as he added vinegar to distilled water. This is neat, he thought. But there must be more interesting things to measure than vinegar.

Ms. Coltrane, the science teacher, pierced his reverie. She was showing the class a small and very portable handheld with sensors connected to it. Dave was impressed with just how small it was. Not much bigger than a pager, he thought. Ms. Coltrane explained that all kinds of sensors could be connected to the little computer, and with the ImagiProbe application things like light, temperature, voltage, and even acceleration could be measured.

An idea popped into Dave's head. What if I could connect an accelerometer to this thing, hide it in my pocket, and show Mom just how slow that old car of hers really is. He also wondered if he could measure the forces he felt in his stomach when riding the roller coaster.

At the end of class he talked Ms. Coltrane into borrowing the ImagiProbe system for a week to develop some of his own science investigations. She was willing to sign them out to all the kids if it motivated their interest in science.

She handed Dave a small black bag that contained everything he needed: the handheld with a sensor interface clipped onto the bottom and a whole set of sensors including the accelerometer (Figure 1). The first thing I'm going to do is check out the acceleration of the school bus, he thought.

At the end of the day. Dave rushed onto the bus and quickly set up his experiment. Rhonda watched over his shoulder as he plugged the accelerometer into the interface and set up a trial to collect acceleration data at 100 samples/sec. “Whatcha doing?” Rhonda asked leaning over the back of Dave's seat.

As Dave shared his ideas for investigations, she got excited. “I wonder what the graph would look like if we collected data while sitting on a swing? Do you think it would look anything like those funny up-and-down curves we've been talking about in math class?”

Figure 1. ImagiProbe setup: PalmPilot, D/A converter, probe.

Rhonda wondered if the ImagiProbe system would work on Mom's handheld computer. We could measure things like light, soil temperature, and soil acidity to assess the growing conditions in our backyard, Rhonda thought. Maybe Mom and I could work together on a garden science project.

The school bus roared to life and jolted out of the parking lot. “Look at this, Rhonda,” Dave said. “You can see that the level of roar we're hearing has no real connection to the amount of acceleration we're experiencing.”

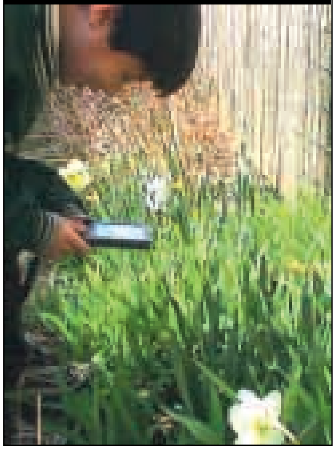
The rest of the way home Dave and Rhonda talked excitedly about all the things they would be able to discover in their own backyards.

The idea of hooking sensors up to a computer and taking scientific measurements is not new. And the educational value of conducting sensor-based science with desktop computers has been well established by many researchers. Even if they're only studying the effect on pH when adding vinegar to distilled water, the ability to collect data and plot it in real time motivates kids to learn more science. However, what's different in the Dave/Rhonda vignette is its description of the educational potential of placing inexpensive handhelds outfitted with sensors in the hands of more kids so they can discover their own worlds.

Though laptops do enable such mobile inquiry, they remain fragile, relatively expensive, and are overkill for the task.

ImagiProbe brings sensor-based science to handhelds. The ImagiProbe system consists of a software application, a Sensor interface that clips to the handheld, and software that enables students to copy data onto their desktop computer. With the system, students can set up investigations and data collection trials, collect data and watch as it is plotted in real time, calibrate sensors, and even annotate investigations, trials, and calibrations with notes and sketches. With the click of a single button, students can move data onto a desktop computer for sharing, for further analysis, or for embedding in science reports.

Figure 2. Measuring soil temperature using ImagiProbe.



Our goal is to create products that enable more students to experience the thrill of discovery and become excited about science by carrying out meaningful investigations. Today, because of ImagiProbe's extreme portability, teachers can move sensor-based science beyond the desktop to exploit a richer range of activities that naturally transforms each student's daily world into a laboratory filled with interesting and relevant scientific opportunity.

Tomorrow, through wireless connections, students will be able to share their data in real time and collaborate with other students to undertake distributed investigations. By creating data-modeled views of their immediate context and comparing these with similar views created by others, students will really begin to understand and enjoy the collaborative nature of science.

Wayne Grant is a cofounder of ImagiWorks, Inc.

NEXT-GENERATION PROBEWARE

Robert Tinker, the Concord Consortium

As part of the Science Learning in Context (SLiC) project, we have scientists eagerly using probes with handhelds. Students use Newtons, eMates, and handhelds equipped with probes and measurement software. Even seven-year-olds immediately pick up the computers and probes and start using them and asking questions.

Figures 2 and 3 show young scientists eagerly using a handheld computer. One of these young investigators wanted to know whether Popsicles got colder faster than water and, with little prompting, devised the controlled experiment in Figure 4.

There is no question the combination of probes and small computers could unleash children's natural curiosity and help them learn far more from the natural world than we have ever thought possible. To permit this to happen, we need to make hardware and software better and easier to use.

Figure 3. Children exploring the PalmPilot.

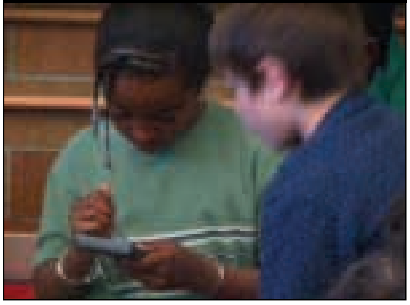
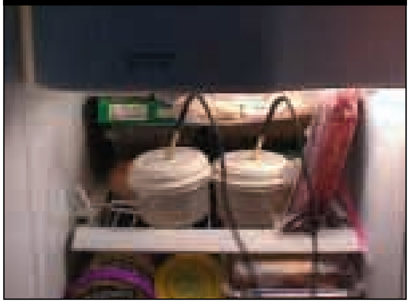


Figure 4. Measuring changes in temperature.



One of the unanticipated needs we identified while watching students conduct field work with portable computers involves the design of the probe system. In the lab, it is possible to lay out a traditional microcomputer-based lab system with cables, interface box, and probes, but that same system cannot just run on batteries and be expected to work well in field applications. The problem: too many wires and boxes requiring too much power.

Not only is this setup unwieldy, it is error-prone, battery consuming, distracting, and potentially dangerous. There are too many parts that can be incorrectly connected, dropped in water, or tripped over. There are too many components to troubleshoot if something such as a dead battery, bent pin, or loose connection causes one of the components to fail. We found students and teachers needed to spend too much time getting the system working and, therefore, lost opportunities to think about science. In the field, the system has to recede into the background. Of course, this is also important in the teaching laboratory as well; it just became more obvious when we tried to use probes with portable computers outside.

Recent advances in low-cost and low-power chips now make it possible to combine the interface, amplifier, and sensor into a single low-power SmartProbe. We can now migrate all the intelligence from the interface into a microcomputer at the probe while incorporating a number of additional features that will simplify data collection and allow students to focus more on science concepts and investigations. Because some low-cost microcomputers also consume very little power, we can create some SmartProbes without batteries.

Because the SmartProbe contains a complete microcomputer, we can add functions to the sensor never before possible. The SmartProbe can store information about itself. It can tell the computer what it measures, its accuracy, and its range. With appropriate software, this could result in a plug-and-play system ready to measure as soon as the SmartProbe is plugged in.

Current sensors send raw data to the computer, typically a binary number between 0 and 1,023 (or one less than some other power of 2). The software must convert these raw data values into physical values such as degrees Celsius, force in Newtons, or light level in lux. Because this conversion is not the same for every probe or even the same probe at different times, the software needs some calibration constants for the particular probe in use. If these constants are stored in the computer, then the computer and probe must stay together—not an easy requirement in a lab with many computers. A SmartProbe can store its calibration constants internally and use them to send to the computer values in physical units. This means that a SmartProbe can be used on any computer without recalibration or copying the calibration constants.

SmartProbes are not yet available, but they are coming. Educators can anticipate a quiet revolution in probeware within a few years. Faster, smarter SmartProbes will be far easier to use, more reliable, and less error-prone. Students will be able to plug any probe into any computer, whether portable, pocket-sized, or a desktop model. As soon as the probe is connected, the software will start working and the student can start thinking immediately about science without having to think about batteries, interfaces, or calibrations.

Robert Tinker is a cofounder of the Concord Consortium.

TOWARD LOW-COST, UBIQUITOUS, COLLABORATIVE COMPUTING FOR THE MATH CLASS

Jeremy Roschelle, SRI International and Mike Mills, IDEO

As 13-year-old Mike enters his math class, his Datagotchi, a $150 handheld device, beeps once. "Configuring for class" reads the message. Even while Mike is chatting to his classmate, Jenny, and finding his way to his seat, his Datagotchi beams last night's homework over a short-range radio network to the teacher workstation, and receives some special applets that will be used during today's class.

Jenny whispers to Mike, "I'll beam you the data I got last night from my bird feeder; we've only got 47 minutes before science class to get it together!"

"Today, we're going to continue our explorations of fitting lines to data in graphs and tables," Mr. Keck, the teacher announces. "Now, here is the assignment." Mr. Keck touches the stylus to his overhead projection panel, and explains to the class what they will be doing, sending a different data set to each of the students' Datagotchis. "Now get into groups, and start working!"

Mike, Jenny, and their partners Tamara and Kirk, gather around a small table. Each has a Datagotchi on which they can interact with graphs using a stylus, enter mathematical formulas via math-specific handwriting recognition, manipulate data in tables, run simulations, and more. Because of the handheld's size, there isn't much room to work so screens must be dynamically configurable.

"I'll enlarge our graph across all four, so we can see all the data at once," Tamara says.

"But wait," interjects Kirk, "we're supposed to be fitting the data in the table to a linear equation. We need to keep a table view, and an equation editor."

"I'll put the graph across Mike's 'gotchi and mine, the table in yours, and the equation on Jenny's," Tamara says. "Then Jenny can adjust the equation, you can check the table, and we'll all see what kind of fit we get on the graph."

As the student groups work, Mr. Keck circulates around the classroom, noting how students engage in mathematical conversations that are supported by the different tools on their Datagotchis. When he reaches our foursome's table, he realizes they're stuck on a problem; their data set contains an outlying point, and they are having trouble fitting a linear function to include it. "Let's beam your group's work to the classroom overhead," Mr. Keck suggests. "This is something I want the whole class to see."

Jenny explains to the class: "We're trying to find a slope that gets us all of these points."

"Which points, Jenny? Use your highlighting tool," instructs Mr. Keck.

Jenny switches her Datagotchi to virtual mousepad mode, which lets her remotely control the projected display, and finishes her explanation.

After discussing how to treat outlying points, Mr. Keck asks, "Now do any of the other groups have this issue? If so, let's beam them up and have a look."

This scenario comes from a brainstorming workshop held by the Center for Innovative Learning Technologies (CILT; www.cilt.org), which drew 16 corporate- and university-based designers from perspectives ranging from hardware design to curriculum development. Far from being hypothetical, most elements of this scenario are realizable now, or will be soon. NetSchools makes a laptop with many of the beaming capabilities we envision; the Bluetooth Consortium and Sun's Jini may make such networks cheap and ubiquitous. Texas Instruments now makes calculators with flash ROM that supports downloadable applets. The SimCalc Project has been building experimental mathematical tools for middle schools on the PalmPilot and on calculators (search for "MathCars" at www.palmcentral.com).

The nature of the innovation we propose, therefore, is not making new technology, but imagining a completely different kind of technology in classrooms. Why should students store work on a PC when they change classes every 42 minutes? Why should students work on their calculators, but go up to the chalkboard to write their answer? Why should students work in groups, but not exchange data and visualizations? The math class vignette is one of five scenarios developed to understand the ecological niche for handheld computing in classrooms, and against which we posed the question of designing a future product line that was ideally suited to classroom needs.

Workshop attendees were quick to agree on some high-level requirements: the product should be inexpensive, have a long battery life, sturdy enough to be thrown in a backpack, and focus on math-specific capabilities, not generic multimedia. It should be part of a product line that includes sensors, LEGO bricks, teacher display panels, and other components.

A Datagotchi, as we called the to-be-designed product, needs a range of ways to use modular screens, including tiling, connecting to larger flat panel display, and controlling a full classroom projection screen. To serve classrooms well, the Datagotchi also should make the transition from being a personal device—in the style of handhelds and calculators—to a collaboration tool that supports classroom information flows. Indeed, many scenarios required configuration templates that would specify which students had access to what information, would create a variety of differentiated and aggregated spaces for student work, and enforce collaboration policies. Finally, participants stressed that the device should ideally meld characteristics of a network terminal with aspects of a personal calculator. When students are in class, they might well take advantage of powerful, server-based visualizations. When they are out of network range, their device should still offer enough functionality to allow them to do their homework. These bolder suggestions are implementable, if only we can redirect the public's enthusiasm for learning technology on PCs to handheld devices that would really meet students' needs.

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BEYOND BLACK BOXES

Mitchell Resnick, MIT Media Laboratory
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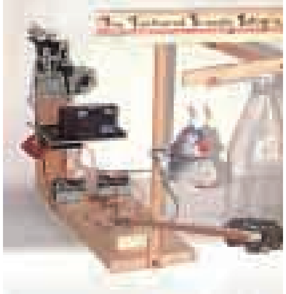
Eleven-year-old Nancy loved all types of animals. In her backyard she had a bird feeder she kept stocked with food. But there was a problem. Often, the birds would come while Nancy was away at school, so she didn't get to see the birds. Nancy decided to try to build a new type of bird feeder that would take pictures of all the birds that landed on it (Figure 5).

Nancy started by making a wooden lever that served as a perch for the birds. The long end of the lever was next to a birdfood container. At the other end of the lever, Nancy attached a simple homemade touch sensor consisting of two paper clips. Then she began exploring ways of connecting a camera to her bird feeder. She built a motorized LEGO mechanism that moved a small rod. She mounted the mechanism so that the rod was directly above the shutter button of the camera.

Nancy connected wires from the paper-clip sensor and the LEGO mechanism to a "cricket"—a tiny computer developed at the MIT Media Lab. Then she wrote a program for the cricket; the program waited until the paper clips were no longer touching one another (indicating that a bird had arrived), and then turned on the motorized LEGO mechanism which moved the rod up and down, depressing the camera's shutter button.

Figure 5. Child-constructed sensing device.



After working on the project for several hours a week over the course of three months, Nancy had the sensor, the LEGO mechanism, and the cricket program all working perfectly. But when she placed the bird feeder outside of her window at home, she got photographs of squirrels (and of her younger sister), not of birds.

Nancy never succeeded in her original plan to monitor what types of birds would be attracted to which types of bird food. But the project was still a very rich learning experience for Nancy. In our view, kids can learn just as much (if not more) in designing and building scientific instruments than in collecting and analyzing data from scientific instruments.

We are testing this idea in our NSF-funded Beyond Black Boxes project, in which we are developing new computational tools and project materials that allow students to create, customize, and personalize their own scientific instruments. This approach follows a long tradition in the scientific community, in which scientists do not merely measure and theorize but also construct the instruments needed to do so. Indeed, many of the most important advances in scientific history were based on a combination of science, engineering, and design.

This instrument-building tradition of science has been attenuated in recent years: today's laboratories are filled with black-box instruments. While these instruments are highly effective in measuring and collecting data—enabling even novices to perform advanced scientific experiments—they are also opaque (in that their inner workings are often hidden and thus poorly understood by their users) and bland in appearance (making it difficult for users to have a personal connection with scientific activity).

Our Beyond Black Boxes project aims to reinvigorate the instrument-building tradition. Kids have used crickets and other new technologies to build a wide variety of creative instruments: an odometer for rollerblades (using a magnetic sensor to count wheel rotations); a diary-security system (using a touch sensor to monitor if someone has been sneaking looks at your diary); an automated hamster cage (using a light sensor to keep track of what your pet hamster is doing while you're asleep).

The crickets are small enough (roughly the size of a nine-volt battery) kids can easily embed them in everyday objects. Our hope is for day-long learning, in which kids conduct scientific investigations not just in classrooms but throughout their everyday lives.

Our research has shown that children, by building their own scientific instruments, become more motivated in science activities. Moreover, we have found these activities help kids develop critical capacities in evaluating scientific measurements and knowledge, make stronger connections to the scientific concepts underlying their investigations, and develop deeper understandings of the relationship between science and technology.

Our ultimate goal is to contribute to the development of a new generation of students who are more likely to "look inside" the technological artifacts in the world around them—and be empowered to develop their own tools for exploring everyday phenomena.

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