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REALIZING THE EDUCATIONAL PROMISE OF TECHNOLOGY

PERSPECTIVE

An Open Letter to President Obama

Together we can change STEM education.

BY ROBERT TINKER

This is no secret: as a matter of national security, the nation's math and science educational system urgently needs repair. Dozens of reports from policy experts, industry, researchers, and educators argue that fundamental improvements need to be made immediately. If we continue in our current trajectory, the education of our workforce will be so inferior that business will despair of hiring Americans. Science and technology research will increase its migration abroad. Most troubling, American citizens will be increasingly unable to make informed decisions that require science and quantitative analysis, as already evidenced by our fateful paralysis over global warming, stem cell research, teaching of evolution, and nuclear energy.

Naturally, there is no magic bullet, no single strategy that will fix a system as vast and decentralized as our educational system. There are interlocking problems at every level from families that fail to encourage their children's academic ambitions to communities that cannot afford quality education to districts and states that treat education as a slush fund to the federal government that is failing to act.

As you assume office, you have an opportunity for a comprehensive, two-pronged response. For the huge educational system that is largely out of your control, you can inspire families, schools, and states to do their part. For the federal agencies you direct, reallocate funding and set priorities to provide the materials and assistance that can only come from the central government.

President Emeritus Robert Tinker, President Chad Dorsey, Board Chair Pendred Noyce (left to right).

The nation is ready to listen to you enunciate the *change* that is needed. Your personal story is inspirational. Families need to be reminded that your rise was based on merit and hard work. The sacrifices you made to get an education were essential parts of your advancement. Your message could be that the federal government is not able to fix education alone, but it can meet the country halfway, and that *together we can.*

The agencies responsible for math and science education, primarily the National Science Foundation and the Department of Education, have not responded with an appropriate sense of urgency. The size of the system baffles most policymakers. One's first instinct is to fix the problem with direct action: use federal resources to hire better science, technology, engineering, and math (STEM) teachers; equalize inequitable funding; and provide massive in-service programs. But the federal

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www.concord.org

A Conversation About Change

BY CHAD DORSEY

Across the country, people are debating and discussing change, considering how to move powerful ideas forward while retaining the best of what has been built before. The Concord Consortium will continue to focus on innovation in STEM education in the coming months and years, and I consider it a great honor to become a part of this discussion. Having been selected as the new president to help build upon the amazing foundation Bob Tinker and staff have created is both humbling and exciting. Having this opportunity as the nation holds such a desire for change and innovation is simply unparalleled.

My background in physics research, classroom teaching, and professional development has taught me that effective STEM education reform must be based on accurate science and mathematics content, a practical view of the teaching environment, and a long-term dedication to professional development. The Concord Consortium has worked for fifteen years to make improvements in these areas. We will continue to do so.

Over the coming months, we will initiate new conversations about how technology can support these important changes. I invite you to join us online at www.concord.org to learn more and to add your own perspective.

Chad Dorsey *(cdorsey@concord.org) is President of the Concord Consortium.*

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government does not have sufficient resources to supplement all STEM teacher salaries so the best are not lured into business by more competitive salaries. It cannot afford to send all current teachers to universities for advanced study. It cannot afford to equalize educational funding between rich and poor districts.

The responsible agencies talk about the problem, but continue relatively unchanged, even withdrawing from the field by increasing their emphasis on academic research. Most of the current federal efforts in STEM education are perfectly defensible and contribute to valuable improvements. The Concord Consortium's work, summarized in this newsletter, has been federally funded and I'm proud that it provides important parts of the foundation needed for radical national change. Because of federal funding to the Concord Consortium and others like us, we now have the tools, experience, manpower, and knowledge to fix STEM education. What is lacking is a coherent, forceful national policy that is equal to the challenge.

The importance of federal money is that it is concentrated, so that it can be used to finance major undertakings of importance to the nation, like building aircraft carriers and researching the causes of cancer. In this light, it is silly to return the concentrated federal dollars to the states and towns for them to spend on projects that lack national expertise and impact, and result in endless low-quality duplications.

A coordinated, sustained effort to improve STEM education nationwide would require just a fraction of the total federal expenditures for education. By devoting $750 million per year for four years on STEM education reform, the nation could be equipped with the materials and teacher skills to address the challenges we face. This amount could be found within the existing $70 billion annual budget at the Department of Education and the $1 billion spent by the National Science Foundation for science education.

That level of funding would allow for the following:

Outstanding curriculum materials for every student. A total revamping of the K-12 STEM curriculum would be based on research and make full use of modern technology for interactive learning, distribution, and assessment. The materials would be available online for all learners at no cost. They would provide embedded assessment so that teachers and parents could know in detail what students learn. Cost: $490 million.

Resources for all STEM teachers. A large collection of short courses specific to grade level and content would be developed for online or face-to-face delivery. These courses would cover the content of the new materials, the pedagogy, and the technology. Cost: $100 million.

Significant professional development for every teacher. A coordinated program would train every K-12 teacher through trainers, universities, and direct programs. Cost: $2.36 billion.

Higher education alignment. Universities would be engaged to offer the new content through in-service and pre-service programs and to incorporate them into their credentialing programs. Cost: $50 million.

To avoid the appearance of a national curriculum, *three* complete sets of curriculum materials would be created. The competition generated by funding three development efforts would ensure the highest quality and speedy completion. The new curriculum would be tied to national standards, so students could move freely among schools during the school year even if the schools used different versions.

This approach would free schools completely from the tyranny of textbooks and the regressive textbook adoption process. The funds saved could go a long way to pay for the costs of the required technology. Ideally, every student would be provided with a laptop. The current cost of putting a networked computer on a student's desk is below $300 per year, including wireless connectivity and servers. This is about twice the cost of textbooks, but less than 3% of the average expenditures per student. The presence of the new online materials would provide a strong incentive for schools to fund the computers.

Putting materials on computers has many advantages. Most importantly, computers enable highly interactive activities that improve learning. Instead of reading static content, students can learn from interactive media through exploration, observation, and experimentation with computer models, visualizations, and data. While based on computers, the curricula should involve hands-on experience. The computer can help there, too, using probes and sensors that turn computers into sophisticated laboratory instruments. These can be intelligent and inexpensive, as "Monday's Lesson" (pages 8-9) demonstrates.

Another advantage of computer-based materials is student assessment. Explicit questions can be embedded in the lessons and intelligent software can infer student skills by monitoring their actions as described in "Can They Do It or Do They Just Know How to Do It?" (pages 12-13). Data about student learning can be quickly fed back to teachers, giving them increased insights on where students are encountering difficulties and even suggesting alternative instructional strategies.

Professional development is the largest expense in this program, but even at the budgeted cost, schools and individuals will have to contribute to the total costs and unions will have to buy in. My budget provides for relatively low expenditures for professional development because of the design of the technology. Often when technology is implemented, extensive professional development is required because no curriculum is provided and teachers have to make it up as they go along. The proposed materials would be far more easily implemented and would, therefore, require less time and expense. The materials could be easily edited. In fact, an important strategy of professional development will be learning about the materials by customizing them, testing them in class, and contributing the improved materials to a national shared library where they would be reviewed and made public. The article "Community-Authored Resources for Education" (pages 6-7) describes how this can happen.

The radically decentralized educational system is a basic tenet of political liberty and freedom, but a disaster for math and science. We cannot afford to have over 10,000 school districts deciding what is important in math and science and then developing their own approaches and curriculum. The laws of science and the generalizations of mathematics are objective and not open for discussion.

The plan sketched above would provide a sensible compromise between a single national STEM curriculum and thousands of local ones. It would save schools the costs of textbooks, encourage them to exploit the power of modern technology, reach every teacher with professional development aligned to the new content, and give schools choices between three world-class STEM curricula.

President Obama, with you providing leadership and inspiration and the government providing all the assistance it can, perhaps American STEM education can be fixed during your presidency.

The Concord Consortium, under our new president Chad Dorsey, will continue to work toward these goals.

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

Computers enable highly interactive activities that **improve learning.** Instead of reading static content, students can learn from **interactive media** through exploration, observation, and **experimentation with computer models,** visualizations, and data.

How Can Less Be More?

BY ROBERT TINKER

Phil Morrison first advanced the hypothesis that "less may be more." In 1963 he was one of an MIT threesome who introduced the idea of science education reform by creating PSSC Physics. He thought students could learn science better by concentrating on a few ideas "to break with the [deductive] Euclidean model … to go beyond mere verbal and formula-learning."[1]

Forty-five years later, science curriculum has gone in the opposite direction, and is famously said to be "a mile wide and an inch deep."[2] Standards and tests demand such a comprehensive range of topics that some courses introduce more vocabulary than foreign language courses. In the rush to cover all the required topics, few students learn real science, just the facts and superficial ideas needed by tests.

The antidote is to dig more deeply into fewer topics, and focus on powerful concepts that students discover through guided exploration enabled, as needed, with technology. Students should be able to apply the resulting deeper conceptual understanding to a wide range of topics, making it possible to create a curriculum that is both deep and wide.

> The technology **helps students understand** by allowing them to experience inaccessible phenomena and **experiment with unrealistic systems.**

An example of going deeper

Most science students must memorize compartmentalized facts about such topics as Kinetic Molecular Theory, latent heat, thermal expansion, and so on. When I was a student, I had to memorize the equation of an ideal gas, PV=nRT. We did experiments with compressing gases that helped me remember the facts and learn to use the gas law equation, but this did nothing to explain where it came from.

Boiling temperature and latent heats were more accumulated facts. I learned that even if you turn up the heat, water boils at a single temperature; this and the melting temperature are so stable that they form the basis of the Celsius scale. These phenomena are somehow related to the fact that it takes energy to convert liquid water into vapor and ice to water. Again, no explanation was given, no connections made to other ideas. These and other facts about the world accumulated in multiple, disconnected areas: thermal expansion, evaporation, diffusion, crystals, conductivity, and more. Science was reduced to learning facts, which results in a completely erroneous image of the nature and conduct of science.

Instead, science should be about unifying concepts and explanations about how the world works. It should not be a catalog of disconnected observations. By going a bit deeper, all of these phenomena can be united through three simple principles:

1. Atoms and molecules find one another repellant—it is very hard to squeeze them together.
2. Atoms and molecules are sticky—they attract when they are close but not touching.
3. Atoms and molecules have no friction. They have no way to dissipate energy, so energy is conserved.

It is not enough to simply state these principles. Students need an opportunity to develop an intuitive understanding of them and build mental models of these kinds of interactions. This cannot be done in the lab. A highly interactive simulation is needed that can allow students to play around in a world of atoms and molecules in order to gain a feel for this peculiar world. This is the very reason we developed the *Molecular Workbench*.

The Molecular Workbench to the rescue

Molecular Workbench guides students through a series of observations and discoveries that link basic properties to all the phenomena described above: gas laws, phase change, thermal expansion, and more. It allows students to experiment with different kinds of atoms, molecules, and mixtures. Atoms can be made huge or tiny, massive or light, energetic or still. The interaction of a pair can be examined in detail, or the emergent behavior of hundreds observed as a group.

To understand the gas laws, for instance, students need to understand how pressure and temperature manifest at the atomic scale. Molecular Workbench experiments demonstrate that temperature is simply the average kinetic energy of atoms. They show that pressure is the average force exerted by large numbers of atoms hitting a wall. With these insights, the gas law is easy to understand.

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[1] P. Morrison, "Less may be more," *American Journal of Physics,* vol. 31, pp. 441-457, 1963.

[2] W. H. Schmidt, C. C. McKnight, and S. A. Raizen, *A splintered vision: An investigation of U.S. science and mathematics education*, Boston, MA/Dordrecht, The Netherlands/London, UK: Kluwer Academic Press, 1997.

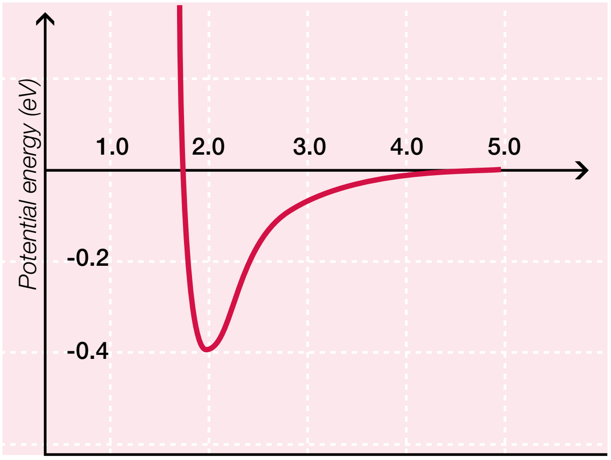

Figure 1. The Lennard-Jones potential used in the Molecular Workbench. The abrupt rise on the left is due to the mutual repulsion when two atoms get too close. The more gradual rise on the right is due to the attraction of atoms when they are near but not touching. Students can adjust the depth of the well and its location to help them understand how this curve relates to effects they observe in the lab.

Is digging worth it?

What is the value of knowing that observables like the gas law actually depend on the properties of atoms? Does it help students remember facts such as the gas law? Or does going deeper simply lengthen the list of things students have to memorize?

The answer requires a different perspective. Observables like the gas law are important only because they are related to more fundamental properties of matter. Tests focus on student ability to recall facts about the observable world and to solve numerical problems using simple algebraic equations. But this is not science. The science is in the interconnectedness, the logic of why the world is the way it is.

Why stop digging?

LINKS *How Can Less Be More?*

Molecular Workbench
http://workbench.concord.org

For students with a bit more sophistication, the three principles stated above can be introduced with the Lennard-Jones potential shown in Figure 1. This graph shows how the potential energy between two atoms depends on how far apart the atoms are. The Lennard-Jones potential may be a more compact and quantitative way of stating the three principles, but it still does not explain where the forces come from. For students able to dig even deeper, the attraction between atoms can be seen as the result of a kind of polarization of the electron clouds and the repulsion as a consequence of the Pauli exclusion principle. These, in turn, can be derived from basic quantum mechanics concepts.

So when should we start teaching these ideas to introductory students? It would be absurd to start at the deepest level with quantum mechanics, but it is equally absurd to never dig deep. A spiral approach seems more logical, starting with a few easily observed phenomena and then introducing an atomic-scale explanation. The red line in Figure 2 suggests how a spiral might start with observations, link to basic principles, and then spiral back to more observations and additional atomic-scale insights.

Going deeper in other topics

Molecular Workbench can give students access to ideas that are normally thought to be too abstract and inaccessible for introductory students. The technology helps students understand by allowing them to experience inaccessible phenomena and experiment with unrealistic systems. The resulting learning is conceptual, but sufficiently robust to be transferred to new situations.

Using technology to provide experience with otherwise inaccessible concepts can be applied in many science topics. BioLogica simulates the genetics of organisms and can be used for student experimentation on breeding, genetic drift, natural selection, and evolution. Similarly, interactive simulations of gravitating objects, colliding plates, structures that can break, and chemical reactions can all help students understand basic ideas behind observable phenomena. Not all these simulations currently exist, but one can imagine that when they do, science education will be forever changed, giving more students access to the powerful concepts that make science the exciting adventure that it is.

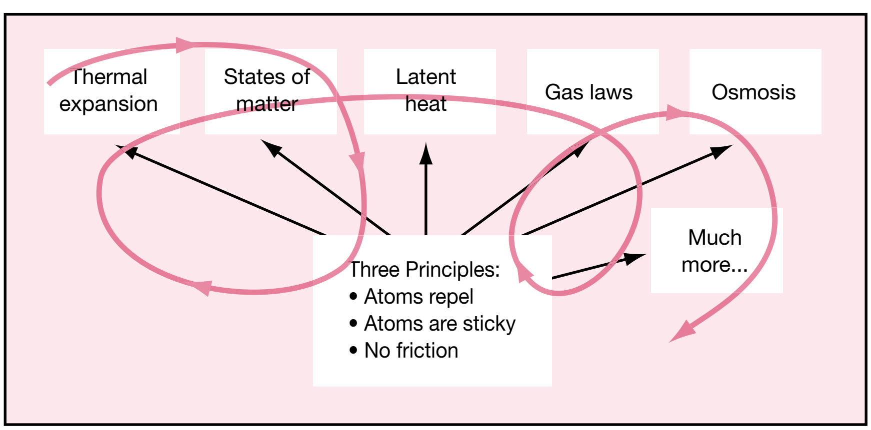

Figure 2. A few basic principles can be used to explain many observable effects. Even young learners can understand the principles and use Molecular Workbench to connect them to effects they see in the lab. A possible learning sequence is shown in red.

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

Community-Authored Resources for Education

BY ROBERT TINKER, MARCIA LINN, LIBBY GERARD, AND CAROLYN STAUDT

The reality: Textbooks are resources for learning that provide the structure, content, assessments, and teacher guidance for an entire course.

The dream: Technology can provide a far better resource that provides the same functions as a textbook, but takes full advantage of computers. This resource would be much more than text on a screen. It would use the best technology has to offer; it would be student oriented, utilizing highly interactive, vivid, inquiry-based activities embedded in intelligent electronic lessons. It would track student use and provide feedback to teachers, giving detailed analysis of student progress. It would be research-based, tied to standards, and well tested. And it would be *free*.

Educators need a similar paradigm for creating outstanding educational materials: a curriculum that is **collaboratively developed and shared** instead of created by publishers or researchers.

Developing the dream

How can this kind of resource be developed? Using the current top-down textbook development cycle, a large, skilled team would be needed: content experts who were classroom savvy, software wizards, assessment statisticians, curriculum designers, and university researchers. Developing comprehensive electronic materials for even a single course would be time consuming and expensive. And after working several years and spending tens of millions of dollars, a team might produce a great design, but it might be too advanced or unfamiliar for most teachers to use.

Let's envision a completely different, bottom-up development strategy. Imagine creating the materials collaboratively through a community of educators who share their knowledge, critique each other, and shepherd the evolution of a cluster of good materials. The result would not be a single, inflexible textbook handed down from on high, but a collection of malleable resources.

This strategy is certainly ambitious, but not impossible.

The traditional encyclopedia is also expensive and time consuming to create. But Wikipedia broke the traditional development mold. It has mobilized an international community of more that 150,000 volunteers to generate an encyclopedia that has over 11 million articles in 265 languages, used by 275 million people a month. It is far larger than any text-based encyclopedia, easier to use, continually evolving, up-to-date, and free. Its sophisticated quality assurance system keeps most junk and errors out. Volunteers do most of the work, so Wikipedia only needs to raise about two cents per user for operating expenses.

Educators need a similar paradigm for creating outstanding educational materials: a curriculum that is collaboratively developed and shared instead of created by publishers or researchers. In this new paradigm, an instructor who creates an activity could submit it online and have it reviewed. Another instructor or teacher should be able to adapt the activity or materials for his own students.

The result would be community-generated materials that are far more practical than any text. Like Wikipedia, the collection could be almost completely self-supporting, with users generating new materials and serving as reviewers and promoters.

There are many online collections of educational materials that could be confused with what we envision. The *National Science Digital Library*, *Curriki*, and *Merlot*, for example, have collections that include fine interactive materials for students. But these are produced and reviewed by experts, and not developed by a community like Wikipedia.

Information Technology in Science Instruction

The Wikipedia analogy is imperfect; a high-quality learning activity is far harder to generate than a single encyclopedia entry. But the Concord Consortium has been experimenting with community-generated materials in a number of projects.

Information Technology in Science Instruction (ITSI) has taken several important steps in realizing the dream. ITSI has a database of almost 100 short activities, each of which features an inquiry activity using a probe or model. Teachers are able to customize these easily for their own use. A central part of the professional development that we provide for these teachers involves learning how and why to make customizations.

Teachers are enthusiastic about this approach and have generated hundreds of new activities.

If community-generated materials are to be useful, however, it is important to ask whether teacher customization results in improvements. If, in the interest of saving class time, a teacher simply cuts out sections of a carefully designed activity, the result could be confusing to students and worse than a well-organized text. Our collaborators in the Technology Enhanced Learning of Science (TELS) Center have looked at this important question using the University of California's WISE (Web-based Inquiry Science Environment) materials, which can be easily authored and customized by teachers. (ITSI was inspired by earlier work at TELS using WISE materials.)

WISE has demonstrated the potential of virtual communities for the development and exchange of educational content. Hundreds of WISE inquiry projects have been authored by a wide range of participants, including educational researchers, teachers who wished to customize existing projects from the WISE public library, pre-service teachers in a curriculum and technology course, and informal science educators from museums, government agencies or nonprofit groups. This huge content development effort was not sponsored by any specific research grant. Rather, the content emerged because WISE was available as a free, flexible, and functional resource to a diverse community of developers.

University of California researchers studied how 20 middle school science teachers from two diverse school districts used evidence from student work to customize WISE units. These units combine Concord Consortium models, simulations, and graphs with student guidance to create five-day activities on standards-based topics such as global climate change, chemical reactions, and mitosis.

A case study in customization

The following case study demonstrates how a WISE teacher effectively customized a web-based inquiry science curriculum. Ted, a 6th grade earth science teacher, worked on a Plate Tectonics WISE unit each summer for three years. In the first summer, Ted made some changes in the unit, but while using the unit in class, he observed that students could not make sense of the multiple processes occurring simultaneously in the

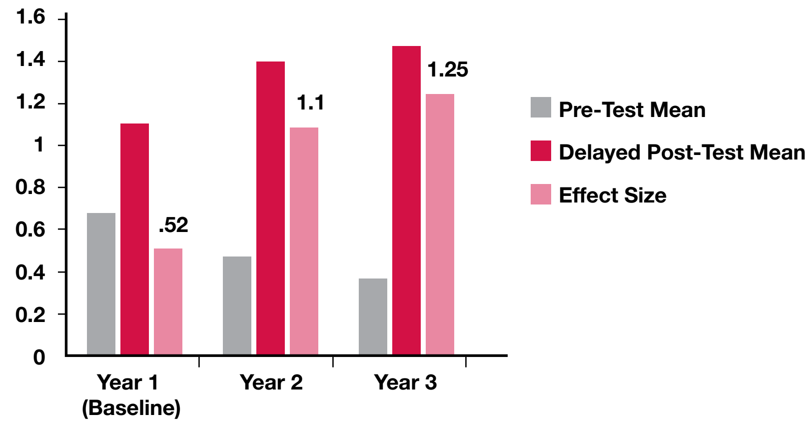

Figure 1. Student Performance on Plate Tectonics pre-test and post-test over three years (N= 475 students).

models of geological events. The students *"got carried away moving [parts of the models] in all different directions…the project needed to be limited, so that students were refining their understanding as they [interacted with the model], rather than burying themselves in something that was not part of their objective."*

In the second workshop, Ted customized the materials to help students understand the interactive visualizations. The following year, he reported that Plate Tectonics was *"a lot smoother and more fluid."* Students were able to more easily guide themselves through the project, freeing him to focus on motivating students to engage thoughtfully with the models and help them make connections among key concepts. In the third summer, Ted added activities that connected plate tectonics to local landforms based on his desire to make the project more relevant to his class. As shown in Figure 1, these changes resulted in significant improvements in student learning.

The first steps towards a community

The changes WISE teachers made were not created on the basis of hunches or opinions. The customizations were effective because they were thoughtful improvements designed to address parts of the activities that they had seen students stumble over. This experience gives us confidence that it is important to make electronic materials malleable and shared.

These beginning steps towards creating a resource of community-generated materials prove that it is feasible. We could yet see a completely new kind of learning resource available to teachers.

LINKS *Community-Authored Resources*

- **Merlot** *http://www.merlot.org*
- **Curriki** *http://www.curriki.org*
- **NSDL** *http://www.shodor.org/refdesk*
- **ITSI** *http://itsi.portal.concord.org*

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What's So Smart About a Gr

BY EDMUND HAZZARD

Your students are about to use an electronic temperature or force sensor, perhaps for the first time. The data will be displayed in a real-time graph. What is the best way to help your students make sense of the data?

An experiment using a sensor has at least four simultaneous representations:

1. The story of what was done (the experimental procedure).
2. The shape of the curve (the appearance).
3. The x and y values at each point (the numerical values, sometimes shown in a table).
4. The equations the data represents (the mathematical description).

An experienced scientist is aware of all four at once, jumping back and forth between representations with ease. But for students, connecting these representations takes considerable effort and practice.

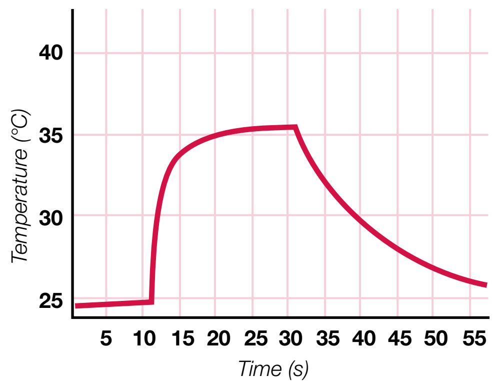
We developed "smart graph" capabilities to help these students. A smart graph "knows" about its own features and can help you investigate it. A smart graph can check your interpretations based on your answers to questions. It can highlight a portion of the graph, confirm your answer, prompt you to try again, describe what you should look for, or explain how to calculate something. Your answers might be labels added to points on the graph, numerical values, or actions, such as rescaling the graph.

Challenge 1: How was this graph made?

We have applied the smart graph feature to pre-determined sample datasets similar to the results of an experiment students might try. This gives them a preview of what might appear when they create their own data. For example, students see the graph above.

The story: I held the sensor in the air. Then I squeezed the sensor between my fingers for a little while and let it go.

Finger temperature: sample data



The appearance: The graph starts roughly level, then increases quickly and levels off. It drops off more slowly and gradually reaches the original value.

The numerical values: Room temperature is about 24.5°C, rises to about 35.5°C between 20 and 30 seconds, then drops back to room temperature over 50 seconds.

The equations: There are two logarithmic response curves, one upward and one downward, with unequal response times.

To help students connect these representations, they are asked to answer these questions:

1. Put a label on the part of the graph that measured room temperature.
2. What was the temperature in the room?
3. Put a label on the graph when the student touched the sensor.
4. How long did the student touch the sensor?
5. What was the temperature of the student's finger?

After each response or action, the student clicks a "check answer" button and learns if she is correct. If not, a hint appears. If, on second try, she is still not right, a second more explicit hint is displayed or the graph is highlighted on the pertinent part.

For example, Question 1 might offer the following prompts:

Try it yourself

Go to: http://www.concord.org/resources/browse/320

Each example with stored data is followed by a real data collector, which you can use with a Vernier fast-response temperature sensor or a Vernier dual-level force sensor. The live data collector does not yet have smart graph features for you to author. That's our next goal.

aph?

- (The student does nothing.) "Use the label tool to add a label to the graph."
- (The student labels the wrong part.) "That's not correct. What part of the graph shows room temperature, before the student touched the sensor?"
- (The student again labels the wrong part.) "That's still not correct. Add a label to the highlighted part of the graph." (The correct region of the graph is highlighted.)

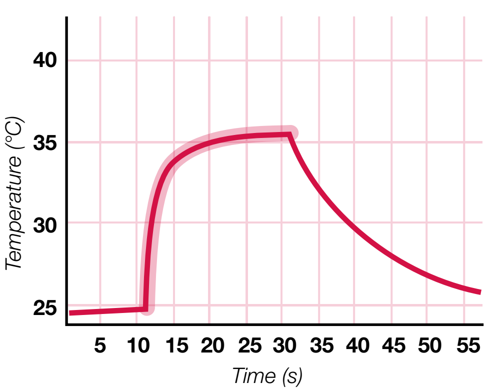
For Question 2, the smart graph looks for numbers:

- (The student enters the wrong value.) "That's not correct. Read the temperature at the beginning of the graph on the y-axis to the left."
- (The student again enters the wrong value.) "That's still not correct. Read the temperature of the highlighted part of the graph. " (The correct region of the graph is highlighted.)

For advanced students, more subtle interpretations could be explored:

1. "What was the fastest rate of increase?" This could involve expanding the scale and finding slope just after the student touched the sensor.
2. "What is the shape of this portion of the graph?" (The relevant region is highlighted.) Relate the shape to the physical situation: the rate of change is proportional to a difference.

Finger temperature: sample data



Challenge 2: Interpret force data

In another experiment, a student pulled a shoe with a force sensor. He pulled gently at first, then harder and harder until the shoe started to slide. The student then tried to pull it at a constant speed, and finally stopped pulling (see figure at right).

As the teacher, you might ask your students to respond to the following:

1. Add a label where the shoe started moving.
2. Add a label where the shoe was being pulled at a constant speed.
3. What was the force needed to get the shoe moving?
4. What was the average force needed to keep the shoe moving?

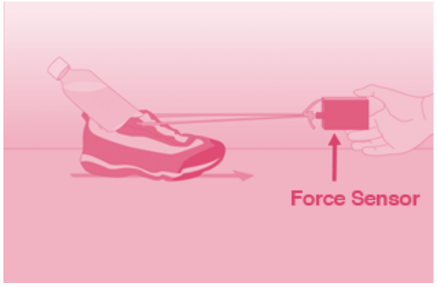
After the questions have been answered, the graph might look like the one to the right.

The smart graph checks that each label is in the correct place.

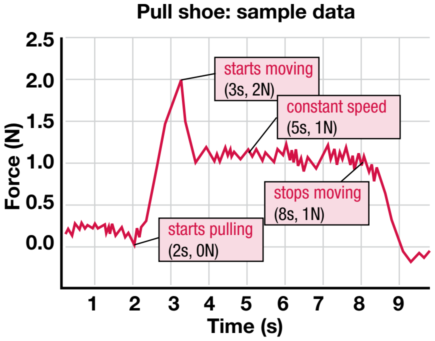
The connection between the story and the graph requires an understanding of physics. For instance, did the shoe start to move when the force went above zero (2 seconds), when it reached a maximum (3.2 seconds), or when it reached a constant value (3.5 seconds)? Why is there a bump before the leveling out at about 1.0 N? When the data is noisy, how do you find the average? If another surface material is used, how will the graph change? A real-time graph allows you to experiment with and talk about these questions; a smart graph can help you do that on your own.

The future of smart graphs: how smart will they get?

With pre-recorded data, it's not difficult for the graph to be smart about itself. The author of the activity enters the proper values or ranges when composing the "check answer" responses. With real data,



Pull shoe: sample data



composing useful responses is more difficult, and also more interesting.

In order to take the next step and respond to real data, the smart graph needs additional capabilities:

• Smooth the data, so that maximum, minimum, averages, and slopes can be calculated more easily.

• Find averages and slopes in regions marked by the student.

• Identify regions with different types of curves, such as constant, increasing, or decreasing slope.

There is also great potential in having the smart graph display the output of models, such as Molecular Workbench and NetLogo.

Graphs contain an enormous amount of information, making them very rich and interesting tools for understanding. In each situation, what should be noticed and interpreted—and what can be ignored—is different. This is a challenge for the author of the smart graph questions, but it's also why this capability is so useful for teaching. Understanding graphs is a fundamental part of scientific literacy. Smart graphs may make your students smarter about graphs—and science.

Edmund Hazzard *(ehazzard@concord.org) is a science curriculum writer.*

Technology and Effective Professional Development

BY ROBERT TINKER AND DAN DAMELIN

Information technologies—networked computers, software, and online communities—can provide incredible new resources for professional development.

What is effective professional development?

Too often, professional development focuses separately on either increasing teacher content knowledge or on abstract teaching methods. A common approach is to take graduate level courses in a discipline. The problem with this is that the impact on teaching is so indirect. A brilliant mathematician can fail as a teacher if she lacks an understanding of pedagogy. Research shows no measurable gains in student performance for this approach.

The other common strategy is to focus on general educational ideas and strategies. This approach can be helpful, but content must also be addressed. A cognitive scientist who understands student learning theories will fall short without content knowledge. Furthermore, unless educational techniques are embedded in a teacher's instruction, it is difficult for most teachers to put educational theory into practice.

The golden grail for professional development programs is proof that they result in student gains. The few programs that meet this test invariably focus teachers on learning to use student materials they can immediately apply to their instruction. If the student materials are high quality and the teacher professional development is effective, student learning increases. These successful programs focus on the content and pedagogy embodied in the materials. This finding has led to the idea that professional development should focus on "pedagogical content knowledge," or PCK, that is based on student materials. A growing literature, especially in science, technology, engineering, and math (STEM) education, suggests that teacher PCK has a positive impact on student learning and that experience enacting inquiry curricula in the classroom is critically important to the development of teacher PCK.

Technology-based materials

The Concord Consortium develops technology that allows teachers and students to tackle difficult concepts in new ways. By creating new representations and models for understanding science and math, we provide teachers with innovative tools made possible by technology. However, the technology itself can be an obstacle for many teachers.

Our materials feature student investigations of real events with probes, explorations of highly interactive models, and exploration of online databases and images. A substantial body of research shows that probeware can speed student learning of complex relationships in math and science. Similarly, computational models and simulations allow students to understand through exploration the behavior and mathematics of systems that are difficult to understand by other means. This use of technology involves new content and requires extensive use of inquiry-based learning.

Many of our materials for students are designed for technology-rich classrooms, which is clearly the direction for STEM education at all levels. Using computer-based student materials in professional development has many advantages: 1) teachers learn content and pedagogy by customizing the student materials; 2) the materials can be used immediately in class; 3) the materials can use the full power of technology to support learning based on guided inquiry; 4) teachers can continue their professional development using the detailed feedback provided by the software; and 5) professional development efforts can assess their impacts by electronically tracking the use of the student materials and measuring student gains.

A feature of our approach to professional development is teacher customization of student materials, a uniquely powerful way of implementing PCK professional development (see also "Community-Authored Resources for Education" on pages 6-7). To modify an activity, teachers need to consider the content and pedagogy of the original activity and how this might better meet the needs of their students and fit their curriculum. In the process of planning how to customize the materials, teachers learn the content more deeply than they might by just reading about it, and they think about the inquiry-based learning strategies that are built into the activities. They acquire pedagogical content knowledge that improves the materials and can improve their overall teaching prowess.

A recent article provides a theoretical basis for our approach.[1] The authors extend the PCK framework to include technological knowledge, which they call "technological pedagogical content knowledge" (TPCK). The authors assert that: "TPCK…requires an understanding of the representation of concepts using technologies [and] pedagogical techniques that use technologies in constructive ways to teach content" as well as PCK strategies.

Using technology to deliver professional development

The Concord Consortium has over a decade of leadership in developing new approaches to online professional develop-

[1] Mishra, P. & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *The Teachers College Record,* 108(38), 1017-1054.

ment for STEM teachers. When launched in 1996, the International Netcourse Teacher Enhancement Coalition (INTEC) was one of the first web-based online professional development programs. Funded by the National Science Foundation, INTEC created and delivered a 120-hour online, credit-bearing graduate-level professional development course to teams of teachers from school districts across the country. INTEC's objective was to assist the systemic improvement in math and science instruction by helping mathematics and science teachers understand and use inquiry as an instructional tool. Over 800 educators participated. As a result of INTEC, we developed the Concord e-Learning Model, a successful course on online facilitation, and a supporting text that remains widely used today.

The success of INTEC led the Concord Consortium to develop the Virtual High School (VHS), which in 1997 was one of the first online high schools. VHS remains the only virtual high school that uses a cooperative design and relies entirely on school-based teachers to develop and facilitate its courses. This highly successful program has made the transition to an independent nonprofit supported entirely from school membership fees. It is fully accredited and currently offers over 200 semester-long courses in all disciplines to students worldwide.

The keys to the success of VHS are two online courses, one on course facilitation and one on course design. These two courses have been offered dozens of times by VHS and regularly receive high praise from participants who often say that they are the most rigorous and rewarding professional development experiences of their lives.

In 2000 we launched Seeing Math, an innovative online professional development project. The Seeing Math project developed 21 online short courses for teachers of mathematics at the upper elementary and middle school levels. Each course features a video case study, using videos of real teachers in real classrooms. The focus of each video is teacher-to-student and student-to-student interactions, including teachers' questioning strategies that elicit student thinking and help make that thinking explicit. Additional video commentaries from math specialists highlight areas of student misconceptions and insights. Activities using interactive software provide course participants with a math challenge, so they explore the same content as students in the videos. Participants are asked to observe carefully their own processes as they work towards a mathematical solution; they share their processes in discussions with colleagues, and are thus exposed to a wider framework for understanding different problem-solving approaches, including those used by their own students. Seeing Math courses are available from PBS TeacherLine and Teachscape.

The Seeing Math experience with student materials and software led to the Information Technology in Science Instruction (ITSI) project in 2006. ITSI provides a professional development experience with optional graduate credit for secondary science teachers using a blended model that includes summer workshops and academic year online courses. ITSI prepares diverse students for careers in information technologies by engaging them in exciting, inquiry-based science projects that use computational models and real-time data acquisition. The project provides over 126 hours of lab-based, credit-bearing activities for 90 teachers and full support for classroom implementation.

Our professional development model is also used in the Rhode Island Information Technology Experiences for Students and Teachers project that helps secondary teachers in Physics First schools to incorporate interactive computer models to support a deep understanding of the molecular basis of science.

This decade of experience with online professional development led to a collaboration with Rhode Island institutions to create the Rhode Island Technology Enhanced Science project. This $12.5 million project, just getting underway, will reach all Rhode Island secondary science teachers with short courses using a blended professional development model based on technology-rich student materials. A large number of short courses will give teachers flexibility in meeting their specific needs.

As student materials take more advantage of the unique power of technology, professional development must change. Technology supports that change by providing teachers with new ways to enhance their knowledge and teaching skills.

LINKS *Professional Development*

- **Virtual High School** *http://www.goVHS.org*
- **Seeing Math** *http://seeingmath.concord.org*
- **PBS TeacherLine** *http://www.pbs.org/teacherline*
- **Teachscape** *http://www.teachscape.com*
- **ITSI** *http://itsi.concord.org*
- **RI-ITEST** *http://ri-itest.concord.org*

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Can They Do It or Do They Just Know How to Do It?

BY PAUL HORWITZ

At first glance it seems obvious that simulation-based performance assessments are preferable to traditional question-and-answer tests as a way of assessing students' understanding, particularly in technical areas. Unlike more static items, simulations provide opportunities to observe student behavior and reasoning in cognitively rich contexts that mirror the complexity of the real world. Using simulations one can assess more than memorization and superficial test-taking skills by confronting students with incompletely defined problems requiring multiple steps for their solution and often affording more than one satisfactory outcome.

But simulation-based challenges of this kind are expensive to create and require extensive and customized research to administer and score effectively. This raises the question whether they really capture aspects of students' learning that are inaccessible to a traditional assessment. It is conceivable, after all, that a student's answers to a suite of cleverly designed questions might act as reliable markers, accurately reflecting the knowledge, understanding, and skills we wish to measure in that student. How likely this is may depend on the particular content we wish to assess. Take, for example, the following scenario:

Imagine that you're learning how to cook a soufflé. The instructor shows you how to make the sauce, how to separate the egg yolks from the whites, how to get the timing just right. You take careful notes. You remind yourself never to open the oven door while the soufflé is baking. You dutifully emphasize the importance of preheating the oven and placing the soufflé in its exact center. The time comes for the final exam. You re-read your notes and memorize various recipes. The written exam consists of a single question: "In your own words, explain how to cook a perfect soufflé." You're well prepared and you receive an "A" on this test. But the next day you take the practical examination, in which you are challenged to make a soufflé, something you have never done in class. Even though on paper you appeared to know every detail of how to make one, your soufflé fails to rise and comes out a gooey mess. As an excellent student who has worked hard in the course, you are as surprised as anyone at your dismal performance. How could you ace the written test and do so badly on the real one?

Does this make-believe story sound unlikely to you or does it seem self-evident that "book knowledge" alone cannot make one a good cook? And what would you say about a good electronic technician? Is there a difference between the ability to troubleshoot a circuit and the ability to correctly answer questions about troubleshooting a circuit?

In the <u>*Computer-Assisted Performance Assessment*</u> (CAPA) project, funded by the National Science Foundation, we have been examining just that question. We have created realistic computer simulations of electronic circuits and

CAPA: http://capa.diy.concord.org/reports/2/otml?users=269,341,342,343,344,345,346,347,348,349,350,351,352,354

File

Using the Digital Multimeter

Class: Thursday 10am

Teacher: Firstname Lastname

	Voltage			Current			Resistance			Final Grade (out of 100)	Total Time (s)	Blown Meters
	Leads	Circuit	Score	Leads	Circuit	Score	Leads	Circuit	Score			
Student A	Good	Correct	100	Bad	Incorrect	0	Good	Incorrect	30	46	63	2
Student B	Good	Correct	98	Bad	Incorrect	8	Good	Correct	100	68	170	1
Student C	Good	Correct	100	OK	Correct	99	Good	Correct	100	99	95	0
Student D	Good	Correct	98	Bad	Incorrect	8	Good	Correct	100	68	112	1
Student E	Good	Correct	98	Bad	Incorrect	8	Good	Incorrect	30	45	92	2
Student F	Good	Correct	100	Bad	Incorrect	8	Good	Correct	100	69	100	1
Student G	OK	Correct	97	Bad	Incorrect	8	Good	Correct	100	68	173	1
Student H	Good	Incorrect	20	Bad	Incorrect	8	Good	Correct	100	42	118	1
Student I	Good	Correct	98	Bad	Incorrect	8	Good	Correct	100	68	135	1
Average	100%	89%	90	11%	11%	18	100%	78%	84	64	118	1

A typical teacher report from an activity that involves using a digital multimeter (DMM) to measure voltage, current, and resistance. In addition to checking the students' answers, we also report on whether they place the DMM leads in the right place and whether they configure the circuit correctly for each measurement.

test equipment; with these simulations we have developed interactive assessments that challenge students to make measurements and troubleshoot circuits. As the students work on these tasks, the computer keeps track of everything they do, and when they're finished, it reports on their performance. The reports, which are intended both for the student and for the instructor, not only indicate whether or not a student was able to accomplish the task, but also contain information on *how she went about it*. If the student did something wrong, the computer will point it out; if she left out a critical step, that too will be observed and reported.

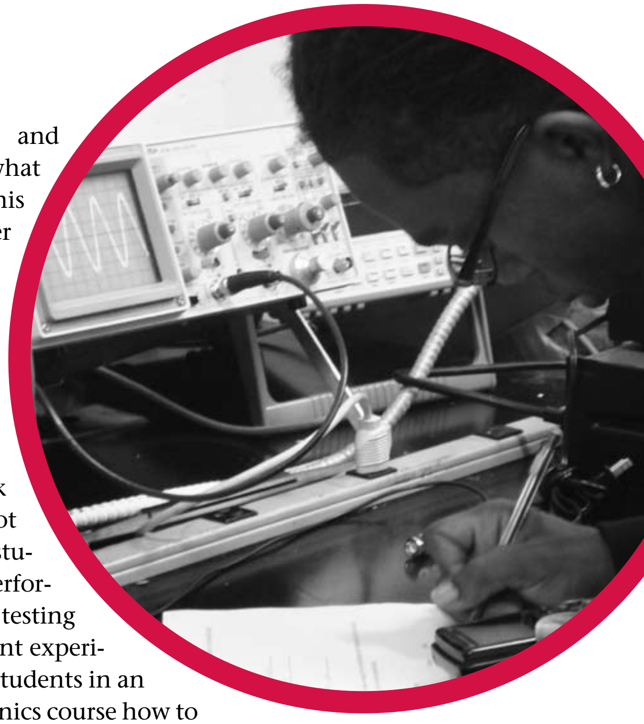
In addition, for each of our simulation-based performance assessments we also gave students a multiple-choice test that asked them how they would perform the task. We have repeated this experiment with three different groups of students from high school, two-year colleges, and four-year colleges. In each case the students performed better on the question-and-answer test than on the corresponding performance assessment—in other words, just as our fictional culinary arts student could recall the instructions for making a soufflé, but couldn't make one, the electronics students in our study are significantly more successful at answering questions about *how* to do something than they are at actually *doing it*.

This finding, which we continue to replicate and study, poses a potentially serious problem for training the nation's technical force. The vast majority of technicians in electronics and other fields are tested using paper-and-pencil tests—often multiple-choice tests—presumably because they are so easy to score. On the basis of such tests, both large and small companies hire "certified" men and women, only to discover that they need considerable further training to master the real-world skills required for their jobs. The resulting expense is a drain on the resources of such firms, and has a negative impact on the nation's ability to compete in a global economy.

What's going on?

Students take our assessments at a point in the introductory electronics course where both they and their instructors agree that the challenges we pose are ones they should have already mastered. And, as we have seen, they are generally able to answer questions about such tasks better than they can actually perform them. But why?

The answer might lie in the greater directedness of a question-and-answer test compared to a corresponding performance assessment, which tends to be more open-ended. As we developed our multiple-choice tests we were forced to ask relatively fine-grained questions. For instance, in order to assess whether students knew how to measure the current in a circuit, we posed separate questions about where to place the multimeter leads, whether a switch should be open or closed, and what setting to put the meter on; the corresponding performance assessment simply provided students with a simulated multimeter and watched to see what they do with it. This task places greater demands on executive function, which might explain why they did relatively poorly on it.



But new data suggests that the difference in task granularity does not account for the students' different performances in the two testing modalities. In a recent experiment we taught 13 students in an introductory electronics course how to measure the current in a circuit. The instruction consisted of a lecture and a demonstration using an actual circuit and meter, and it made a point of warning students always to insert the meter directly into the circuit, so as not to draw too much current and blow out the fuse.

A few days later the class was asked to write a short essay describing how to measure current. Ten students answered the question correctly. Later the same day, after a short break for lunch, the class reconvened and the students were given a real circuit and asked to measure the current. This time three of the students were able to complete the task correctly; the other 10 blew out the fuse!

Are we really leaving children behind? How can we tell?

The No Child Left Behind (NCLB) Act attempts to measure the achievement of schools, teachers, and students by asking questions and evaluating answers. This seems like a reasonable approach, but—at least in the field of electronics—the CAPA project is casting doubt on its validity by demonstrating that students' ability to answer questions may not be a reliable indicator of their relevant knowledge, skills, or understanding. This finding is not truly unexpected; NCLB has been criticized, in fact, precisely because it encourages educators to "teach to the test," the implication being that the skills required to succeed on question-and-answer assessments are not necessarily those that are important outside of school. The ultimate significance of performance assessments may lie in the fact that they are hard to "fool" by the application of narrow test-taking techniques irrelevant to the learning we are trying to assess. The introduction of such a realistic assessment methodology would make it possible to embrace accountability without trivializing educational goals.

LINKS *Can They Do It?*

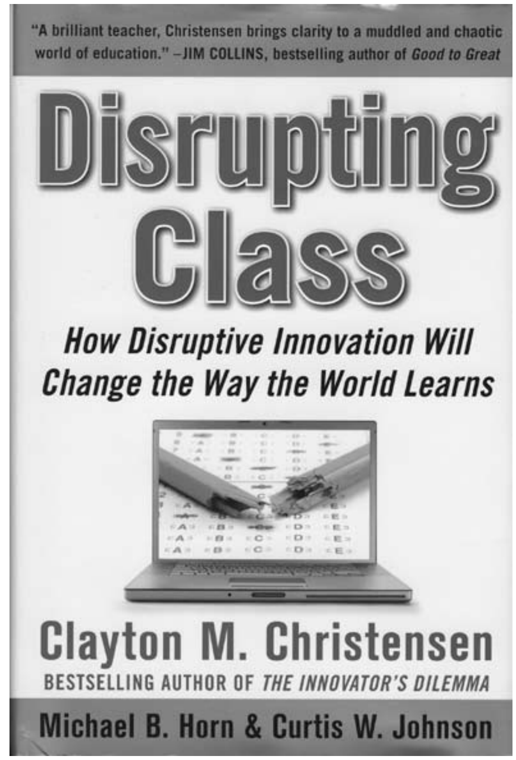
CAPA *http://capa.concord.org*

Paul Horwitz *(phorwitz@concord.org) directs the CAPA project.*

Lost in Cyberspace: A Review of *Disrupting Class*

BY ANDY ZUCKER

In *Disrupting Class,* the authors write about the shifts in many industries caused by what they call "disruptive technologies" and how such shifts affect schools. Because *Disrupting Class* has created a loud buzz in the education community and beyond, I was eager to read it.



Disrupting Class: How Disruptive Innovation Will Change the Way the World Learns. **Clayton M. Christensen, Michael B. Horn, & Curtis W. Johnson. McGraw-Hill, 2008.**

Strengths of the book

The authors know a great deal about how technology has affected many industries, and they argue that schools need to more clearly understand the profound changes and opportunities brought about by computers and the Internet. A central idea in the book is that new technologies often are initially less capable than the old ones. For example, the first wireless phones were not very effective. But if existing industries fail to understand how much and how quickly the devices or services will improve, they underestimate the long-term impacts of new technologies.

Another central idea is that new technologies often succeed first in market niches poorly served by older technologies. This allows new technologies to mature without competing directly with the old technologies.

Finally, another important set of ideas concern what others have called digital "learning objects," meaning electronic tools, lessons, or pieces of curriculum that may be used or combined in a variety of ways. Although the authors seem unaware of the considerable and complex history of this subject, they share the widely held opinion that learning objects will become more important to education.

Weaknesses of the book

Many people have been thinking and writing about how computers and networks will impact education for decades. Yet *Disrupting Class* gives the impression that the authors are the first ones to have thought carefully about this issue. They ignore or disparage almost all of the useful work that has been done in the past.

For example, the idea that computer-based technology should be used to assist students who are not well served in current schools is an old one. For decades, the federal government has spent billions of dollars trying to improve education for poor, rural, and other educationally disadvantaged students using the best and newest technology available. But almost everyone interested in education has concluded that while digital tools have many virtues, they are not a silver bullet or a panacea. *Disrupting Class*, however, shares the view of the utopians, who for years have claimed that technology will replace teaching as we know it. According to the authors, this will happen "because of the technological and economic advantages of computer-based learning, compared to the monolithic school model" (p. 99).

One often-cited claim in the book is that "by 2019, about 50 percent of high school courses will be delivered online" (p. 98). Some readers interpret this to mean online courses as they are offered now—but that would in effect require half of all high school teachers to teach only via the Internet. Other readers believe the authors are referring to true computer-based (that is, software-based) courses. Only the latter—which currently don't exist—will have the "technological and economic advantages" that the authors claim are so important.

This book review is excerpted from the white paper, "Lost in Cyberspace: A Review of *Disrupting Class,*" available at: http://www.concord.org/publications/detail/2008_DisruptingClass_WhitePaper.pdf

Consider the economic advantages. The largest online high school in the country is the Florida Virtual School (FLVS). Like other online high schools, FLVS hires teachers who are trained to provide online courses. The state gives FLVS 11% more money per course enrollment than a face-to-face school to pay for instruction and administration.[1] The money is transferred from the brick-and-mortar school's allotment to FLVS. *Disrupting Class* ought to explain that it is not instruction that costs less in online high schools. Instead, online schools do not need to pay for building construction, meals, transportation, libraries, theaters, art rooms, science labs, and many other features of brick-and-mortar schools. Are the authors recommending we give up those features in order to gain an "economic advantage"?

Disrupting Class states that **computers have had little effect** "save possibly to increase costs and draw resources away from other school priorities" (p. 72).

Readers will not learn how **creative school systems for years have been applying technology** in precisely the ways that *Disrupting Class* recommends, namely to individualize learning, to make it more effective for greater numbers of students, and to **offer alternatives to students who are not being served well** by existing schools.

The authors declare that "the way schools have employed computers has been perfectly predictable, perfectly logical—and perfectly wrong" (p. 73). But they demonstrate little interest in anything schools are actually doing with computers, besides online courses. Is using computers to read aloud to blind students or struggling readers wrong? Is teaching students physics using less costly virtual laboratory simulations that can be as effective as using actual laboratory equipment wrong? Is connecting every school in the nation to the Internet wrong? According to *Disrupting Class*, almost nothing currently done with technology by schools is valuable.

The book's claim that everything schools have done with computers is "perfectly wrong" is especially odd considering that so many states support online schooling, which is the technology *Disrupting Class* highly advocates. The Web has existed for only 15 years and already 44 states support online schooling. Schools are not ignoring the possibilities offered by technology.

The authors would like to see education become more "student-centric," meaning more individualized, through the use of computer software, but they say too little about students' need to have personal contact with adults and peers.

Would Christensen, Horn, and Johnson recommend that schools abandon the use of computers altogether? The book states that computers have had little effect "save possibly to increase costs and draw resources away from other school priorities" (p. 72). Tell that to the special education teachers who use computers and swear by them, or the teachers of civics and current events for whom outdated textbooks are an inferior teaching tool compared to the Web, or the roughly 50% of high school science teachers who use "probes" to collect, display, and analyze lab data on computers, or the states like Virginia and Oregon that are making student assessments more efficient and useful by delivering the assessments online, or…the list is very long and includes many applications of digital tools not even hinted at in *Disrupting Class*.

What you should make of *Disrupting Class*

Disrupting Class comes along at a time when the topic of integrating technology in schools is more important than ever because technology is more mature and ubiquitous. But the book is disappointing.

Readers may learn something about the process of innovation from *Disrupting Class*, but they will not learn how creative school systems for years have been applying technology in precisely the ways that *Disrupting Class* recommends, namely to individualize learning, to make it more effective for greater numbers of students, and to offer alternatives to students who are not being served well by existing schools. Readers will learn little or nothing about how to fund online learning or other technology innovations. Nor will they find a vision of how cyber charter schools and similar innovations can co-exist with regular public schools without taking funds from them and leaving them less effective.

Disrupting Class urges schools to do better, but it provides few practical suggestions and gives almost no credit to tens of thousands of schools that have taken steps already.

Andy Zucker *(azucker@concord.org) is the author of* ***Transforming Schools with Technology: How Smart Use of Digital Tools Helps Achieve Six Key Education Goals*** *(Harvard Education Press, 2008) and is a senior research scientist at the Concord Consortium.*

[1] See section (r) of http://www.myfloridahouse.gov/FileStores/Web/Statutes/FS07/CH1011/Section_1011.62.HTM.

NEWS at Concord Consortium

Teaching Evolution Readiness

Working with school districts in Massachusetts, Missouri, and Texas, the "Evolution Readiness" project, funded by the National Science Foundation, will teach fourth graders some of the fundamental concepts in biology that are essential to a full understanding of evolution. We will provide students with a virtual environment they can populate with different species of plants and animals. By running the model in fast forward, students can watch these populations evolve and adapt to different habitats over many generations. An expert team of researchers from Boston College will assess gains in student content knowledge and scientific inquiry skills.

Assessment Strategies that Work

"Cumulative Learning using Embedded Assessment Results" (CLEAR) is a collaborative project with the University of California, Berkeley, to develop curriculum and research middle school students' understanding of energy concepts in science. The National Science Foundation has funded CLEAR to work with four middle schools from the Mount Diablo Unified School District in California. We will follow groups of 1,000 students for two or three years to determine instruction and assessment strategies that help learners develop cumulative, integrated ideas about science.

Improving Secondary Science in Rhode Island

The "Rhode Island Technology Enhanced Science" (RITES) program is a targeted Math-Science Partnership funded by the National Science Foundation to improve secondary science learning statewide. RITES combines world-class academic science and education resources with comprehensive statewide STEM education reform supported by all levels of government and education. Partners include the University of Rhode Island, Rhode Island College, Johnston Public Schools, the Rhode Island Department of Education, Brown University, the Community College of Rhode Island, the Rhode Island Economic Development Corporation, and the Concord Consortium. The Education Alliance at Brown will evaluate the project.

Partners will develop an extensive series of short courses for teachers to implement effective teaching strategies and research-based content closely tied to the 64 state standards for secondary science and applied mathematics. The courses will feature guided inquiry using probes for labs, computational models of virtual environments, and software tools that access science databases. Embedded assessments will give students and teachers prompt and accurate data on student proficiency in each standard.

Online Courses for Students and Teachers

Looking for the highest quality online courses for middle and high school students? Check out the Virtual High School (*www.goVHS.org*) for over 200 courses ranging from Animal Behavior and Zoology to AP Calculus, and Advanced Web Design to Criminology. VHS offers full-year and semester-long courses, Gifted and Talented courses for middle school students, and summer school courses for enrichment or credit recovery.

For professional development courses, try PBS TeacherLine (*www.pbs.org/teacherline*). The Concord Consortium developed the Seeing Math™ series of algebra courses for teachers that make use of innovative, interactive computational models for solving linear equations, quadratic functions, and more. Videos of content experts and students supplement course material.

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