BRUCE ALBERTS

Restoring Science to Science Education

What is taught in schools today is a caricature of science. Young people need to be introduced to science's full riches.

I love biology, and nothing in my four decades as a professional biological scientist has given as much satisfaction as seeing that spark of passion for the subject ignited in a young person. So it should be no surprise that nothing frustrates me more than to see that spark extinguished by misguided educators and mind-numbing textbooks. As I write this article, I have just returned from a discussion with 7th-grade students in San Francisco, at which they described their year-long biology class that they found tedious and anything but inspiring. The course was structured around a textbook that was among those officially selected by the state of California two years ago, after an elaborate and expensive process that California repeats every eight years. The exploration of the wonderful world of living things should be a fascinating delight for students. But in California, as in so many other parts of the United States and the world, most students gain no sense of the excitement and power of science, because we adults have somehow let science education be reduced to the memorization of "science key terms."

How did this happen? And what can we do to recover from this tragic misuse of our young people's time and effort in school?

Part of the answer to the first question lies in the fact that producing and selling textbooks is a big business, and the prevailing market forces have invariably led to mediocrity. Twenty years ago, the situation was elegantly described in a book whose title says it all: *A Conspiracy of Good Intentions: America's Textbook Fiasco*. Sadly, the situation has not changed. Much of the problem lies in the simplistic ways in which these books are usually evaluated, stressing the coverage of science terms and computerized text analyses.

In response to the education standards movement of the 1990s, the 50 states set about establishing their own very different sets of detailed science education standards. Because of this heterogeneity, textbook companies are forced to waste great amounts of time and resources on producing books that can satisfy the needs of as many states as possible. Even before the standards movement made things worse, U.S. textbooks had become known around the world for being "an inch deep and a mile wide." The result today is what I call science education as mentioning.

Take for example my field of cell biology, where for grades 5 to 8, the National Science Education Standards produced by the National Academies in 1996 emphasized understanding the essence of cells as the fundamental units of life, rather than learning the technical names of cell parts. The California state standards, on the other hand, stress all of these names. As a result, the adopted textbook for 7th grade contains five pages with 12 cell parts highlighted as key terms: including endoplasmic reticulum, Golgi body, lysosomes, mitochondria, and ribosomes. Because this 700-page book is forced by the California state standards to cover much of biology in similar detail, there is not enough room to explain most of these cell parts. Thus, for example, for the highlighted word "endoplasmic reticulum," the book simply states that "The endoplasmic reticulum's passageways help form proteins and other materials. They also carry material throughout the cell." Why should memorizing these two sentences be of any interest or importance to a 12-year-old? And what if anything will even the best students remember a year later?

Another part of the answer to why the United States has let science education go badly astray is that it is much easier to test for science words than it is to test for science understanding. The new age of accountability in U.S. education has led to a massive increase in testing, and the individual states have generally selected simple, low-cost, multiple-choice tests that can be rapidly scored. Because these high-stakes tests drive teachers to teach to them, they are thereby defining what science education means in our schools. This is a great tragedy, inasmuch as it trivializes education for young people. For far too many of them, education appears to be a largely senseless initiation ritual that is imposed on them by adults.

Consider, for example, the following question that is offered in California as a sample item for its 5th-grade science test:

A scientist needs to take a picture of the well-ordered arrangements of the atoms and molecules within a substance. Which of the following instruments would be best for the scientist to use?

A. A laser light with holograph
B. A seismograph
C. An electron microscope
D. A stereoscope

There are two major problems with this question. The first is that there is no right answer; an electron microscope does not generally have the resolution to decipher the relative arrangement of atoms. But much more important to me is the fact that learning the names of the different machines that scientists use is neither interesting nor relevant to the education of 10-year-olds.

The following anecdote illustrates how far we have strayed from what should be the central purpose of education: empowering students to learn how to learn on their own. A scientist parent notices that her elementary school child has thus far not been exposed to any science in school. As a volunteer teacher, she begins a science lesson by giving the children samples of three different types of soil. Each child is told to use a magnifying glass to examine the soils and write down what they observe in each sample. She waits patiently, but the children are unwilling to write anything. Her probing reveals that after three years of schooling, the students are afraid to express their views because they don't know "the right answer."

In fact, we know that life is full of ambiguous situations and that as citizens and workers we will have to solve many problems to which there is no right answer. To quote former Motorola CEO Robert Galvin, "Memorized facts, which are the basis for most testing done in schools today, are of little use in an age in which information is doubling every two or three years. We have expert systems in computers and the Internet that can provide the facts we need when we need them. Our workforce needs to utilize facts to assist in developing solutions to problems."

Life is nothing like a quiz show. If we adults allow students to believe that we think being educated means knowing all of the right answers, is it any wonder that nearly half of U.S. middle- and high-school students are found to be disengaged from their schooling?

The four strands of science learning

Ten years after producing the National Science Education Standards, the National Academies convened a distinguished committee of scientists and science education experts to take a fresh look at science education, considering all that had been learned in the interim. In 2007, this group produced the valuable report *Taking Science to School: Learning and Teaching Science in Grades K-8*. This analysis proposes that students who are proficient in science be expected to:

- know, use, and interpret scientific explanations of the natural world;
- generate and evaluate scientific evidence and explanations;
- understand the nature and development of scientific knowledge; and
- participate productively in scientific practices and discourse.

These four strands of science education were judged in the report to be of equal importance. Yet what is taught in most schools today, from kindergarten through introductory college classes, focuses almost exclusively on only a portion of the first of the four strands: teaching students to know scientific explanations of the natural world. Adopting the agenda in *Taking Science to School* will therefore require an ambitious effort to redefine the term "science education."

The source of the problem is college. For the most part, those of us who are scientists have made a mess of science education. Scientists are deeply engaged in attempting to unscramble the puzzle of how the world works, and we are thrilled to read about each year's startling advances that increase our understanding of the universe that surrounds us. It seems that each new finding raises new questions to be answered, providing an endless frontier for the next generation of scientists to explore. We believe passionately in the power of science to create a better world, as well as in the critical importance for everyone in society of the values and attitudes that science demands of scientists: honesty, a reliance on evidence and logic to make judgments, a willingness to explore new ideas, and a skeptical attitude toward simple answers to complex problems. But very little of this is conveyed to students in our teaching.

It is college science, both because of its prestige and because it is the last science course that most adults will take, that defines science education for future teachers and parents. And yet, when my science colleagues in academia teach a first-year course to college students, most will at best attempt to cover only the first of the four strands of science proficiency recommended in the National Academies report. Any redefinition of science education at lower levels will therefore require a major change in the basic college courses in biology, chemistry, physics, and earth sciences. Each must add an emphasis on the other three strands: on enabling college students to generate and evaluate scientific evidence and explanations; to understand the nature and development of scientific knowledge; and to participate productively in scientific practices and discourse. This requires that students actively experience science as inquiry in their classes, being challenged to collect data and solve problems in the way that scientists do. They will also need to explore a few aspects of the subject in depth and be challenged to come up with some of their own explanations, rather than simply parroting back what they have been told in lectures or in textbooks.

A four-part recipe for action

As in science, strategy is everything when attempting to tackle a difficult problem. And redefining science education along the lines recommended in the Academies' *Taking Science to School* report will certainly be difficult. To be effective, we need focus, and I therefore propose the following four-part strategy. Much of what I say here about how to move forward is reflected in the new *Opportunity Equation* report from the Carnegie Institute for Advanced Study Commission on Mathematics and Science Education, on which I served.

1) ***Enlist the National Academies, in collaboration with the National Science Teachers Association and the American Association for the Advancement of Science, to develop a pared-down set of common core standards for science education that reflect the principles in* Taking Science to School.** We have learned a great deal since 1996 from the response to the standards movement, and the governors and the chief state school officers of a majority of states now recognize the enormous disadvantages of having 50 different state standards for science education. The federal government should provide incentives to the states to sign on to this common standards movement. For example, it can help link the core standards to an energetic, nationwide development of high-quality curricula, to online teacher education and professional development resources, and to the development and continual improvement of a research-based system of quality assessments and standards, as described below.

2) ***Initiate a high-profile effort to produce quality assessments that measure student learning of all four strands of science proficiency.*** Poor tests are currently driving poor teaching and learning, and the development of much better tests at all levels, from elementary school through introductory college courses, is therefore an urgent and challenging matter. Our nation's leaders should make this a matter of national service, recruiting a group of the very best scientists and science assessment experts to work together over successive summers, as was done in the post-Sputnik era in the United States. At the K-12 level, two very different types of high-quality tests will need to be developed around the core standards: formative assessments that teachers can use to measure student progress, so as to adjust their teaching appropriately during the school year; and summative assessments that the states will use for accountability purposes. At the college level, I envision an effort to develop and disseminate quality questions to be given on the final exam in introductory science courses. These would be designed to test for an understanding of the last three strands of science proficiency in *Taking Science to School* and therefore be applicable to courses in a variety of scientific fields. Has the course enabled the students to understand "science as a way of knowing", and has it prepared them to use scientific processes and evidence as adults? The professors who teach these courses are scientists and should therefore care deeply about the answer.

3) ***Link the core science standards and their associated assessments to an intensive research program in selected school districts, so as to provide the "ground truth" needed***

for their continuous improvement. Education is much too complex to ever expect to get it permanently right. What is the effect of the use of these standards and assessments in actual schools? In what ways are they driving high-quality teaching and learning of science? How should they be revised and improved? Answers to these types of questions require collaborations between skilled researchers and teachers, and they are critical if we are to develop the science of education that our nation needs. The Strategic Education Research Partnership (SERP) is a nonprofit institution that resulted from two successive studies by the National Academies that addressed the question, why is research knowledge used effectively to improve health, agriculture, and transportation, but not education? Now in its fourth year, SERP has demonstrated how highly effective research can be produced when groups of academics and practitioners collaborate in real school settings, setting an example for the substantial research effort that is essential to continuously improve science education.

4) ***Work to strengthen to strengthen the human resources systems of states and school districts so as to recruit, retain, and deploy a corps of highly qualified science and math teachers***. We must improve teacher retention by making school districts more attractive places to work. Teachers must be treated as professionals and teacher leaders recruited to help incorporate the wisdom of outstanding teachers into school, school system, and state education practices and polices. Without such advice from a district's best teachers, continual improvement cycles are unlikely to be maintained. The United States should consider international models, such as Singapore's, that incorporate rotating groups of outstanding teachers into the highest levels of the education policymaking apparatus. We should also consider the possibility of recruiting outstanding Ph.D. scientists into state and district office, so as to readily connect our schools to national and local resources in the scientific and science education communities.

The broad goal for science education must be to provide students with the skills of problem solving, communication, and general thinking required to be effective workers and educated citizens in the 21st century. Business and industry need problem solvers throughout the enterprise, as witnessed by many studies. These same skills are also crucial to enable everyone to navigate the increasingly complex and noisy world that we live in. Thus, they are essential to empower the citizens in a democracy to make wise judgments for themselves and their communities, which they are required to do in the midst of a cacophony of voices striving to sway rather than enlighten them.

Recommended reading

B. Alberts, "Redefining Science Education," *Science* 323 (2009): 427.

Carnegie–Institute for Advanced Study Commission on Mathematics and Science Education, *The Opportunity Equation* (2009).

R. Marshall and M. Tucker, *Thinking for a Living: Education and the Wealth of Nations* (New York: Basic Books, 1992).

National Research Council, *National Science Education Standards* (Washington, DC: National Academy Press, 1996).

National Research Council, *Taking Science to School: Learning and Teaching Science in Grades K-8*, R. A. Duschl, H. A. Schweingruber, and A. W. Shouse, eds. (Washington, DC: National Academies Press, 2007).

National Research Council, *Ready, Set, Science!: Putting Research to Work in K-8 Science Classrooms*, Sarah Michaels, Andrew W. Shouse, and Heidi A. Schweingruber, eds. (Washington, DC: National Academies Press, 2007).

L. Steinberg, B. Brown, and S. Dornbusch, *Beyond the Classroom* (Cambridge, MA: Touchstone Books, 1997).

H. Tyson-Bernstein, *A Conspiracy of Good Intentions: America's Textbook Fiasco* (New York: Basic Books, 1988).

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