Considering Science Education

I CONSIDER SCIENCE EDUCATION TO BE CRITICALLY IMPORTANT TO BOTH SCIENCE AND THE world, and I shall frequently address this topic on this page. Let’s start with a big-picture view. The scientific enterprise has greatly advanced our understanding of the natural world and has thereby enabled the creation of countless medicines and useful devices. It has also led to behaviors that have improved lives. The public appreciates these practical benefits of science, and science and scientists are generally respected, even by those who are not familiar with how science works or what exactly it has discovered.

But society may less appreciate the advantage of having everyone acquire, as part of their formal education, the ways of thinking and behaving that are central to the practice of successful science: scientific habits of mind. These habits include a skeptical attitude toward dogmatic claims and a strong desire for logic and evidence. As famed astronomer Carl Sagan put it, science is our best “bunk” detector. Individuals and societies clearly need a means to logically test the onslaught of constant clever attempts to manipulate our purchasing and political decisions. They also need to challenge what is irrational, including the intolerance that fuels so many regional and global conflicts.

So how does this relate to science education? Might it be possible to encourage, across the world, scientific habits of mind, so as to create more rational societies everywhere? In principle, a vigorous expansion of science education could provide the world with such an opportunity, but only if scientists, educators, and policy-makers redefine the goals of science education, beginning with college-level teaching. Rather than only conveying what science has discovered about the natural world, as is done now in most countries, a top priority should be to empower all students with the knowledge and practice of how to think like a scientist.

Scientists share a common way of reaching conclusions that is based not only on evidence and logic, but also requires honesty, creativity, and openness to new ideas. The scientific community can thus often work together across cultures, bridging political divides. Such collaborations have mostly focused on the discovery of new knowledge about the natural world. But scientists can also collaborate effectively on developing and promulgating a form of science education for all students that builds scientific habits of mind.

Inquiry-based science curricula for children ages 5 to 13 have been undergoing development and refinement in the United States for more than 50 years. These curricula require that students engage in active investigations, while a teacher serves as a coach to guide them to an understanding of one of many topics. This approach takes advantage of the natural curiosity of young people, and in the hands of a prepared teacher, it can be highly effective in increasing a student’s reasoning and problem-solving skills. In addition, because communication is emphasized, inquiry-based science teaching has been shown to increase reading and writing abilities. This approach to science education has been slowly spreading throughout the United States in the past decade, but it requires resources and energy on the part of school districts that are often not available. With strong support from scientists and science academies, a similar type of science education is also being increasingly implemented in France, Sweden, Chile, China, and other countries. In these efforts, catalyzed for the past 8 years by the InterAcademy Panel in Trieste, scientists are sharing resources and helping to form new bridges between nations.

With appropriate modifications, could such an education also help make students more rational and tolerant human beings, thereby reducing the dogmatism that threatens the world today with deadly conflict? In future editorials, I will explore the many potential advantages of inquiry-based science education. I will also discuss the barriers that must be overcome for its widespread implementation across the globe, because we may face no more urgent task if future generations are to inherit a peaceful world.

– Bruce Alberts

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Hybrid Vigor in Science

When I was president of the U.S. National Academy of Sciences, I came to believe that the future success of humanity may depend on learning to use the tools of science—including the collection of objective evidence on what works and why—at all levels of decision-making. Thus, the National Academies have repeatedly addressed questions such as “How can we make a science out of education?” or “How can we make a science out of sustainable development?” Developing a sound platform of knowledge to address such critical issues will require harnessing research of the highest quality, both in the natural and social sciences. And for this research to be effective, scientists will need to develop much deeper connections with the rest of society.

A formative experience in my first few months as president of the National Academy of Sciences was participating in a workshop for a study on violence in urban America, for which a mixture of social and behavioral scientists, law enforcement agents, mayors, and others came together to formulate recommendations. The wide range of perspectives created an electric, highly creative, and collaborative atmosphere at the workshop that informed and enriched the results. Many of the scientists made new connections that seemed certain to improve their future research, as well as to make their findings more useful for society. Since then, I have repeatedly witnessed the innovation that arises from recruiting scientists and outstanding practitioners to work together, using scientific approaches to tackle important problems.

A recent experience began when the National Academies confronted the question of why research has supported innovation and continuous improvement in medicine, agriculture, and transportation, but not in education. The two successive committees that struggled with this problem were composed of a mixture of national leaders in business, research, policy, and educational practice. The result is the Strategic Education Research Partnership (SERP, a nonprofit organization whose board I chair). SERP is a 3-year-old experiment in which school districts are established as research “field sites,” the first two being Boston and San Francisco.

In a field site, a cooperative team of distinguished researchers works hand in hand with local school district personnel to address a select set of challenges that have been identified by the school district. The research is carried out in real classrooms to explore the effect of jointly designed interventions that take advantage of local teacher expertise. There are valuable take-home lessons for all involved, underscoring how everyone can benefit when scientists take on practical problems.

There are many precedents for such productive partnerships. My office at the University of California, San Francisco (UCSF), is located at the new Mission Bay campus, where biotech buildings are springing up like mushrooms across the street. Most faculty look forward to the many synergistic interactions that are likely to arise from this proximity. I was at UCSF in 1976 when this industry began, and at that time the whole idea of university biology faculty becoming involved with the private sector seemed inappropriate and, to most of us, a waste of faculty time. But after many of our students moved on to jobs in the local biotech industry, they formed an effective bridge between the quite different cultures of industry and academia. They became the real agents of technology transfer from university laboratories and also helped to create new arrangements that now benefit the fundamental work of the university. Rather than distracting faculty from productive scholarship, as we had feared, the interactions have increased the pace of discovery.

By analogy with biotech, the formation of strong, long-lasting synergies between academic science and other critical institutions will require that some of our best students of science leave academia to become curriculum specialists inside school districts, policy analysts in state government offices, and so on. These people will form the bridges needed for science to affect a wider society. We should therefore be generating new programs to support such career transitions, while cheering on the scientists who pursue them.

– Bruce Alberts

10.1126/science.1158519
New Career Paths for Scientists

Last week on this page, I stressed the benefits to both science and society of transitioning well-trained scientists into a broad array of endeavors, in research and in other roles. Here I suggest two strategies that could help achieve this goal.

For more than 30 years, the Science and Technology Policy Fellowships of the American Association for the Advancement of Science have recruited U.S. scientists and engineers at various stages of their careers, from ages 25 to 72, to work in the U.S. federal government for a year. Similar 10-week fellowships at the U.S. National Academies in Washington, DC, allow graduate students and postdoctoral fellows in science and engineering from many nations to contribute to science and technology policy issues. Other fellowship opportunities in the United States and elsewhere provide exposure to the worlds of policy-making, teaching, and communication, among others (see Science Careers, p. 390).

These valuable programs serve multiple purposes, most obviously allowing scientists and engineers to explore possible careers outside of academia and industry. After fellows complete such programs, they return home and share their experiences. Thus, a single fellow can provide an entire academic department with a broader view of career paths. Working with a science fellow can also make an organization or government agency aware of the advantages of hiring full-time staff with scientific talents and connections, permanently increasing its scientific capabilities.

The several thousand past participants in these fellowship programs are engaged in various pursuits. Many are research scientists, but others have entered careers in policy, science education, journalism, and environmental protection, among others. Exemplars include physicists Rush Holt, a U.S. congressman, and E. William Colglazier, the chief of staff at the National Academies. Scientists in such non-traditional careers are invaluable as two-way interpreters: people who can readily bring the benefits of scientific analysis to their institution or profession, as well as help traditional scientists better understand how their science might contribute in new ways. Even a single such individual can make a huge difference.

There would therefore be many advantages to expanding these types of opportunities. Perhaps the simplest way would be through new short-term programs that allow fellows to sample a career in government, pre-college education, nongovernmental organizations, the media, or industry. If offered for a period of 4 months or so, such fellowships could be accommodated as temporary excursions from traditional career paths. Minimal stipends could cover living costs, as is done for some other fellowship programs, with groups of fellows being mentored by professional staff.

More ambitious would be a new type of graduate program for scientists, with a branching set of options after the first or second year. Although many students would continue to pursue the standard research path, other options would specifically prepare a student to become a professional policy analyst, a science education researcher, a science-oriented journalist, or a science curriculum specialist in a school district, for example. Although there are good stand-alone programs leading to some of these careers, most remain unconnected to standard science Ph.D. programs and are of limited capacity.

Developing new, integrated programs will require that partnerships be forged with other organizations; these could be established regionally to involve students from different universities. They can be viewed as the next logical step from programs such as the U.S. National Science Foundation (NSF) Graduate Teaching Fellows, which enables graduate students in science, technology, engineering, or math to broaden their training through extensive interactions with young students and their teachers.

According to NSF, there are more than 45,000 postdoctoral fellows in the natural and social sciences in the United States alone. Many will gather in Boston next week at the National Postdoctoral Association’s Annual Meeting. They and the tens of thousands of graduate students just behind them in the pipeline represent a tremendous resource for the future. It is good news that a surprising percentage are interested in using their science training in nontraditional ways. Those of us who are their mentors must help them do so.

– Bruce Alberts

10.1126/science.1158719
Making a Science of Education

FOR SUCCESS IN AN INCREASINGLY COMPLEX, CROWDED, AND DANGEROUS WORLD, A NATION must strive to be a meritocracy: Its education and social systems should be structured to select those with the most talent, energy, wisdom, and character as the next generation of leaders for each segment of society. When I was young, I was taught that providing equal opportunities for everyone was a matter of social justice—part of the social contract in the United States. Now, I believe that it is also a matter of national survival. Any country that fails to encourage and develop the talent in each individual through its public school system will suffer greatly, because the quality of a nation depends on the collective wisdom of both its leaders and its citizens.

An outstanding education system imparts values that support good citizenship, while empowering adults to be life-long learners and problem solvers who can make wise decisions for their families, for their communities, and for their workplaces. Such an education system must continually evolve to remain relevant to the interests and needs of each new generation. To achieve these ambitious goals, we will need much more emphasis on both science education and the “science of education.” It is my hope that Science can help to promote progress on both scores.

In 2006, Science began a monthly Education Forum. We now plan to build on this strong beginning by recruiting high-quality articles on education from the world’s best experts for every section of the magazine. Thus, we will be publishing important work in education as Perspectives, Policy Forums, Reviews, or as original Research Reports and Articles, while continuing to cover education in the News section. This first issue of 2009, with its focus on Education and Technology (see page 53), represents a start that will hopefully inspire many more articles to come.

As this special issue explains, the computer and communication technologies that have profoundly altered many other aspects of our lives seem to hold great promise for improving education as well. But technology is only a tool. To fulfill its promise for education will require a great deal of high-quality research, focused on its utilization and effects in both school and non-school settings. Only by collecting and analyzing data on student learning can we hope to sort out the many variables that determine effectiveness.

The same type of scientific research is also needed to explore, analyze, and improve each of the many other components of educational systems. For example, the most important element of any education system is a highly skilled teacher. Teacher recruitment, preparation, retention, and professional development all need to be informed by scientific research in education. Curricula, pedagogy, assessment, and school system management similarly require focused research. We hope that what scientists are learning about each of these important aspects of education will be reported and reviewed in Science.

Research in the social sciences is especially challenging because of the conditionality of its findings: The effects of an intervention are likely to depend on many variables that need to be studied and understood. Some readers may therefore question whether the science of education deserves a prominent place in this prestigious journal. For them, I offer the wisdom of Alfred North Whitehead, who wrote 80 years ago: “The art of education is never easy. To surmount its difficulties, especially those of elementary education, is a task worthy of the highest genius.” “But” “when one considers...the importance of this question of the education of a nation’s young, the broken lives, the defeated hopes, the national failures, which result from the frivolous inertia with which it is treated, it is difficult to restrain within oneself a savage rage. In the conditions of modern life the rule is absolute, [a country] that does not value trained intelligence is doomed.”

The sense of rage is every bit as appropriate today. But we now recognize that we must look at the “art” of education through the critical lens of science if we are to survive.

—Bruce Alberts

10.1126/science.1169941
Redefining Science Education

THERE IS A MAJOR MISMATCH BETWEEN OPPORTUNITY AND ACTION IN MOST EDUCATION SYSTEMS today. It revolves around what is meant by “science education,” a term that is incorrectly defined in current usage. Rather than learning how to think scientifically, students are generally being told about science and asked to remember facts. This disturbing situation must be corrected if science education is to have any hope of taking its proper place as an essential part of the education of students everywhere.

Scientists may tend to blame others for the problem, but—strange as it may seem—we have done more than anyone else to create it. Any objective analysis of a typical introductory science course taught today in colleges and universities around the world, whether it be biology, chemistry, physics, or earth sciences, would probably conclude that its purpose is to prepare students to “know, use, and interpret scientific explanations of the natural world” (strongly emphasizing the “know”). This is but one of four goals recommended for science education by the distinguished committee of scientists and science education experts convened by the U.S. National Academies that produced Taking Science to School: Learning and Teaching Science in Grades K-8. And yet college courses set the model for the teaching of science in earlier years.

The three other goals of equal merit and importance are to prepare 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 (summarized in the Academies’ Ready, Set, Science!). Scientists would generally agree that all four types of science understanding are critical not only to a good science education but also to the basic education of everyone in the modern world. Why then do most science professors teach only the first one?

As the scientist and educator John A. Moore emphasized in his prolific writings, science provides a special way of knowing about the world.* The failure of most students and adults to understand this fact, despite having taken science courses, reveals a serious deficiency in our education systems. And the failure of students to acquire the logical problem-solving skills of scientists, with their emphasis on evidence, goes a long way to explain why business and industry are so distressed by the quality of our average high-school and college graduates, finding them unable to function effectively in the workforce.

Vast numbers of adults fail to take a scientific approach to solving problems or making judgments based on evidence. Instead, they readily accept simplistic answers to complicated problems that are confidently espoused by popular talk-show hosts or political leaders, counter to all evidence and logic. Most shocking to me is the finding that many college-educated adults in the United States see no difference between scientific and nonscientific explanations of natural phenomena such as evolution. Their science teachers failed to make it clear that science fundamentally depends on evidence that can be logically and independently verified; instead, they taught science as if it were a form of revealed truth from scientists.

Teaching the missing three strands requires that students at all levels engage in active inquiry and in-depth discussion in classrooms. What would it take to get scientists to teach their college courses this way? I suggest that we start with new assessments. It is much easier to test for the facts of science than it is to test for the other critical types of science understanding, such as whether students can participate productively in scientific discourse. For the United States, I therefore propose an intense, high-profile national project to develop quality assessments that explicitly measure all four strands of science learning that were defined by the National Academies.† Designing such assessments for students at all levels (from fourth grade through college), energetically advertising and explaining them to the public, and making them widely available at low cost to states and universities would greatly accelerate the redefinition of science education that the world so urgently needs.

— Bruce Alberts

10.1126/science.1170933

†E. S. Quellmalz, J. W. Pellegrino, Science 323, 75 (2009).
On Becoming a Scientist

ONE NORMALLY BECOMES A SCIENTIST THROUGH A SERIES OF APPRENTICESHIPS, PURSUING research in laboratories directed by established scientists. My own scientific mentors were Jacques Fresco and Paul Doty at Harvard, where I learned not only technical skills but also how to think and function as a scientist. Both from them, and by making my own mistakes,* I learned how to identify important problems, how to think critically, and how to design effective research strategies. Because so much of one’s scientific future is shaped by early experiences, it is critical that beginning scientists select their mentors wisely. Unfortunately, what constitutes a “good” choice is not always obvious. Here I offer some personal advice to help young scientists make these tough decisions wisely.

The exact project pursued for a Ph.D. degree is not nearly as important as finding the best place for learning how to push forward the frontier of knowledge as an independent investigator. My first piece of advice for graduate students is to begin research training in a laboratory led by a person with high scientific and ethical standards. It is by talking to people in that lab or those who have previously trained there, and by consulting other scientists in the same field, that one can gain this important insight.

It is also important to find an adviser who will pay close attention to your development as a scientist. Brilliant scientists sometimes make poor mentors. Often, an established leader who has no more than about a dozen people to manage can best nurture a creative, exciting, and supportive place to work. But carrying out research with an outstanding new professor with a very small group can frequently provide even better training.

Students enter graduate school both to learn how to do science well and to discover where their talents and interests lie. Success at either task requires that they be empowered to create new approaches and to generate new ideas. In my experience, beginning scientists will only gain the confidence needed to confront the unknown successfully by making discoveries through experiments of their own design. The best research advisers will therefore provide their graduate students with enough guidance to prevent them from wasting time on nonproductive pursuits, while giving them the freedom to innovate and to learn from their own mistakes.

In my field of biology, two apprenticeships are standard for beginning scientists: first while earning a Ph.D. degree and then in a second laboratory in a postdoctoral position. The choice of a postdoctoral laboratory is best made with a long-term career plan in mind. Scientists at this stage should intentionally try to choose a laboratory where they can acquire skills that complement those they already have. For example, a student whose Ph.D. thesis gave her strong skills as a yeast geneticist might choose to do postdoctoral research with an expert protein biochemist, planning to later use a combination of powerful genetic and biochemical tools to attack a biological problem in an area where very few scientists have the same abilities.

But success as an independent scientist will require much more than technical skills. It is critical to be able to design research strategies that are ambitious enough to be important and exciting, innovative enough to make unique contributions likely, and nevertheless have a good chance of producing valuable results. An enormous number of different experiments are possible, but only a tiny proportion will be really worthwhile. Choosing well requires great thought and creativity, and it involves taking risks.

Senior scientists have the responsibility of maintaining a system that provides talented young scientists with the opportunity to succeed in whatever career they choose. My next editorial addresses the importance of ensuring that innovation and risk-taking are rewarded for those pursuing a life of independent research. Also, a new series in Science Careers highlights conversations with audacious scientists who give their own advice about selecting institutions, mentors, and projects.†

† http://dx.doi.org/10.1126/science.caredit.a0900139.

— Bruce Alberts

10.1126/science.1184202
Promoting Scientific Standards

THe scientific enterprise is built on a foundation of trust. As Kenneth Shine and I emphasized 15 years ago in this journal, if science is to flourish and attain its appropriate role in aiding human progress, “It is incumbent upon all of us in the scientific community to help provide a research environment that, through its adherence to high ethical standards and creative productivity, will attract and retain individuals of outstanding intellect and character to one of society’s most important professions.”

Journals such as Science occupy a special place in the maintenance of scientific standards. As an influential gatekeeper to the peer-reviewed literature across the natural and social sciences, what Science decides to publish helps to define scientific excellence for scientists. And with remarkable frequency, the broader media uses our selections to decide which scientific advances to convey to the public, adding to our profound sense of responsibility. For these reasons, the chief editors of the journals Science, Nature, and the Proceedings of the National Academy of Sciences have been working together to consider how to improve our procedures, so as to help make science as productive as possible in serving both scientists and the greater society. As a start, we have focused on two critical authorship issues.

First, to discourage “honorary authorships,” we agreed that before acceptance, each author will be required to identify his or her contribution to the research (see www.sciencemag.org/about/authors). Science’s policy is specifically designed to support the authorship requirements presented in On Being a Scientist: Third Edition, published by the U.S. National Academy of Sciences.† That report emphasizes the importance of an intellectual contribution for authorship and states that “Just providing the laboratory space for a project or furnishing a sample used in the research is not sufficient to be included as an author.”

Second, Science will require that the senior author for each laboratory or group confirm that he or she has personally reviewed the original data generated by that unit, ascertaining that the data selected for publication in specific figures and tables have been appropriately presented. Thus, for example, a researcher who prepares a digitally processed figure displaying an assortment of electrophoretic gel separations will need to present all of the original gel data to a specified senior author, who must certify that this has been done when the manuscript is returned for revision.

In this way, Science aims to identify a few senior authors who collectively take responsibility for all of the data presented in each published paper. Traditionally, a single individual has been asked to accept this responsibility. But the former requirement has become increasingly unrealistic, considering that a large fraction of publications now contain contributions from groups with very different expertise—and that half of the papers published in 2009 by Science had authors from more than one nation.

One issue not yet resolved is what scientific journals might do to encourage good mentoring practices by experienced scientists. Many universities now require that their young faculty members choose one or more mentors among the senior faculty. These mentors then use the wisdom and connections developed from their decades of experience to help the younger scientist in whatever ways are requested, including decisions that involve ethical standards. Being a good mentor resembles being a good parent: It involves a great deal of listening and help with problem solving and requires mutual respect and trust. Should the acknowledgments section of a publication specifically list any mentoring that made a major contribution to the research? Could a special “mentor search” function on PubMed (and on other literature compilation Web sites) then help to reward mentors?

Effective mentoring is critical to the future success of science, and as scientists remain active to more advanced ages, it provides a meaningful way to end a career. Scientists everywhere can and should do more to promote it.

—Bruce Alberts

†www.nap.edu/catalog/12192.html.

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Bruce Alberts is Editor-in-Chief of Science.

Science Education Web Sites

IN THIS ISSUE, WE ANNOUNCE THE FIRST OF 12 WINNERS OF A COMPETITION FOR WEB SITES THAT best promote science education. Each month this year, Science will publish an essay by the creators of a winning Web site that describes their online resource. This month’s featured site focuses on teaching and learning genetics, and it originates from the University of Utah (see p. 538). The Science Prize for Online Resources in Education (SPORE) recognizes outstanding freely available online materials that enrich science education. There were nearly 100 entries for 2009 from many nations. They spanned diverse subjects, ranging from astronomy, chemistry, and physics to geology and biology. Most sites targeted students, ranging from elementary through graduate school, whereas others focused on the general public. Many included videos, animations, real-world data sets, or teaching materials.

A panel of 16 scientists and nine teachers performed the challenging task of selecting the winners from the excellent entries. In the end, two that were judged to be of the very highest quality were nevertheless not chosen. The Physics Education Technology (PhET) Web site, created at the University of Colorado, Boulder, was considered ineligible because Science had recently published an Education Forum that describes how to use PhET’s physics simulations.* In fact, this article provided the inspiration for the SPORE contest. An entry from the Howard Hughes Medical Institute (HHMI) was also not selected; although it produces an outstanding education Web site (www.hhmi.org/biointeractive), HHMI is Science’s partner in producing the Education Forum, and we felt uncomfortable awarding them one of only 12 slots.

Why did Science create such a competition? There are many prizes for those who produce excellent scientific research, but only a few awards for educators. Yet being an outstanding science educator is as demanding and valuable to society as being an exceptional research scientist. And, as it does for research, highlighting education excellence sets a standard for others to aim at, while simultaneously emphasizing the enormous value of the endeavor. There is another important reason for the recognition that this competition brings. The World Wide Web is a fantastic information resource, but it can be overwhelming. Many had hoped, for example, that the U.S. National Science Digital Library Project might go a long way toward solving this problem.** But the collection of science education Web sites that resulted, although a valuable resource, contains so many entries that additional guidance seems warranted. With a limit of 12 Web sites a year, Science aims to make it easier to find valuable materials, both for one’s intellectual growth and for teaching.

This last point raises a broader issue. When I began my academic career as an assistant professor at Princeton University in 1966, I sought to learn everything about what others had discovered previously, before beginning my research on chromosome replication. Yet when I taught, I rarely sought to build on what other teachers had developed before me. This difference between how scientists approach their research and their teaching goes a long way, I believe, to explain why the quality of university science education lags so far behind the quality of science itself.

Through the Web, a rapidly expanding OpenCourseWare Consortium, with more than 150 universities from 36 nations, makes different approaches to teaching readily observable globally. Based on this wide visibility, many more contests can be developed to reward innovation in science education. Scientific societies might, for example, annually recognize the best 1-month teaching modules for an introductory science course in college, or provide an award for the best set of laboratory modules for a science class that are inquiry-based and require only modest resources (thereby being readily exportable). The nomination process for Science’s 2010 SPORE contest has just begun (www.aaas.org/go/spore). According to Wikipedia, a “spore is a reproductive structure that is adapted for dispersal and surviving for extended periods of time in unfavorable conditions.” Analogously, we hope that SPORE seeds the proliferation of many other education awards, adapted for dispersal and survival in the world of education.

– Bruce Alberts

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Prioritizing Science Education

IN THIS SPECIAL ISSUE ON EDUCATION, SCIENCE FOCUSES ON THE CONNECTION BETWEEN LEARNING science in school and the acquisition of language and communication skills, emphasizing the benefits of teaching science and literacy in the same classrooms whenever possible. In the United States, this would be viewed as a radical proposal. Unfortunately, the great majority of Americans are accustomed to science classrooms where students memorize facts about the natural world and, if they are lucky, perform an experiment or two; in language arts classes, students generally read fictional literature and write about it in fossilized formats such as “compare and contrast.”

The exciting news, affirmed in many articles in this issue, is that “science learning entails and benefits from embedded literacy activities [and]…literacy learning entails and benefits from being embedded within science inquiry.”* Here, it is helpful to distinguish between factual (or informational) and fictional (or narrative) text. Science reading and writing is largely of the former type, and it is this factual, informational text that dominates today’s knowledge-everywhere world. Yet, most of the formal teaching in language arts classrooms deals with fictional text. My own failed efforts at storytelling lacked the imagination to do anything more than rewrite Hansel and Gretel in a thinly disguised new context. Without doubt, learning to write and read clear and concise informational text, as in summaries of investigations in science class, is an essential preparation for nearly all of life out of school.

By reconceptualizing science education through closely connecting literacy lessons with active inquiry learning in science class, one can make a strong argument for greatly expanding the time spent on science in primary school, to at least 4 hours a week. This alone would carry tremendous benefit in places where, like the United States, science for young students has often become marginalized to less than an hour a week.

A second advantage to forging this connection between literacy and science teaching is that a well-taught science class gives everyone a chance to excel in something. It is hard to stay motivated and interested in schooling if one is always in the bottom half of the class. By linking literacy and science education, those who are more challenged with making progress in reading can gain the self-confidence needed to succeed by demonstrating skills in analyzing a problem that stumps the better readers. Or they might excel in the mechanical manipulation of objects required in a science lesson. From this perspective, the penalties for “failing” schools in my home state of California are tragically wrong: Students who struggle with reading or math are given double periods of reading or math drill, and the very set of activities that could excite them about school is eliminated.

I am reminded of the schooling of P. Roy Vagelos, an outstanding scientific leader in U.S. academia and industry. A fellow biochemist and a friend, Roy topped off his career by becoming the chief executive officer of the major pharmaceutical company Merck, with Fortune magazine anointing his company as the “most admired in America” for seven successive years (1987 to 1993). In his biography, he describes himself as a poor memorizer, who nearly failed first and second grade and was largely alienated from school until he was given the chance to demonstrate other skills that allowed him to excel.†

How many talented young people are we losing in today’s schools, driven by test scores that reward teachers for drilling students to remember obscure science words, and by an early reading curriculum based on stories and folk tales? Instead, we should be rewarding them for teaching science inquiry skills and literacy together, through collaborative and critical discourse.‡

—Bruce Alberts

Reframing Science Standards

A PROMISING DRAFT FRAMEWORK FOR SCIENCE EDUCATION WAS RECENTLY POSTED BY THE U.S. National Academies for public comment (until 2 August) and review (see www7.national-academies.org/bose). Its goal is to define the science that all students should be taught from age 5 through precollege in the United States, building on lessons learned from the 1996 National Science Education Standards (NSES). Will this new effort, initiated to help produce a common core for science education across states,* be more successful than the last one?

In 1989, the governors of all 50 states issued a call for “voluntary national standards” in each of the major academic disciplines. In response, the NSES were issued by the National Academy of Sciences in 1996. The results have been disappointing. In particular, the requirement for students to master a large number of facts and concepts took precedence over the strong emphasis on “science as inquiry” in the NSES. The new Framework attempts to overcome this problem in several interesting ways.

First, the draft Framework focuses on only four core concepts in each of four disciplines: life sciences, physical sciences, earth and space sciences, and engineering and technology. And differing from the NSES, each core concept extends over all years of schooling. The intention is to leave room during the school day for three important strands of science learning that have been systematically ignored in favor of the traditional content strand, which focuses on knowing, using, and interpreting scientific explanations of the natural world. The critical strands that have been missing are generating and evaluating scientific evidence and explanations, understanding the nature and development of scientific knowledge, and participating in scientific practices and discourse.†

Second, the Framework supplements the dominant theme of inquiry in the NSES with a greatly expanded discussion of why any definition of science education must center around active participation in scientific practices and extensive experience with evaluating evidence. The current focus on transmitting only the knowledge that scientists have discovered fails to provide students with the thinking and problem-solving skills that are essential for life in our complex societies, and it also fails to give them a sound understanding of why science has been so successful as a special way of knowing about the world. Thus, the draft Framework contains a powerful chapter containing 16 useful tables entitled Scientific and Engineering Practices. (The inclusion of engineering itself represents a major, positive break with tradition.)

The Framework also stresses the importance of building coherence into the science curriculum from year to year through reference to the ongoing research on “learning progressions.” As an example, the recognition that any object is composed of specific materials, and has certain properties because of those materials, is known to be an important first step toward understanding atomic-molecular theory. To guide curriculum design, the last half of the draft document presents prototype learning progressions for each of the core concepts to be learned, expanding on the landmark Atlas for Science Literacy produced by the American Association for the Advancement of Science.

The Framework will be finalized in response to the feedback received on the public draft, and then, because responsibility for education is assigned to each state by the U.S. Constitution, the final standards will be developed through a coalition of states led by the nonprofit organization Achieve. The worst thing that scientists could do would be to insist that the core disciplinary ideas be expanded to include their specialities. Instead, the scientific community should focus on preparing college students to “ask questions; collect, analyze, and interpret data; construct and critique arguments; communicate and interpret scientific and technical texts; and apply and use scientific knowledge”—precisely as the Framework specifies for the precollege years.

—Bruce Alberts

10.1126/science.1195444

An Education That Inspires

WHY IS IT THAT CHILDREN, WHO ENTER SCHOOL AT AGE 5 FILLED WITH EXCITEMENT AND WONDER about the world, often become bored with education before their teenage years? How might the United States produce a more engaging education system, one that allows a child with a specific fascination to explore that interest in depth as an integral part of his or her early education? Here I sketch a possible plan based on science, technology, engineering, and math (STEM) awards that would be largely earned through student activities outside of school.

The idea has been partly inspired by the U.S. Advanced Placement (AP) system of courses and exams, which makes a first-year college-level education in selected subjects available to high school students. As a nationally recognized standard of achievement, passing an AP course is a mark of success for both students and schools. High schools now strive to increase the number of students taking such courses, and this nongovernmental but nationally certified program has been rapidly growing in popularity. Could a nationally validated set of “STEM challenge awards,” designed for students at earlier stages of schooling, similarly motivate schools and school systems to value a new type of achievement?

I suggest that the proposed STEM challenge awards be modeled on the achievement badges that youth organizations around the world have developed to promote the active learning of specific subjects in depth. For example, the Boy Scouts of America allows more than 100 different merit badges to be earned, each focused on a specific topic such as Plant Science or Lifesaving.* In addition to this large selection, each badge provides a young person with a variety of options. Thus, to earn a Plant Science merit badge, a scout can choose between agronomy, horticulture, or field botany. Most learning experiences are active ones, such as “Select a study site that is at least 100 by 100 feet. Make a list of the plants in the study site by groups of plants: canopy trees, small trees, shrubs, herbaceous wildflowers and grasses, vines, ferns, mosses, algae, fungi, lichens. Find out which of these are native plants and which are exotic (or non-native).” This is infinitely more interesting than a typical school experience in which students memorize the names of plants and their parts from pictures in a textbook, often without encountering the actual object.

A STEM challenge award program might provide 100 different challenges to choose from at each level of schooling (for example, sets of awards of increasing difficulty for ages 5 to 8, 9 to 13, and 14 to 18), on subjects ranging from reptiles to Web design. Scientific and engineering societies in each discipline could create the requirements for many awards, as could industry groups or government agencies such as the U.S. National Aeronautics and Space Agency. But a single umbrella organization would be needed to certify the contents of the award projects, as well as the mechanisms used to judge and record their completion. Such national certification would be critical for the awards to have a substantial positive impact, serving as a widely recognized, valid mark of success for both students and school districts.

The most ambitious and revolutionary part of this plan supplements the teachers in schools with adult volunteers, each serving as an expert for a particular STEM challenge award. To earn a merit badge, a scout must demonstrate to a qualified adult volunteer (a “counselor” for that badge) that he has satisfied that badge’s requirements. In a similar way, many thousands of adults with science and technology backgrounds would be enlisted as counselors, both to help teachers and to judge each student’s performance, making full use of modern communications tools. A great many scientists and engineers would be willing to contribute to improving science in schools if an efficient and effective way for them to do so could be generated. And their contributions could truly inspire today’s students.

– Bruce Alberts

10.1126/science.1199138

Policy-Making Needs Science

OVER THE LONG RUN, ANY NATION THAT MAKES CRUCIAL DECISIONS WHILE IGNORING SCIENCE is doomed. Consider, for example, the decision about how much arsenic should be allowed in drinking water supplies. There is no one “right answer” to this or many other policy questions, but it is critical that national legislation be based on what science knows about potential harm. It is therefore disturbing that so many lawmakers elected to the new U.S. Congress reject the overwhelming scientific consensus with respect to human-induced climate change. It will be difficult to make wise choices with such attitudes. The question now facing the United States is not only how to effectively reintroduce the facts of climate science back into the core of this particular debate, but also how to ensure that good science underlies all legislative decisions.

For 12 years, I served as the president of the U.S. National Academy of Sciences. As part of a larger nongovernmental organization known as the National Academies, it produces more than 200 reports a year, aimed at making the current scientific consensus on important issues available to policy-makers and the public. In major reports released this spring, the National Academies strongly reiterated its position that climate change, caused largely by human activities, poses significant risks to the world’s future.* This conclusion is nevertheless challenged by numerous politicians, as well as by a substantial fraction of the public. There is only one effective solution for this type of problem: Scientists must make both science education and community outreach a much more central part of the scientific culture.

Most Americans have never met a scientist, and despite having been “taught science” at school, most have no real idea of how a scientific consensus is reached through continuous open debate and experiment. Every adult should have a base of scientific understanding about how the world works. But understanding the process through which scientific knowledge develops is equally critical. By the end of any introductory college science class—which can be an adult’s final exposure to science—a student should have a realistic understanding of the nature of science. Scientists are taught to challenge authority, and their responsible challenges to a consensus help science advance. Thus, adults should expect to find some scientists who disagree with the scientific consensus on an issue. And they should appreciate why a strong scientific consensus, such as that about climate change, must nevertheless form the basis for making wise personal and community decisions, representing by far the best bet for predicting the future consequences of present actions.

In addition to education, an energetic community outreach to schools, the public, and decision-makers is key. Both established scientists and those in training can be highly effective in putting a human face on science and conveying optimistic, honest attitudes toward grappling with society’s problems. Week-long science festivals, to which local institutions based on science and engineering contribute ideas and personnel, should become an annual event at hundreds of sites around the nation. And programs that encourage and facilitate outreach into nonscientific communities need to become a standard part of every university and science-based industrial establishment.

The environment in which decisions are made in a democracy will always be highly politicized, but it is crucial that both sides of any argument pay close attention both to what science knows and how that knowledge has been gained. Attaining this goal in every nation will require that scientists vigorously reach out to their communities, informing them not only about their new discoveries, but also about the path they took to get there.†

— Bruce Alberts

10.1126/science.1200613


Bruce Alberts is Editor-in-Chief of Science.
A New College Science Prize

TO START THE NEW YEAR, SCIENCE IS PLEASED TO ANNOUNCE THE “SCIENCE PRIZE FOR Inquiry-Based Instruction” to highlight outstanding “modules” for teaching introductory college science courses that can readily spread to other settings and schools. Therefore, a unit can neither be unusually expensive nor require highly specialized expertise. To be eligible, a module must provide a coherent piece of coursework in a field such as biology, chemistry, physics, or earth sciences and require 8 to 50 hours of student effort. It should also be free-standing: that is, suitable for teaching as a discrete unit, independent of other modules in the course. How do inquiry-based science modules differ from other science lessons, and why does Science care enough about them to create a special prize?

Inquiry-based classes focus on activating students’ natural curiosity in exploring how the world works, differing from traditional lectures that focus on transmitting facts and principles derived from what scientists have discovered. Inquiry-based teaching is often associated with hands-on activities. But not all hands-on activities involve inquiry. Consider the laboratory work that traditionally accompanies an introductory college science course. As a science major, I spent three afternoons a week in such laboratories throughout my first 2 college years. Most of us who later became scientists recall these laboratories as tedious “cooking classes,” where we learned to follow directions. True, we encountered various pieces of scientific apparatus, such as measuring devices for weights and liquids, and we learned how to keep a laboratory notebook. But we gained neither any real understanding of the nature of science nor experience in generating and evaluating scientific evidence and explanations—two central elements of a modern definition of “science education.”* Many college laboratory exercises remain deficient in precisely these ways today.

Science is looking for lessons in which students become invested in exploring questions through activities that are at least partially of their own design. Instead of a typical laboratory exercise that begins with an explanation and results in one correct answer, an inquiry-based lesson might begin with a scenario or question and then require students to propose possible solutions and design some of their own experiments.

In addition to honoring the 12 winning modules, we will attempt to disseminate them as widely as possible. To this end, each winner will write a brief essay describing the module, to be published in Science, with complete details in the supporting online material that accompanies the printed article. Direct applications from the course organizers are welcome, as are nominations from former students and colleagues. Different submission forms have been provided for these two groups, posted at http://scim.ag/inquiryprize, along with instructions describing the information required by our judges. The deadline for receiving the short nomination form is 28 February 2011; the longer application form is due from the course organizers on 15 April.

The 1990s science education standards movement in the United States revealed that teachers at the precollege level cannot be expected to teach “science as inquiry” unless they themselves have previously participated in such inquiry as students. Incorporating inquiry into college science teaching will thus be critical for the future teachers of science in all nations. But it will also be crucial for many other adults, because successful modern societies need large numbers of citizens who are skilled, rational problem-solvers—both in the workplace and in their daily lives. Every society also requires citizens who understand the nature of science and value “science as a way of knowing” about important issues. In fact, our new award has been stimulated by the fact that the world badly needs a revolution in science education—a revolution that must begin at the college level.

— Bruce Alberts

Getting Education Right

SCIENCE HAS PUBLISHED THREE EDUCATION SPECIAL ISSUES SINCE I BECAME EDITOR-IN-CHIEF in 2008. We first focused on harnessing computer technologies for education (January 2009) and then highlighted the synergies between inquiry science teaching and the acquisition of literacy skills (April 2010). In this issue, we review the research on early childhood education. Especially informative are the long-term studies on the effects of early childhood interventions, which indicate that an appropriate schooling of children as young as 3 years old produces remarkably large benefits for society, even in cases where the children do not perform significantly better academically. A critical variable appears to be the effect of these early education programs on what neuroscientists call “executive function”: the brain activities that underlie each individual’s mastery of self-control.* This finding raises critical questions about how nations educate their youth. For example, how can the programs that have thus far been used to enhance children’s self-control be further improved?

To what ages should these programs extend in school, and how can the most effective practices be scaled up to apply them universally? And why has so little of what we have learned from research about schooling been incorporated into the way that most school systems function?†

In recent years, Science has been devoting increased attention to matters of education, both to highlight such fundamentally important questions and to encourage the work needed for solutions. There is nothing more important for the future of the world than how we prepare the next generation, and there is a clear need for a much larger investment by governments in science-based education research, both in laboratory and school-system settings. In addition, the science and scholarship of education are vastly underappreciated at the university level, where a vigorous collaboration between schools of education and other faculty will be required to address these issues. And most of all, we need to attract many more talented young people—like those who read Science—to meet education’s many challenges.

In his famous 1959 Rede Lecture on The Two Cultures, British scientist and novelist C. P. Snow criticized his own early dismissal of applied science, writing, “Pure scientists have by and large been dim-witted about engineers and applied science. They couldn’t get interested. They wouldn’t recognise that many of the problems were as intellectually exacting as pure problems, and that many of the solutions were as satisfying and beautiful.” Snow’s view that the division between “pure” science and other fields is an obstacle to solving modern society’s problems is reflected in J. P. Shonkoff’s Education Forum (p. 982), which describes a need to combine the best scholarship from many different disciplines to address education challenges. This synergy will not happen unless the world’s most prestigious institutions—universities, government agencies, academies, scientific societies, and journals—give this type of research the support, respect, and attention that it clearly deserves.

My own views on this matter have been deeply influenced by the scientist and great biology educator John A. Moore, who became a friend long after I first met him through his biology textbooks. After his death in 2002, I was privileged to have the responsibility for writing his memoir for the U.S. National Academy of Sciences,‡ thereby discovering his 30-year-old exhortation urging “the scholars in the universities to see beyond their specialities and their laboratories to the problems of general education and to be willing to join with colleagues in the schools of education to work towards excellence in the substance of education; in short, to seek to make education as respectable a commitment as scholarly research and publishing.” Well said.

— Bruce Alberts

10.1126/science.1212394

Science Adapters Wanted

THE BIOLOGICAL SCIENCES ARE FLOURISHING, WITH AN ABUNDANCE OF FRESH, EXCITING DISCOVERIES that continue to spur the development of powerful new techniques and expand creative scientific investigation. And the core challenge of deeply understanding cells, tissues, and whole organisms promises endless possibilities for controlling human disease and rescuing the environment. But in this very exciting time to be a biological scientist, there is an ominous sense of a major crisis brewing. Budget realities have begun to constrain scientific progress across the board, with an especially heavy impact on the careers of young scientists. Beyond advocating for larger budgets for scientific research as a critical investment in each nation’s future, how should the scientific community respond?

My answer—to vigorously support expanding the career opportunities for young scientists—is based on two observations. The first is that a surprisingly large portion of today’s science graduate students are interested in nontraditional careers. I interact with many of these exceptionally bright and energetic young people at my home institution, the University of California, San Francisco (UCSF), and I am excited about the range of contributions that they could make to society. A recently published anonymous survey of nearly 500 UCSF doctoral students in basic biomedical sciences reveals that, by the time they enter their third year in graduate school, one-third are intending to pursue a career that does not involve laboratory research.*

My second observation stems from the enormous success of the AAAS Science and Technology Fellowship program, which brings nearly 200 highly selected scientists and engineers to Washington, DC, each year to work in government.† Many of these individuals accept permanent jobs in science public policy once their fellowship ends, and in these positions they efficiently serve as “adapters” to connect their government offices to scientists and to scientific advice. Many different parts of society urgently need such scientifically trained people to connect them to the rich resources of the scientific community.

Many possible career pathways deserve special attention, but one seems especially urgent. As science and its values become ever more central to the future of nations and the world, it becomes increasingly critical that scientists become deeply engaged in supporting the teachers and school systems that educate children. How can we best connect the invaluable resources of the many vibrant communities of science and engineering professionals to the large community of professional educators directly responsible for educating a nation’s youth? My conclusion, after decades of experience in the United States, is that a new type of individual is needed inside each precollege (K-12) education system to act as the liaison between two professional worlds with very distinct cultures: that of science and that of precollege educators. Thus, I would like to challenge a group of the relevant experts—teachers, principals, superintendents, education researchers, scientists, policy-makers, and experienced science curriculum specialists from school systems—to create a 15-month program aimed at preparing and certifying outstanding Ph.D. scientists as “science curriculum specialists” whom U.S. school districts would want to hire. These individuals would need to be competitively selected, provided with prestigious fellowships to cover their living expenses, and networked to each other and to the scientific and engineering communities. The goal is to produce large numbers of school system administrators with “science in their souls,” passionate people skilled at working inside the system to connect it to the very best resources available for helping science teachers to inspire their students.

The timing is perfect to spread science and its values by “spreading” young scientists and engineers into new types of careers. These young people are demonstrating a strong interest in living lives of science beyond the bench. The critical task at hand is to generate many more pathways to ease their way.

– Bruce Alberts

10.1126/science.1216650

Trivializing Science Education

I was prompted to write this editorial after playing an electronic version of the old board game Trivial Pursuit with my grandchildren over the holiday break. For decades, my favorite category of questions to answer had been “Science and Nature.” But in this 2009 edition, I could answer almost none of those questions—because “science” had apparently been redefined as knowing what disease killed character X in movie Y. Trivial Pursuit is of course merely a game; but it reminded me of the much more serious battle over the California State Science Education Standards that I and many others lost in 1998. As a result, for my grandchildren, “science” includes being able to regurgitate the names of parts of the cell in 7th grade, after memorizing terms such as Golgi apparatus and endoplasmic reticulum. Those of us who are passionate about science have thus far failed to get real science taught in most of our schools. Is it time to regroup with a different strategy?

Few people are aware of what has been learned from research about the teaching of complex scientific concepts to young people, and there is a strong tendency to assume that the best science curricula are the most “rigorous.” Although rigor might appear to be a worthy goal, the unfortunate result of this persistent view is that difficult concepts are taught too early in the science curriculum, and they are taught with an overly strict attention to rules, procedure, and rote memorization. Below is an excerpt from my testimony to the California Standards Commission in 1998, when unsuccessfully opposing such ideas as teaching the periodic table of the elements in 5th grade:

“When we teach children about aspects of science that the vast majority of them cannot yet grasp, then we have wasted valuable educational resources and produced nothing of lasting value. Perhaps less obvious, but to me at least as important, is the fact that we take all the enjoyment out of science when we do so. Consider my field, for example. I have spent 30 years of my life working out the mechanisms that allow the DNA in our chromosomes to replicate. The entire DNA story is a beautiful one that should produce aesthetic enjoyment in the student when first learned. I was fortunate enough to have finished my precollege biology education before Watson and Crick unraveled this mystery with their discovery of the DNA double helix in 1953. I can therefore still remember the joy that I felt when I first learned about DNA. Unfortunately, most students today are taught about DNA at such an early age that they are forced to merely memorize the fact that ‘DNA is the material from which genes are made,’ a chore that brings no enjoyment or understanding whatsoever. Much later, when they do have the background to understand both the structure of the DNA molecule and its explanatory power, I fear that the joy of discovery has been eliminated by their earlier memorization of boring DNA facts. We have spoiled a beautiful story for them, by teaching it at the wrong time.”

The preference for “rigor” in science education can also interfere with the teaching of science at the college level. For example, in an introductory biology class, students are often required to learn the names of the 10 enzymes that oxidize sugars in a process called glycolysis. But an obsession with such details can obscure any real understanding of the central issue, leaving students with the impression that science is impossibly dull, causing many to shift to a different major.

Tragically, we have managed to simultaneously trivialize and complicate science education. As a result, for far too many, science seems a game of recalling boring, incomprehensible facts—so much so that it may make little difference whether the factoids about science come from the periodic table or from a movie script. For my thoughts on how we can do better, stay tuned for next week’s Editorial.

Bruce Alberts is Editor-in-Chief of Science.

10.1126/science.1218912

Bruce Alberts

www.sciencemag.org
Teaching Real Science

IN THIS ISSUE OF SCIENCE, WE ARE PUBLISHING THE FIRST OF 15 WINNING ENTRIES FOR the 2011 Science Prize for Inquiry-Based Instruction (p. 418), a laboratory module entitled Light, Sight, and Rainbows. Created for introductory college science courses, each module can be readily used in many different settings and schools. The winning modules were selected by a jury of more than 70 scientists and science teachers, and the subjects include physics, math, chemistry, geology, molecular biology, plant science, and evolution. Throughout 2012, each will be published as a two-page printed synopsis supplemented by online material that contains the details needed to teach it.

Our goal is to make it much easier for teachers everywhere to provide their students with laboratory experiences that mirror the open-ended explorations of scientists, instead of the traditional “cookbook” labs where students follow instructions to a predetermined result. To this end, we are announcing a second year of the contest, now broadened to include engineering in addition to science, as well as courses at the advanced high-school level (see www.scim.ag/inquiryprize). We hope that these contests will help support a rethinking of science education that is consistent with the new Framework for K-12 Science Education (precollege) from the U.S. National Academies, as well as with one of the central goals in the international Programme for International Student Assessment (PISA) Science Competencies: “Understands the characteristic features of science as a form of human knowledge and enquiry.”*

Although our 2011 contest focused on college science teaching, the same goals can be applied even to early years of schooling. Consider, for example, an article published by the U.S. National Science Teachers Association, Growing Seeds and Scientists, which describes a science lesson for kindergarten students (age 5).† The students are presented with seeds of very different sizes and shapes—an avocado seed, a corn kernel, a marigold seed, and so on—mixed with objects such as pebbles and shells. For three times a week over the course of 6 weeks, the students explore the question, “How do we know if something is a seed?”, forming a “scientists’ conference” to share ideas respectfully and learn from each other as real scientists might in a laboratory. Thus, after the students discover that they disagree about what makes an object a seed, the class is asked to come up with ways in which they might test their ideas, again modeling the behavior of scientists. Through experiments that they suggest and perform on their own, the class discovers which objects are seeds. Finally, the students dissect some of the seeds and examine them with a magnifying glass, finding the tiny embryo inside and its source of food. Compare this exercise with a more traditional approach, which would at best give the students a seed and step-by-step instructions on how to grow it, bypassing the scientific process of facing a question, proposing solutions, and testing one’s theories.

Last week, I described how current school science often resembles a game in which the participants are challenged to recall boring, incomprehensible facts.‡ How might the world recover from this destructive form of science education? We should begin by teaching science to young children with a curriculum like that described in Growing Seeds and Scientists, which might require a total of only 20 hours of the school year. And we should aim for an education system in which every child is exposed to at least this many hours of high-quality science inquiry in each year of elementary and middle school, supported by carefully prepared science specialists. In this way, “science education” would be redefined, with a laser-sharp focus on gaining the scientific habits of mind that will be needed by everyone to successfully negotiate his or her way through our increasingly complex, crowded, and confusing societies.

– Bruce Alberts

10.1126/science.1219216

Planning Career Paths for Ph.D.s

THERE WAS A TIME NOT SO LONG AGO WHEN NEW SCIENCE PH.D.S IN THE UNITED STATES WERE expected to pursue a career path in academia. But today, most graduates end up working outside academia, not only in industry but also in careers such as science policy, communications, knowledge brokering, and patent law.* Partly this is a result of how bleak the academic job market is, but there is also a rising awareness of career options that Ph.D. scientists haven’t trained for directly—but for which they have useful knowledge, skills, and experience. Still, “there is a huge disconnect between how we currently train scientists and the actual employment opportunities available for them,”† and an urgent need for dramatic improvements in training programs to help close the gap. One critical step that could help to drive change would be to require Ph.D. students and postdoctoral scientists to follow an individual development plan (IDP).

In 2002, the U.S. Federation of American Societies for Experimental Biology (FASEB) recommended that every postdoctoral researcher put together an IDP in consultation with an adviser. Since then, several academic institutions have begun to require IDPs for postdocs. And in June, the U.S. National Institutes of Health (NIH) Biomedical Research Workforce Working Group recommended that the NIH require IDPs for the approximately 32,000 postdoctoral researchers they support. Other funding agencies, public and private, are moving in a similar direction.

IDPs have long been used by government agencies and the private sector to achieve specific goals for the employee and the organization. The aim is to ensure that employees have an explicit tool to help them understand their own abilities and aspirations, determine career possibilities, and set (usually short-term) goals. In science, graduate students and new Ph.D. scientists can use an IDP to identify and navigate an effective career path.

A free Web application for this purpose, called myIDP, has become available this week.‡ It is designed to guide early-career scientists through a confidential, rigorous process of introspection to create a customized career plan. Guided by expert knowledge from a panel of science-focused career advisers, each trainee’s self-assessment is used to rank a set of career trajectories. After the user has identified a long-term career goal, myIDP walks her or him through the process of setting short-term goals directed toward accumulating new skills and experiences important for that career choice. After each step, the user updates the plan, documenting efforts and progress. The user can opt to receive monthly e-mail reminders from myIDP to stay focused on goals and update progress and plans. Very importantly, the plan can be altered as skills develop, interests change, and career objectives are reconsidered.

Although surveys reveal the IDP process to be useful, trainees report a need for additional resources to help them identify a long-term career path and complete an IDP. Thus, myIDP will be most effective when it is embedded in larger career-development efforts. For example, universities could incorporate IDPs into their graduate curricula to help students discuss, plan, prepare for, and achieve their long-term career goals. The participation of faculty mentors is essential because trainees need a safe, supportive atmosphere in which to openly discuss their career plans and interests.

By turning introspection into a structured exercise, the use of IDPs allows trainees to translate a vague source of anxiety into a working plan, applying their well-developed analytical skills to the critical problem of building their own lives and careers.

– Jim Austin and Bruce Alberts

10.1126/science.1226552

Failure of Skin-Deep Learning

THERE IS A DISCONNECT AT THE HEART OF THE U.S. EDUCATION SYSTEM THAT IS HAVING A DEVASTATING effect on how and what children learn. Research shows that the most meaningful learning takes place when students are challenged to address an issue in depth, which can only be done for a relatively small number of topics in any school year.* But the traditional process of setting standards tends to promote a superficial “comprehensive coverage” of a field, whether it be biology or history, leaving little room for in-depth learning. The curricula and textbooks that result are skin-deep and severely flawed.

The factoid-filled textbooks that most young U.S. students are assigned for biology class make science seem like gibberish—an unending list of dry, meaningless names and relationships to be memorized. Take, for example, my 12-year-old grandson’s life science textbook. Approved by the State of California, it is filled with elaborate drawings and covers an astonishingly broad range of biology. But the text is largely incomprehensible for its student audience, reminding me of a commercial exam-cramming guide that proudly states: “We’ll show you that you don’t really have to understand anything. You just have to make a couple of simple associations, like these. Aerobic respiration with: presence of oxygen, more ATP produced . . . Anaerobic respiration with: absence of oxygen, less ATP produced.” When my grandson and his classmates successfully complete that book and the class based on it, it is clear that they will know nothing of the kind of biology that inspires passion in the souls of the scientists working in the labs around me at the University of California, San Francisco. How might we instead give schoolchildren the gift of experiencing the profound joys of science, or history, or literature?

My answer is based on a remarkable year-long history course I took as an undergraduate at Harvard—Social Sciences 2, Western Thought and Institutions—that demonstrated the critical importance of in-depth learning for students. The course, taught for three decades by the legendary Professor Samuel Beer, focused intensively on six brief periods of time from the Magna Carta to the rise of Communism. In attempting to analyze each period of 50 or so years in depth, we read original documents as well as essays by famous historians, and through term papers and exams we explored the forces that have shaped human history. Although I had taken history courses in high school, memorizing enough facts and dates to be awarded an A grade, I had learned nothing essential about history. It was only in Professor Beer’s class that history came alive for me as a critical tool for understanding human societies.

I believe that the above course has important lessons for all educators. At all levels of schooling, we need to replace the current “comprehensive” overviews of subjects with a series of in-depth explorations. To do so, we will need to abandon the one-size-fits-all textbooks used in schools in favor of a large set of much shorter curriculum units, each designed to facilitate the active exploration of one important topic in depth for a month or so. Importantly, the teachers in each school district should be empowered to cover only a fraction of the topics available for their grade level. Rather than attempt to cover an entire subject such as biology, an impossible task, the goal of each unit should be to challenge students to explore one narrow topic deeply. To this end, it will be important to avoid the fatally flawed, state-based textbook- adoption process. † For science education, could a national process of curriculum unit validation be parceled out to a set of major scientific societies? More about this in my next Editorial, focused on the biology of cells and organisms.

— Bruce Alberts

Improving Education Standards

THIS MONTH, ACHIEVE, AN ORGANIZATION ESTABLISHED BY THE 50 U.S. STATE GOVERNORS to improve academic standards and testing, will begin finalizing its draft document (released in January 2013) of the Next Generation Science Standards (NGSS).* This document aims to establish new common standards for science education for students aged 5 to 18 in the United States, and it explicitly builds on the U.S. National Academies’ 2011 Framework for K-12 Science Education.† The Framework put forth a vision of science education that is notable for emphasizing student participation in key science and engineering practices, such as asking questions and defining problems; developing and using models; engaging in argument from evidence; and learning cross-cutting concepts such as energy and matter, cause and effect, and structure and function. To allow room for these in the school day, the Framework stressed the importance of minimizing the number of disciplinary core ideas that standards require to be taught. Now that the NGSS document has entered its final revision stage, it is important to ask how well these standards match the powerful vision for them that was laid down by the Framework.

There is much to be commended in the draft. In particular, its emphasis on science and engineering practices could lay the groundwork for productive shifts toward helping students understand how science helps us make sense of the natural world, instead of just what science has learned. But the sheer volume of content referenced in the Framework moves to the foreground in the NGSS draft and threatens to undermine this promise. Any emphasis on practices requires a science-rich conceptual context, and certainly the core ideas and cross-cutting concepts presented are useful here. However, the draft contains a vast number of core disciplinary ideas and sub-ideas, leaving little or no room for anything else. In the three grades of middle school (ages 11 to 13) alone, the NGSS draft specifies more than twice the disciplinary content than did the 1996 National Science Education Standards. Thus, before finalizing the new standards, we urge Achieve to quickly convene small groups of the nation’s best teachers at the primary, middle-school, and high-school levels. Although teachers have been involved in the writing effort, their new charge should be to bring ground truth to the NGSS by determining the maximum number of disciplinary core ideas that can be covered in a single school year, while still leaving time for a productive focus on practices and cross-cutting ideas. And scientists should immediately be charged with prioritizing the disciplinary core ideas in the current draft (and their performance expectations) to reduce them to a more feasible number.

The welcome shift in priorities to teaching science and engineering practices along with the content brings an assessment challenge. The NGSS draft document addresses this challenge by delineating many performance expectations. However, current measurements and approaches do not allow these types of performances to be assessed easily; it is much more difficult to evaluate the quality of such engagement than to determine the accuracy of an explanation or a word definition. Urgently needed is a vigorous R&D agenda that pursues new methods of and approaches to assessment. This will be difficult but critically important long-term work. A systematic commitment to the wrong quantitative measures, such as the inexpensive multiple-choice testing of factoids, may well result in the appearance of gains at the tremendous cost of suppressing important aspects of learning, attending to the wrong things in instruction, and conveying to students a distorted view of science. Outstanding scientists must be willing to work side by side with measurement specialists and science educators to develop methods for evaluating what is important to measure, after completing the short-term task of prioritizing and reducing the number of disciplinary core concepts in the new standards.

— Janet Coffey and Bruce Alberts

Am I Wrong?

I HAVE SEVEN GRANDCHILDREN, AND I WORRY ABOUT THEIR FUTURE. THE NATION THAT I WAS RAISED in, the United States, has clearly lost its way at a time when the world badly needs wise leadership. Nations with a long-term view are making huge investments in their infrastructure—transportation, water, energy, waste, and recreation. And they have a laserlike focus on supporting science and engineering research with government resources. As examples, Germany, China, and South Korea come to mind. Meanwhile, the United States is living off its past. Not only do we face a crumbling infrastructure* but our federal investments in fundamental long-term R&D have been stagnant, dropping from 1.25% of the gross domestic product (GDP) in 1985 to 0.87% in 2013.† Now, on top of that comes a mindless budget “sequester” that will make the situation considerably worse, causing the U.S. National Science Foundation to announce last week that it may award 1000 fewer research grants in 2013 than it did in 2012.

Governments might justifiably be considered deranged when they fail to take actions today that will generate tremendous future benefits. Consider the fact that human lifespan is increasing, and, without a medical breakthrough, 1 in 5 of those who reach the age of 85 are projected to have Alzheimer’s disease. Without research that reduces this terrible burden, the Alzheimer’s Association estimates that the costs associated with this disease and other forms of dementia in the United States will increase fivefold by 2050, to $1.1 trillion a year. Given that 70% of such costs are expected to be billed to Medicare and Medicaid,‡ the U.S. government is clearly being “penny wise and pound foolish” by cutting the fundamental research in physics, chemistry, mathematics, and biomedicine that can be expected, in some way that is completely unpredictable today, to prevent this terrible disease. And of course, no financial cost can begin to reflect the terrible toll of old-age dementia on human happiness.

I was fortunate to become a scientist at a time when the U.S. system of research was flourishing, thanks to visionary national leadership. It is no accident that the U.S. economy and global status subsequently flourished, or that the success was built in partnership with many of the best minds from other nations. The brilliance of U.S. science and engineering enabled its universities to attract a very large number of the most energetic and talented students from around the globe. A major fraction of these young scientists and engineers decided to remain here after their training, where they have made enormous contributions not only as academic leaders but also as leaders in industry and government. As one indicator, for both the U.S. National Academy of Sciences and National Academy of Engineering, 25% of members were born outside of the United States, even though they had to be U.S. citizens to be elected. It is hard to imagine a Silicon Valley, or any of the other U.S. centers of innovation, prospering without such talented immigrants.

Other nations have been increasing their research intensity at an impressive pace. With the latest cuts created by the shortsighted political gridlock in Washington, DC, are we headed to a future where the world’s most talented young scientists and engineers no longer want to pursue careers in the United States? If so, in what nation will the next Silicon Valley be developed? The declining opportunities for research funding have made survival for some of the most able researchers resemble a lottery—or perhaps Russian roulette is a better analogy. The effect on the U.S. research system seems devastating. Am I wrong? To what extent do you think the current grant-funding environment is undermining the intellectual environment and creativity in your institution? Post comments at http://scim.ag/wrong_comments, and take the Science poll at http://scim.ag/wrong_poll.§

*www.asce.org/reportcard. †www.aaas.org/spp/d/guisthist.shtml. ‡www.alz.org/alzheimers_disease_facts_and_figures.asp#expanding. §Polling results reflect only the votes of those who choose to participate.
Prioritizing Science Education

THIS SPECIAL ISSUE OF SCIENCE EXPLORES “GRAND CHALLENGES IN SCIENCE EDUCATION,” A CRITICAL set of the problems and exciting opportunities now facing science education on a global level. The 20 Challenges, addressed by a team of education experts, range from “Enable students to build on their own enduring, science-related interests” to “Shift incentives to encourage education research on the real problems of practice as they exist in school settings.” Here I propose three additional Grand Challenges. These focus on harnessing the wisdom of teachers, helping the business community promote new directions in precollege science education, and—last but not least—catalyzing major changes in the way we teach college-level science.

From my many close contacts with outstanding U.S. teachers, I have come to deeply appreciate their wisdom. They uniquely understand today’s 5- to 18-year-old students and have many valuable suggestions for improving education systems. I am also painfully aware of the many past failures that have been caused by not giving the best teachers a strong voice in the public policies that profoundly affect their profession. In the 1980s, the Japanese taught the world that building a better automobile requires listening to workers on the assembly line. More generally, experience shows that actively soliciting advice from those most intimately involved is essential for wise decision-making at higher levels. Regrettably, education is one of the few parts of U.S. society that fails to exploit this fact. Hence, my initial Grand Challenge: “Build education systems that incorporate the advice of outstanding full-time classroom teachers when formulating education policy.” A start has been made,* but much more remains to be done (see the Perspective by B. Berry on p. 309).

To be competitive in the global economy, businesses need to be able to hire workers who can “think for a living.” More specifically, studies reveal that the private sector seeks employees who can apply a capacity for abstract, conceptual thinking to “complex real-world problems—including problems that involve the use of scientific and technical knowledge—that are nonstandard, full of ambiguities, and have more than one right answer.” These employees must also have “the capacity to function effectively in an environment in which communication skills are vital—in work groups.”† Achieving the revolution in U.S. science education that is called for in the Next Generation Science Standards released last week‡ would go a long way toward creating the type of high-school graduates that the private sector needs (see the Perspective by R. Stephens and M. Richey on p. 313). Business leadership in the United States often fails to advocate for wise education policies, despite its potential for influence. Hence, my second Grand Challenge: “Harness the influence of business organizations to strongly support the revolution in science education specified in the Next Generation Science Standards.”

Several years ago on this page, I pointed out that, “Rather than learning how to think scientifically, students are generally being told about science and asked to remember facts. This disturbing situation must be corrected if science education is to have any hope of taking its proper place as an essential part of the education of students everywhere. Scientists may tend to blame others for the problem, but—strange as it may seem—we have done more than anyone else to create it.”§ College science courses are taught by scientists, and they define “science education,” modeling for teachers and adults what should be done at lower levels. Most college faculty have not yet faced up to the urgent need to improve on the standard one-size-fits-all lecture format (see News story by J. Mervis on p. 292). Thus, my final Grand Challenge: “Incorporate active science inquiry into all introductory college science classes.”

The aim is nothing less than a more rational world.

— Bruce Alberts

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