Middle-School Texts Don't Make the Grade

Thousands of teachers are saddled with error-filled physical science textbooks that fail to present what science is all about. Physicists deserve some of the blame.

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Did you know that elephant vocal sounds occur at about 400 Hz and can't be heard by humans? The caretaker at your local zoo didn't either. But your children may have been taught that tidbit if their science class used one of the most popular middle-school physical science texts. I learned of the elephant blunder and many other problems with the content and presentation of texts used in grades 6 through 9 as part of an ongoing project that began in 1998, when I received a grant from the David and Lucile Packard Foundation.

The foundation was especially concerned about errors in texts, but the goal of the 1998 grant (and a parallel one investigating high-school texts)[1] was not limited merely to fact checking. Its purpose was to review and critique middle-school physical science textbooks with regard to scientific accuracy, adherence to a realistic portrayal of the scientific approach, and appropriateness and pedagogic effectiveness of the material for the grade for which it was presented.

Several years before I was awarded the Packard grant, I had encouraged the American Association of Physics Teachers to form a committee bringing together members who were involved with science teaching at the pre-high-school level. The committee was set up and has since been active.

I recruited six members of the AAPT committee to help critique the middle-school texts; they were joined by a concerned parent with whom I had been communicating and a recent graduate student who had gone into teaching. We searched for and recorded all errors (except typos). We looked at how text authors portrayed the scientific approach: Was it described as a method that, even though tentative, has been quite successful in helping people learn about nature, or was it simply described as a series of rote steps to be followed? My colleagues and I recorded instances in which material was inappropriate for the age level of the students for whom it was written--perhaps it was too abstract or required dexterity beyond their abilities. We paid attention to the texts' readability, because we knew that students' reading level was a general concern--some important related issues are discussed in box 1 on page

Figure 1

52. We also noted attractiveness, quality of illustrations, and material such as laboratory activities, suggested home activities, exercises to test understanding, and resource suggestions.

Our study, available on the World Wide Web at http://www.psrc-online.org/curriculum/book.html, determined that, according to the criteria we set forth, none of the 12 most popular middle-school physical science texts was acceptable. The study has been widely broadcast and has generated some interesting responses; see box 2 on page 53.

Inaccurate and poorly presented

The committee was particularly concerned with scientific accuracy, and with good reason. Mass and weight were often confused. The speed of light was first timed in 1926, according to one text. Isaac Newton's first law was often incorrectly stated, and although the third law was correctly stated, the examples illustrating it were wrong. Yellow, magenta, and cyan are not the primary pigment colors, as one book had it. The Van de Graaff generator does not store charge in its base. Lamps don't supply voltage and those things in the wall are sockets, not plugs. Absolute zero was defined as the temperature at which molecules are so cold they don't move. One text explained that fusion, unlike fission, does not happen spontaneously. We found that the acceleration due to gravitation on the Moon is one-sixth that on Earth because the Moon's mass is one-sixth that of Earth's.

Many of the errors involved sloppy use of language. We regularly saw "speed," "velocity," and "acceleration" confused. Often writers referred to the gravitational acceleration, 9.8 m/s^2, as "gravity" or "the force of gravity." Cause and effect were frequently backwards as in "an acceleration is a change in velocity that results from speeding up, slowing down, or changing direction." Note the use of "change in velocity" instead of the correct "change in velocity with respect to time." That imprecision was a common error. One text reported that an object *is* a force rather than *exerts* a force. Iron particles are not "separated by a magnet," as one textbook stated, but are separated from nonmagnetic materials by a magnet.

Figure 2

Graphics and layout were problematic, too. The depictions of light passing through a prism were often incorrect. Electrical circuits were frequently drawn improperly, as were mirror and lens figures. In one illustration, the acceleration due to gravity was given as 7.8 m/s^2. The stated number may have been a typographical error or, because it was written in the space above Earth, it might have been referring to some point in outer space--the context was not clear. We found a photograph of pop diva Linda Ronstadt: In the caption she was labeled as a silicon crystal. She had been labeled as a vacuum triode in a previous edition of the book.

When I pick up something that claims to be a "textbook," I expect a book of text. Yet, in our study, we found mostly pictures, sidebars, and capsules that interrupted what little text there was. Apparently, text is seen as much too slow a medium for disseminating information. Capsules and sidebars present the story in small units, but at the cost of ruining the natural flow of the narrative. How can middle-school students, ages 11-14, concentrate with such a barrage of information? Borrow a middle-school science text and randomly open it up. It'll be obvious what I am getting at. In my opinion, textbook layout contributes significantly to our students' dislike of science and inability to "get it."

When a book purports to be about physical science, I expect to find science. But the texts we reviewed were filled with irrelevant information on a host of things, especially careers. True, a good text will, by its nature, stimulate students to think in general about careers in math, science, or engineering. But the texts we looked at focused on narrowly defined careers, many of which might not even exist when the students graduate. In any case, there wasn't enough context to make it clear just what the various careers were all about. In one series of texts, we found 26 identical pictures of a fellow in a black and yellow jacket and a hard hat. That one repeated picture exemplified 26 different careers!

Pedagogically ineffective

Textbooks need to be accurate, but they also need to be aimed appropriately at their audience. We found much of the material in the texts we studied to be totally inappropriate for middle-school students. A typical textbook's presentation of the periodic table provides an instructive example. Usually, the periodic table is accompanied by a discussion of atomic and (perhaps) nuclear structure. Middle-school students have neither the experience with the very small nor the powers of abstraction to place atoms and nuclei into a meaningful size hierarchy. The textbook discussions are inappropriate for young middle schoolers.

Much more important and meaningful are the properties of the elements. What do they look like? How hard are they? Are they gas, liquid, or solid under normal conditions? Where can they be found? Publishers spend a lot of effort promoting their up-to-date periodic tables, but who cares what the latest addition to the table has been? It's sufficient to point out that scientists are continuing to construct new nuclei that extend the table. No text asked the fundamental question, Why is the table called "periodic?" And no text offered suggestions for making some of the measurements that led to building up the periodic table.

Indeed, none of the books we reviewed spent much time on making measurements, period. Making measurements, reporting data, and interpreting one's results are crucial to gaining an appreciation of what science is all about. More than 30 years ago, Clifford Swartz wrote an excellent series of books for middle-schoolers, *Measure and Find Out: A Quantitative Approach to Science* (Scott, Foresman, 1969). All publishers of the books we reviewed would benefit from perusing that series.

Students at all levels, but perhaps especially middle-school students, require material that is interesting to them. Hands-on activities are the order of the day. A large percentage of middle-school teachers, however, have never taken a physical science course, and those who have typically find no use in their classrooms for the course that they did take. They have not had laboratory experience and cannot be expected to introduce one if their text doesn't suggest appropriate labs. On the other hand, middle-school teachers know their students and can offer important advice about how science activities should be designed. They know if their students can manipulate the equipment required, if students can follow the steps of the activity while understanding the ultimate goal, and if that goal will be meaningful to their class.

The scientific approach was not described in any of the popular books we reviewed. Those books did not indicate why science has been so successful at describing our world and encouraging technological innovation. Early in their education, students must learn the difference between observation and inference and the difference between law and theory. They should understand that research is both theoretical and experimental. Students should be developing an ever-growing set of skills as they advance through school. They should understand why they carry out their experiments in a particular way; experiments are not only exercises in following cookbook recipes. Students should realize that no experiment is complete without clearly analyzing the results and discussing them with others. They need to know that answers obtained by scientists are tentative.

Although students should learn that some principles generally apply to the scientific approach, they should also understand that there is no one scientific method. Scientists in different disciplines ask different kinds of questions and take varying approaches to answering those questions. Examples from history can be helpful. Many great scientists are good writers and their struggles might well impress upon students the idea that scientific inquiry is work that is worth the effort.

Texts should not present the elements of the scientific approach as chapter sections in isolation. Rather, those elements must be integrated throughout the text, and teachers should constantly remind their students that all they do is within a broad context that shapes the activities of all scientists.

What went wrong

The Third International Math and Science Study (TIMSS) of 1995 considered 4th, 8th, and 12th graders from as many as 41 nations (participating countries differed at the three grade levels). At each grade level, the study compared students' abilities in science and mathematics. US 4th graders scored above the international average in physical science.[2] US 8th graders didn't do as well, but they did match the international norm.[3] Our 12th graders got the lowest scores in physical science of the 21 nations participating in TIMSS.[4]

The obvious question is, What happened between the 4th and 12th grades? For one thing, middle school happened. Most middle-school teachers have not had a physical science course that can serve as appropriate training for their classrooms. With a good textbook, however, they can keep ahead of most of their students and learn as they go. It is not a good situation, but it could work. Teachers, though, need to have enthusiasm for their subject. They must be able to spot errors. They must be flexible enough to break away from their lesson plans and satisfy the enthusiastic student who heard about something interesting on TV. Many factors contribute to the decline in student performance from middle school to high school, but the textbook problem is the most critical one.

Textbooks are not written, they're "developed." Twenty-two states have various topics that their textbook selection committees insist must be included in a physical science text. The demands of Texas, California, and Florida carry particular weight because the texts chosen by the selection committees of those populous states are adopted statewide. Publishers aim to satisfy the committees that select texts, even though the members of those committees typically have little knowledge of physical science. Selection committee members, however, are impressed by pretty pictures and seemingly up-to-date new information that is not relevant for middle-school students.

An editor at the publishing house finds out the topics that the states require and, for each topic, assigns an in-house person to put some material together. Dictionaries and encyclopedias become prime sources. With so many contributors, continuity is lost and contradictions are easily missed. It takes a dedicated author to decide on a theme, direct the text, and put a personal flavor on the material.

The publishers put as much as 28% of their budget into marketing. That's money that could be spent on royalties for authors or on fact checking. Deadlines may be tight and production may be rushed. Political correctness is often more important than scientific accuracy: Middle-school text publishers now employ more people to censor books for content that might offend any organized lobbying group than they do to check facts. From a business point of view, that makes sense. A book is far more apt to be struck off a purchase order because it contains terminology or vignettes that irritate the hypersensitive reader than because it is erroneous.

Good textbooks are out there[5] but far too few students get to use them. Those good books challenge readers to interact with the author and to engage the subject matter so that they will appreciate previously unnoticed phenomena and find answers to questions about the world around them. Such books may challenge teachers, too, especially those who have not had a meaningful science experience and are approaching science at the same level as their students.

Why aren't more high-quality books adopted? A text written at a high reading level may be at a disadvantage: Teachers who have learned from texts written for low reading levels may be reluctant to adopt such texts. Other texts don't make it into the classroom because their approaches don't mesh with teachers' ideas of what needs to be covered. Teachers will not use texts that make them uncomfortable. Still, teachers must recognize that a textbook cannot explicitly address the needs of every individual instructor.

Economics and the precedents set by states like Texas, California, and Florida also work against the publication of good texts. The criteria set by those states become the criteria of smaller markets simply because it is cheaper, per text, to have books printed in the millions than in the thousands.

What is to be done?

Physics departments need to become more involved in preparing teachers rather than leaving the task solely to education departments. Historically, physicists have done well at, and have been prominent in, major efforts to improve science education at all levels (see the article by Ramon Lopez and Ted Schultz, Physics Today, September 2001, page 44). For example, the Physical Science Study Committee, led by Jerrold Zacharias and Francis Friedman, produced rich source materials designed to attract students to physics; those materials emphasized fundamental physics principles. Harvard University's Project Physics Course, a curriculum comprising a book, films, experiments, and other aids, is also excellent. The book part of the curriculum has been reworked as *Understanding Physics*,[6] and there are plans to revise the rest of the curriculum in the future. The AAPT's *Powerful Ideas in Physical Science Program* is a series of course materials for elementary-school physical science teachers. Post-secondary physics departments should regularly offer a course based on the AAPT materials.

Why were so many excellent programs and materials not used more widely in courses that prepare physical science teachers? My opinion, in brief, is that physicists decided to pay attention only to those courses that were aimed at physics majors and potential physics majors such as engineers. They ignored many courses designed by physicists for potential teachers and the general public. Nonscientists sometimes had to take an inappropriate physics course, or forgo physics courses in favor of a survey course in another science. That's part of the reason so many middle-school teachers have not taken a course whose material they could later use in their teaching.

The situation has not changed. Physics departments on the whole still pay little attention to meeting the needs of nonmajors, in particular teachers. Physicists tend to look down on physics-education researchers[7] and don't accept them as "real physicists," despite the excellent work education researchers have done to determine how students understand physics concepts. Teachers using traditional methods deny the worth of physics-education research--even as they admit they are shocked to discover that their students can solve problems without grasping elementary concepts.

We who are interested in our children's science education must fight the battle everywhere. State legislatures are not the places to determine science curricula. Contact your legislators. Let them know that middle-school science curricula should be determined by a working group of scientists and by teachers, the folks who know best what is appropriate for middle schoolers. At least for some time, though, state selection committees will continue to choose texts as they have been doing. Get on the selection committees. Encourage a free-market approach to selecting texts. (That approach is close to what is used in the college market.) Get on local school boards. They have the power to choose or reject texts whether or not those texts appear on the state's official list. True, if a board adopts a book that's not on the state list, it has to find a way to pay for it and will lose its district's state subsidy for textbooks. The acceptance of those costs strengthens the message that a local board sends to the state when it selects a superior text that's not on the state's approved list. Write appropriate textbooks. Encourage your department members to emphasize and devote resources to programs that offer physics for everyone. Meet and help middle-school teachers. Volunteer to visit the classrooms and become familiar with the freely available literature concerning developmental psychology, instructional design, and pedagogy.

Physicists contributed to the mess in middle-school science education by abandoning teachers, but past experience shows they can help clean up that mess. After concluding the middle-school texts review, I obtained a second Packard Foundation grant that allowed me to set up a Middle School Physical Science Resource Center on the Web at http://www.science-house.org/middleschool/index.html. The MSPSRC provides middle-school teachers with reviews of books and classroom materials, topical essays, directions to good resources on the Web, and a forum where they can discuss problems and get answers. In its first year, the MSPSRC was visited about 50 000 times.

Swartz considered the role of physicists in an article he wrote for a 1991 Physics Today special issue on precollege education (September 1991, page 22). "For over 150 years," he noted, "American physicists have been making forays into elementary [through] high school science teaching. Their novel approaches have usually worked--but the results have always been short-lived." The observation that the benefits of physicists' contributions have been short-lived remains true today. If that situation is to change, physicists must have an unflagging commitment to education.

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September 1991, page 22