

# Physics First: Opening Battle in the War on Science/Math Illiteracy? \* † †

Richard R. Hake<sup>a</sup>

*Indiana University (Emeritus), 24245 Hatteras Street, Woodland Hills, CA 91367*

(Received 27 June 2002)

It is argued that Lederman's "Physics First" regime, while not an ideal ramp to science/math literacy for all students, should nevertheless be vigorously supported as an important opening battle in the full scale war on science/math illiteracy as envisaged by the AAAS "Project 2061." This is because a widespread first physics course for *all* ninth graders might (a) help to overcome some systemic roadblocks to science/math literacy of the general population – most importantly the severe dearth of effective pre-college science/math teachers, (b) enhance the numbers of physics major and graduate students, through programs designed to provide a large corps of teachers capable of *effectively* teaching physics to vast numbers of students in the Physics First schools: ninth-graders plus those taking high-school honors and AP physics courses.

## I. "PHYSICS FIRST"

The Lederman (1999; 2000a,b; 2001a,b; 2002) "Physics First" brigade appears to be attracting recruits: e.g., two sessions on "Physics First" at the January 2002 AAPT meeting in Philadelphia; recent pro-"Physics First" editorials by AAPT leaders (Chiaverina 2002a, Khoury 2001, Hubisz 2001a); a "Physics First" website (Livanis 2000); and "more than a hundred schools around the country . . . that have switched the sequence to the rational order." (Lederman 2001b). Lederman (1999) writes:

*"Our reform thrust, in military metaphor, is toward a weak section of the barriers to change that surround the school systems. We have observed that 99 percent of our high schools teach biology in 9th (or 10th) grade, chemistry in 10th or 11th grade, and, for survivors, physics in 11th or 12th grade. This is alphabetically correct, but by any logical scientific or pedagogical criteria, the wrong order. A standards-based science curriculum must contain at least three years of science and three years of mathematics. And the coherent order begins with 9th grade physics, taught conceptually and exercising only the math of 8th and 9th grade; then*

---

\*Partially supported by NSF Grant DUE/MDR-9253965.

† The reference is R.R. Hake "Physics First: Opening Battle in the War on Science/Math Illiteracy?", Submitted to the *American Journal of Physics* on 27 June 2002. Online as ref. 20 at < <http://www.physics.indiana.edu/~hake> >

†A drastically truncated version of this article is scheduled to appear in the Summer 2002 issue of the *APS Forum on Education Newsletter*, and is online as ref. 19 at the above URL.

© Richard R. Hake, 6/26/02. Permission to copy or disseminate all or part of this material is granted provided that the copies are not made or distributed for commercial advantage, and the copyright and its date appear. To disseminate otherwise, to republish, or to place at another website (instead of linking to the above URL) requires written permission.

chemistry, building on the knowledge of atomic structure to study molecule; then the crowning glory of modern, molecular-based biology . . . . We stress that this is a design for *all* students, work bound, liberal arts-college-bound, or science-and-technology-bound. The schools that are 'doing it right' report greatly expanded enrollments in fourth-year electives and Advanced Placement science courses. *Thus, a solid, core curriculum will enlarge rather than . . . (diminish the pool of) . . . future scientists.*" (My italics.)

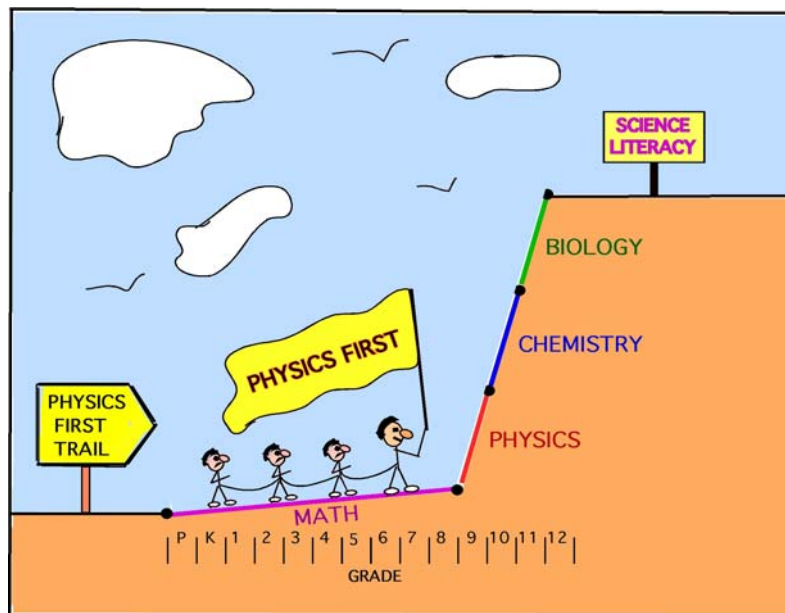


Fig. 1. Lederman's "Physics First" Brigade

## II. OPENING BATTLE IN A FULL SCALE WAR ON SCIENCE/MATH ILLITERACY ?

But does P-12 education (P = Preschool) need "Physics First" or "Physics For All," I agree with Hubisz (2001a) that *both* are desirable. However, considering the appallingly low level of science literacy among the general population (NSF 1998, Arons 1983), and society's need to solve the monumental science-intensive problems (economic, social, political, and environmental) that beset it (see, e.g., Lederman 1999, Hake 2000a), I would rate "Physics For All" or, more generally, "Science/Math Literacy for All," as being by far the more important.

Viewed from that perspective, Lederman's "Physics First" reform thrust could be *an important opening battle in a full scale war on science/math illiteracy* as envisaged by "Project 2061" of the American Association for the Advancement of Science (AAAS 20002). As indicated in AAAS (1989, p. 11), Project 2061 "was started in 1985, a year when Comet Halley happened to

be in the earth's vicinity. That coincidence prompted the project's name, for it was realized that the children who would live to see the return of the comet in 2061 would soon be starting their school years." But I would submit that "2061" could also designate the earliest year by which scientific literacy as defined in *Benchmarks for Science Literacy* (AAAS 1993) might characterize a *majority* of Americans (even despite the thorough and thoughtful efforts of Project 2061), given the formidable roadblocks to education reform (Section III), and the monumental inertia of the U.S. educational system (Hake 2002a, Lesson #13).

Regarding the *physics* aspects of "Science/Math Literacy for All," the cogent arguments of Ken Ford (1989) for "Physics for All," *starting in the very early grades* are worth considering:

". . . Physics is difficult in the same way that all serious intellectual effort is difficult. Solid understanding of English literature, or economics, or history, or music, or biology - or physics - does not come without hard work. But we typically act on the assumption (and argue to our principals and deans) that ours is a discipline that only a few are capable of comprehending. The priesthood syndrome that flows from this assumption is, regrettably, seductive . . . If physics is not more difficult than other disciplines, why does everyone think that it is? To answer indirectly, let me turn again to English. Six-year-olds write English and (to pick a skilled physicist writer) Jeremy Bernstein writes English. What separates them? A long, gradual incline of increased ability, understanding, and practice. Some few people, illiterates, do not start up the hill. Most people climb some distance. A few climb as far as Bernstein. *For physics, on the other hand, we have fashioned a cliff. There is no gradual ramp, only a near-vertical ascent to its high plateau.* When the cliff is encountered for the first time by. . . (14- or) . . . 16- or 17-year olds, it is small wonder that only a few have courage (and the skill) to climb it. There is no good reason for this difference of intellectual topography. First-graders could be taught some physics . . . (Hammer 1999, Snyder 2001). . . , second-graders a little more, and third-graders still more (Love 2001) . . . [and Middle School'ers still more (Hubisz 2001 a,b)]. . . Then for the. . . (ninth-). . . , eleventh- or twelfth-grader, a physics course would be a manageable step. Some might choose to take it, some not, but few would be barred by lack of 'talent' or background." (My *italics*.)

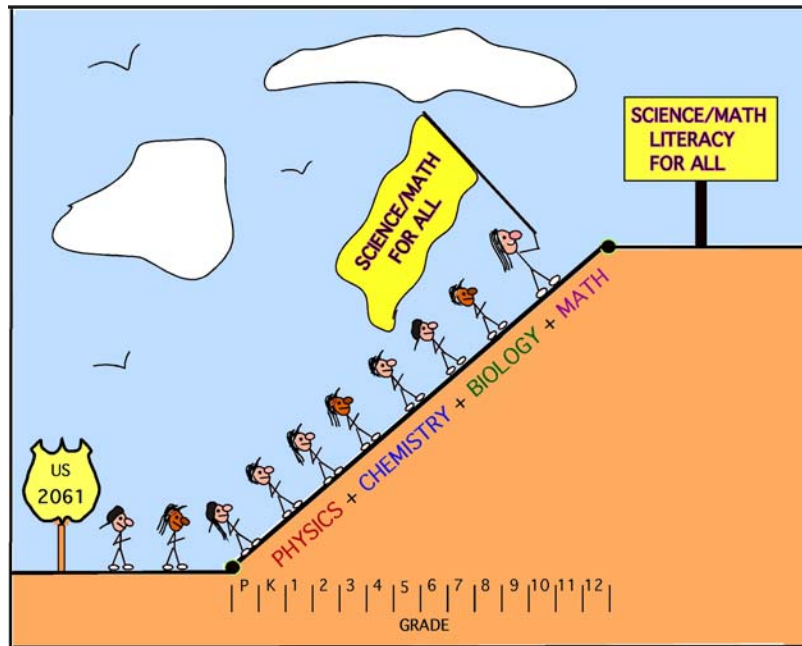


Fig. 2. Ascending a ramp to science/math literacy.

The arguments of Ford are in consonance with:

A. The AAAS "Project 2061" as indicated above.

B. Table 2 of Mahajan and Hake (2000): "A possible physics curriculum." [Inspired by the pioneering but virtually forgotten work of Louis Paul Benezet (1935/36)]:

**Grade****Physics and Mathematical Ideas**

1 to 8 Benezet's mathematics program as a basis. Add physical quantities to it: angles, volumes, weight (mass), force (estimating only), density as students learn division, energy, power. All quantities are related to everyday experience: density of rocks, volume of houses, power required in climbing stairs or cycling, power in the falling water at Niagara Falls.

Proportional reasoning and scaling: 'If you double the side of a cube, what happens to the volume?' Use scaling throughout, starting in grade 4, with the introduction of square measure, and emphasize it especially in grade 8.

9 to 11 Gravitation, motion of planets by hand simulation to develop a tick-by-tick model of how Newton's second law works. Dimensions, units, dimensional analysis to guess formulae. Springs, waves, sound, music, pressure. Matter is made of atoms. This order would fit with a physics-first curriculum as suggested by Leon Lederman

12 Begin exact calculations, including conservation laws.

C. Table 3 of Mahajan and Hake (2000): "Possible topics for K-12 suggested by Cliff Swartz (1993)." See also Swartz (1969).

<b>Grade</b>	<b>Physics and Mathematics Topics</b>
1 to 6	<p>Use standard measuring tools.</p> <p>Students measure their foot lengths, then organize and interpret a class distribution graph</p> <p>Students time their pulses, plot a distribution of class results, and make comparisons with results of before and after physical exercise.</p> <p>Select the needed apparatus and make all the measurements, calculations, and graphs to determine who runs faster in their class, tall kids or short kids.</p>
7 to 9	<p>Use standard measuring tools.</p> <p>Use wire, battery, and bulb with the right tools and connectors to make the bulb light.</p> <p>With a convex lens as a magnifier, produce both real and virtual images.</p> <p>Measure the volume and mass of an object and calculate its density.</p> <p>Measure work input and output of a simple machine.</p> <p>Use echoes to measure the speed of sound.</p>
10 to 12	<p>Use standard measuring tools.</p> <p>Given the mass of a pollutant in a quantity of water, calculate the degree of pollution in parts per million.</p> <p>Organize the history of the universe on a power-of-ten map.</p> <p>Characterize the electromagnetic spectrum in terms of wavelengths, frequencies, and photon energies, doing necessary calculations and examples to illustrate each regime.</p> <p>Use Archimedes' principle to explain how a boat floats.</p>

D. The *National Science Education Standards* (NRC 1996).

E. The "Revolutions in the Goals and Methods of K-12 Science Education" (Lopez & Schultz 2001).

### **III. SYSTEMIC ROADBLOCKS TO SCIENCE/MATH LITERACY**

Among important roadblocks to science/math literacy are, in my opinion, the following:

**A. High-stakes state-mandated tests of reading and mathematics** (see, e.g., AAAS 1997e; Heubert & Hauser 1998; AIP 2001; Amrein & Berliner 2002). Will these crowd out K-8 science education? Heller (2002) writes:

"In many places, science teaching will only survive in the schools if there is an effort of concerned citizens and teachers stressing its importance for children. The language of Congress in both the authorization law and the committee report accompanying the appropriation law can give weight to those efforts. It will clearly help if university and college groups in collaboration with school districts design professional development programs for science teachers that also help increase math and reading test scores."

**B. State science standards that are antithetic to the National Science Standards (NRC 1996) and the AAAS (1993) "Benchmarks for Science Literacy."** An outstanding example is the California science standards (Feder 1998, Woolf 1999). Feder (1998) writes:

". . . The standards stress learning facts over conceptual understanding; they will force teachers into covering subjects superficially just to get through the prescribed material; their level is too high; they ignore what is known about cognitive development. . . [Druckman & Bjork (1994), Bransford et al. (1999), Donovan et al. (1999)] . . . and they are not compatible with the sets of standards already prepared by the NAS . . . (NRC 1996). . . . and the American Association for the Advancement of Science . . . . (AAAS 1993)."

**C. An antiquated K-12 science/math curriculum** [AAAS (1997c; 2000b; 2001a)]. According to the AAAS (2000b):

"In spite of many reform attempts, the 20th century has ended with virtually the same curriculum it started with—a curriculum that does not effectively teach what students most need to know and that does little to improve student achievement in science, mathematics, and technology. Much of the typical curriculum today is obsolete, fostering little of what is needed for literacy. It is usually assembled from unrelated fragments, without reference to a conceptual whole and with no coherence across grade levels or subject matter. Curricula tend to cover too many topics, far more than can be taught effectively during the average school year. Curricula also tend to lack the sensitivity or flexibility necessary to meet the needs of diverse student populations."

**D. Science textbooks that are overstuffed, uninformed by education research, and often riddled with scientific errors** (see, e.g., AAAS 2001b; Raloff 2001a,b; Hubisz 2001c). [For a list of physics-education-research based undergraduate curriculum materials, including textbooks, see the University of Maryland Physics Education Research Group site UMPERG (2002).] Harriet Tyson-Bernstein (1988) writes:

"Textbooks, for better or worse, dominate what students learn. *They set the curriculum, and often the facts learned, in most subjects.* For many students, textbooks are their first and sometimes only early exposure to books and to reading. The public regards textbooks as authoritative, accurate, and necessary. And teachers rely on them to organize lessons and structure subject matter. But the current system of textbook adoption has filled our schools with Trojan horses — glossily-covered blocks of paper whose words emerge to deaden the minds of our nation's youth, and make them enemies of learning. . . *altering the system of textbook adoption and consequently the quality of textbooks requires not money, but enlightened political will.*" (My italics.)

Attempts to overcome roadblocks "A" – "D" will require considerable educational redesign (Wilson & Daviss 1994, AAAS 2001a) as well as grass-roots political effort. In my view those four roadblocks, challenging as they are, will be far easier to overcome than the fifth and most formidable:

**E. The dearth of effective P-12 science/math teachers.**

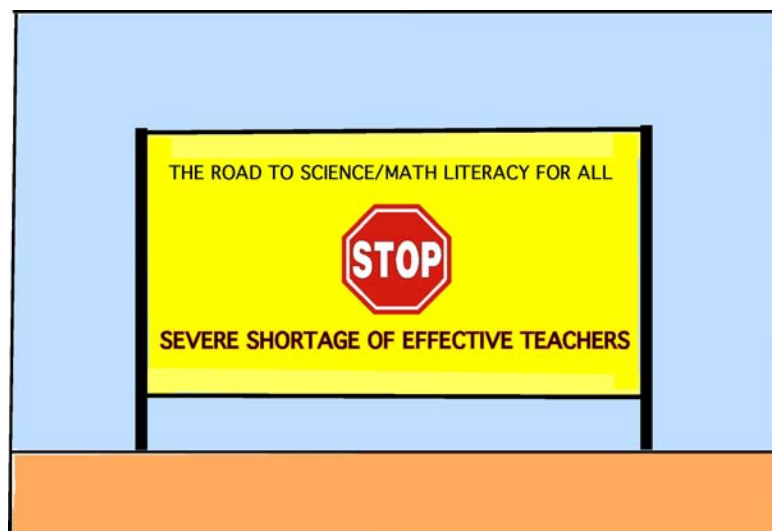


Fig. 3. Whence do get the teachers ?



The late Arnold Arons (2000), wrote:

"This . . . (consideration of implementing the Benezet (1935/36) method, but the same considerations apply to "Science/Math Literacy for All") . . . brings us back to the same old problem: *Whence do we get the teachers* with the background, understanding, and security to implement such instruction? They will certainly not emerge from the present production mills." (My *italics*.)

The shortage of effective K-12 science/math teachers has recently been emphasized by the National Science Board (NSF 2002, Dawson 2002), and by Hake (2002c) with reference to "assessment in the service of student learning."

Among steps that might be taken for alleviating the current shortage of *effective* teachers are (in my judgment of approximate order of importance):

***1. Motivate universities to discharge their obligations to:***

**a. Adequately educate prospective K-12 teachers** [NSF (1996; 1999a,b); AAAS (1997f,g); Joint Physics Societies (1999); AAPT (2000); APS (2001); Hake (2002a, Lesson 12h; 2000a,b). The NSF (1996) Advisory Committee, chaired by Melvin George, had this to say:

"Many faculty in SME&T. . . . (Science, Math, Engineering, and Technology) . . . at the post-secondary level continue to blame the schools for sending underprepared students to them. But, increasingly, the higher education community has come to recognize the fact that teachers and principals in the K-12 system are all people who have been educated at the undergraduate level, mostly in situations in which *SME&T programs have not taken seriously enough their vital part of the responsibility for the quality of America's teachers.*" (My *italics*.)

**b. Vigorously pursue R & D directed towards the development and implementation of effective methods of instruction** [Reif (1974); Wilson & Daviss (1994); AAAS (1993, Chapter 15; 1997g); Redish (1999); NRC (1999); Duderstadt (2000, 2001); Shavelson & Towne (2001); Pelligrino et al. (2001); Hake (2002a,b).

**c. Think of education in terms of *student learning* rather than the delivery of instruction** (Barr & Tagg 1995).

**2. Lobby legislators and school boards to treat P-12 teachers like the valued professionals they are by drastically upgrading their salaries (Heller 2001) and working conditions (Jones 2001) [especially in the inner cities (Kozol 1992)].** Heller suggests that teachers be paid *at least as much as mechanical engineers*. Other concrete proposals to substantially increase salaries of P-12 teachers have been given by Don Langenberg (2000), the Hart-Rudman Commission (2001b), and Vladimir Putin [see Daniszewski (2001)] (but *not* George Bush). For a review of the Heller, Langenberg, and Hart-Rudman proposals see Lesson #12i of Hake (2002a).

**3. Form collaborations of disciplinary departments with Schools of Education to better educate prospective teachers and mentor new teachers, as in the recently funded "PhysTEC" (Physics Teacher Education Coalition) Project**  
< <http://positron.aps.org/educ/undergrad/main-phystec.html> >,  
< <http://www.phystec.org/> >, and Stein (2001).

**4. Promote the research and development of effective curricula for pre-service P-12 teachers** (AAPT 2002). Examples from physics are the *CPU Project*, *Physics by Inquiry*, *Powerful Ideas in Physical Science*, *Science Helper K-8 CD-ROM*, and *Workshop Physical Science*.

**5. Support the research, development, and operation of programs to enhance the pedagogical skills and content knowledge of in-service P-12 science/math teachers.** For a hot-linked list of 25 such programs in physics see Hake (2000b, Section IIIC). See also the resources at the APS "Education and Outreach" website  
< <http://www.aps.org/educ/> >.

**6. Revitalize moribund science-major programs.** Physics departments might consider improving deficient programs for their majors (Wilson 2002) by implementing the 1960's "Curriculum S" (Jossem 1964, Ford 1987, Hake 2000b). A very effective Curriculum-S-type program appears to be in operation at Rutgers (Lindenfeld 2001). Ken Ford (1987) wrote, with characteristic insight:

"From the ..... second Ann Arbor Conference, November 1962 - came a succinct and memorable recommendation: that two kinds of curricula for physics majors be developed (to meet the needs of two kinds of students). These were named curriculum R and curriculum S. Curriculum R (for Research) was the then-current (and still dominant) undergraduate curriculum, whose principal aim is to prepare students for graduate study. *Curriculum S (for Synthesis) was to serve students who wanted to study physics as background for something other than physics research: business, law, medicine, teaching, some other scientific study, or just informed citizenship.* What has happened? Sad to say, nothing. Curriculum R was already strong and is still strong. *Curriculum S did not exist then and it does not exist now (in first approximation). . . . It is time to look again at Curriculum S . . . . We need majors with aspirations other than physics research. Ours is an exciting field, a central part of the liberal arts. It provides a useful background for many activities. Should we not promote its serious study by future teachers, lawyers, and business people? Above all, we need a physics major program suitable for (and attractive to) some of the teachers of the next generation - not just high-school physics teachers, but elementary and middle school teachers as well.*" (My italics.)

**7. Implement (a) Master's Degree programs related to teaching and education, such as two-year Professional Master's Degree physics programs** (Norton et al. 2002) **and MAT** (Master of Arts in Teaching) **degrees** (for a discussion see Hake (2000b, Section III E); **(b) Ph.D. programs in education research such as now exist for physics in about 20 different departments** (for a discussion see Hake 2002a, Lesson #4).

#### IV. CONCLUSIONS

The reports of the Glenn (2000), Hart-Rudman (2001a,b); NSF (1996; 1999a,b; 2002); Joint Physics Societies (1999); AAAS (2002a); AAPT (2000); APS (2001); recent editorials by AAPT leaders (Khoury 2002, Chiaverina 2002b); and the "No Child Left Behind Act" (U.S. Congress 2001, Heller 2002); all testify to the current national interest in improving pre-college teaching and education. On the other hand, there exist very serious systemic *roadblocks* to improving P-12 science/math education that may take sixty years or so to overcome. In the meantime, Lederman's "Physics First" regime, while not the ideal *ramp* to science/math literacy, might – if vigorously supported – be adopted by thousands of U.S. school systems within the next decade. This would auger well for the eventual attainment of the goal of "Science/Math Literacy for All" by demanding that serious attention be paid to the several roadblocks that are common to both "Physics First" and "Science/Math Literacy for All," most importantly, *the dire shortage of effective science/math teachers*.

In particular, physics departments might help to overcome this roadblock and at the same time enhance their numbers of physics major and graduate students, through programs designed to provide a large corps of teachers capable of *effectively* teaching physics to vast numbers of students in the "Physics First" schools: ALL ninth-graders plus those taking high-school honors and AP physics courses. Then to, once ninth graders have experienced the excitement of well-taught conceptually oriented physics they will doubtless flock to enroll in twelfth grade and undergraduate physics classes, many of them as physics majors.

#### ACKNOWLEDGMENTS

This work was partially supported by NSF Grant DUE/MDR-9253965. I have benefited from discussions on: (a) "Physics First" with Art Hobson; (b) "Curriculum S" with Ken Ford, David Gavenda, and Len Jossem; (c) the "Benezet Method" with Jack Lochhead, Sanjoy Mahajan, and the late Arnold Arons; (d) physics education generally with the subscribers to discussion lists with archives at:

PhysLrnR < <http://listserv.boisestate.edu/archives/physlrnr.html> > ,

Phys-L < <http://lists.nau.edu/archives/phys-l.html> > , and

Physhare < <http://lists.psu.edu/archives/physhare.html> > .

<sup>a)</sup>Electronic Mail: rrhake@earthlink.net

AAAS. 1989. *Science for All Americans*. AAAS Press; online at  
< <http://www.project2061.org/tools/sfaaol/sfaatoc.htm> >.

\_\_\_\_\_. 1993. *Benchmarks for Science Literacy*. Oxford University Press; online at  
< <http://www.project2061.org/tools/benchol/bolframe.htm> >.

\_\_\_\_\_. 1997. *Blueprints*; especially (a) Research, (b) School Organization, (c) Curriculum Connections, (d) Materials and Technology, (e) Assessment, (f) Teacher Education, (g) Higher Education; online at  
< <http://www.project2061.org/tools/bluepol/blpframe.htm> >.

\_\_\_\_\_. 1999. *Dialogue on Early Childhood Science, Mathematics, and Technology Education*;  
online at < <http://www.project2061.org/newsinfo/earlychild/default.htm> >.

\_\_\_\_\_. 2000a. *Atlas of Science Literacy*. AAAS; description at  
< <http://www.project2061.org/tools/atlas/default.htm> >.

\_\_\_\_\_. 2000b. "Designs for Science Literacy: Guiding the K-12 Curriculum Reform," in *2061 Today* **10**(1), online at < <http://www.project2061.org/newsletter/archive.htm> >.

\_\_\_\_\_. 2001a. *Designs for Science Literacy*. Oxford University Press.

\_\_\_\_\_. 2001b. *Project 2061 Textbooks Evaluations*: middle grades mathematics, middle grades science, algebra, high-school biology; online at  
< <http://www.project2061.org/newsinfo/research/textbook/default.htm> >.

\_\_\_\_\_. 2002a. Project 2061; online at < <http://www.project2061.org/> >:

\_\_\_\_\_. 2002b. "Project 2061 Update 2002-2002"; online at  
< <http://www.project2061.org/newsletter/default.htm#Update> >.

AAPT. 2000. *White Paper on Teacher Preparation*, L.M. Adair & C.J. Chiaverina, "The Preparation of Excellent Teachers at All Levels," online at  
< <http://www.aapt.org/governance/> >.

AAPT. 2002. American Association of Physics Teachers, *Physical Science Resource Center*; online at < <http://www.psrc-online.org/> > / "Curriculum" / "College-University Physical Science" / "Pre-service Teacher Education" where "/" means "click on."

AIP. 2001. "Intersociety statement on 'The Better Education for Students and Teachers Act' and reauthorization of the Elementary and Secondary Education Act." March 19: "*Include science in assessment and accountability provisions, in addition to reading and mathematics.* Research shows that teaching time shifts toward subject matter that is assessed. An exclusive focus on testing reading and mathematics may inadvertently harm science teaching and learning, by reducing available classroom time. We urge inclusion of science in testing provisions, as is proposed by ESEA reauthorization bills S303, HR340 and HR345"; online at < <http://www.aip.org/gov/educstatement.html> >. (My *italics.*)

Amrein, A.L. & D.C. Berliner. 2002. "High-Stakes Testing, Uncertainty, and Student Learning," *Education Policy Analysis Archives* **10**(18); online at < <http://epaa.asu.edu/epaa/v10n18/> >: "Evidence from this study of 18 states with high-stakes tests is that in all but one analysis, student learning is indeterminate, remains at the same level it was before the policy was implemented, or actually goes down when high-stakes testing policies are instituted."

APS. 2001. American Physical Society, "Policy Statement on K-12 Science and Mathematics Education"; online at < <http://www.aps.org/apsnews/0201/020101.html> >: "To support a vision of science and mathematics education that ensures that all students receive high quality instruction, the APS recommends that policy makers: enhance support for the preparation of prospective science and mathematics teachers, particularly those programs that involve collaborative efforts of college or university departments of science and mathematics with their departments of education . . . ."

Arons, A.B. 1983. "Achieving Wider Scientific Literacy," *Daedalus*, Spring. (Reprinted in Arons 1990). For Arons's "Twelve Hallmarks of Science Literacy" see Hake (2000a, Section II).

Arons, A.B. 1990. (a) *A Guide To Introductory Physics Teaching*, Wiley; reprinted with minor updates in (b) *Teaching Introductory Physics* (Wiley, 1997) [also contains *Homework and Test Questions for Introductory Physics Teaching* (Wiley, 1994) along with a new monograph *Introduction to Classical Conservation Laws*].

Arons, A.B. 2000. Private communication, 30 June 2000.

Barr, R.B. & J. Tagg. 1995. "From teaching to learning – a new paradigm for undergraduate education." *Change*, Nov./Dec.:13-25; reprinted in D. DeZure, *Learning from Change: Landmarks in Teaching and Learning in Higher Education from 'Change Magazine' 1969-1999*. American Association for Higher Education.

Benezet, L.P. 1935-1936. "The teaching of arithmetic I, II, III: The story of an experiment," *Journal of the National Education Association* **24**(8), 241-244 (1935); **24**(9), 301-303 (1935); **25**(1), 7-8 (1936). The articles were (a) reprinted in the *Humanistic Mathematics Newsletter* #6: 2-14 (May 1991); (b) placed on the web along with other Benezetia at the *Benezet Centre* < <http://wol.ra.phy.cam.ac.uk/sanjoy/benezet/> >. See also Mahajan & Hake (2000).

Bransford, J.D., A.L. Brown, R.R. Cocking, eds. 1999. *How people learn: brain, mind, experience, and school*. National Academy Press; online at < <http://www.nap.edu/catalog/6160.html> >; see also Donovan et al. (1999).

Chiaverina, C. 2002a. "Physics First: Some Personal Observations," *AAPT Announcer* **32**(1): 4.

Chiaverina, C. 2002b. "Stopping the Revolving Door," *AAPT Announcer* **32**(2): 6-7.

*Daedalus*. 1998. *Education yesterday, education tomorrow*. *Daedalus* 127(4); online description < <http://daedalus.amacad.org/inprint.html> >.

Daniszewski, J. 2001. "Putin Gives Teachers a Big Boost: Celebrating nation's back-to-school day, the president pledges to double the amount of the average instructor's pay," *Los Angeles Times*, 2 September 2001, page A3.

Dawson, J. 2002. "Science Board Says US Leadership in R&D Strong, but Faces Growing Foreign Competition," *Phys. Today* **55**(6): 20-21: "[Richard] Tapia, the Rice University mathematics professor who chaired the NSB subcommittee that oversaw the study . . . (NSB 2002). . . said. . . 'To do that . . . (build our own [science and technology] workforce) . . . *the US must first solve the crisis in its elementary and secondary school education system.* The problems the report identifies in K-12 education, especially in mathematics and science, are long-standing and well known: *too few science and math teachers with relevant academic backgrounds; inadequate ongoing training for teachers already on the job; low salaries that keep top science graduates from going into teaching; science and math textbooks of poor quality; and uneven standards and testing across school districts.*' " (My italics.)

Donovan, M.S., J.D. Bransford, J.W. Pellegrino, eds. 1999. *How People Learn: Bridging Research and Practice*. National Academy Press; online at < <http://www.nap.edu/catalog/9457.html> >.

Druckman, D. & R.A.Bjork, eds. 1994. *Learning, Remembering, and Believing; Enhancing Human Performance*. (Nat. Acad. Press); online at < <http://www.nap.edu/catalog/2303.html> >. See especially the Epilogue "Institutional Impedements to Effective Training" : ". . . what has become apparent to us is that specifying the techniques and innovations that do and do not have the potential to enhance individual and team performance is only part of the battle. *Without an organizational culture that fosters the changes needed to implement those innovations, proposals for change, however credible their source or convincing the evidence, will have little effect.*"

Duderstadt, J.J. 2000. *A University for the 21st Century*. University of Michigan Press; synopsis online at < <http://www.press.umich.edu/titles/11091.html> >, also < <http://www.nap.edu/issues/16.2/duderstadt.htm> >.

Duderstadt, J.J. 2001. "Science policy for the next 50 years: From guns to pills to brains." AAAS Annual Meeting, San Francisco, February; online at < [http://milproj.umm.umich.edu/publications/aaas\\_text\\_2](http://milproj.umm.umich.edu/publications/aaas_text_2) >.

Etkina, E., K. Gibbons, B. L. Holton, G. K. Horton. 1999. "Lessons learned: A case study of an integrated way of teaching introductory physics to at-risk students at Rutgers University," *Am. J. Phys.* **67**(9): 810-818.



Feder, T. 1998. "California's Science Standards Slammed for Demanding Too Much, Too Early," *Physics Today* **51**(11): 54.

Ford, K.W. 1989. "Guest Comment: Is physics difficult?" *Am J. Phys.* **57**(10), 871-872 (1989).

Ford, K.W. 1987. "Guest Editorial: Whatever Happened to *Curriculum S*?" *Phys. Teach.*, March 1987, pp. 138-139.

Glenn Commission. 2000. *Before it's too late: A report to the National Commission on Mathematics and Science Teaching for the 21st Century*; online at < <http://www.ed.gov/americaaccounts/glenn/toc.html> >: "More than one in four high school mathematics teachers and nearly one in five high school science teachers lack even a minor in their main teaching field. More than 12% of all new hires enter the classroom without any formal training; another 14% start work without meeting the teaching standards of their states. About 56% of high school students taking physical science are taught by out-of-field teachers, as are 27% of those taking mathematics. These percentages are much greater in high poverty areas. Among schools with the highest minority enrollments, for example, students have less than a 50% chance of getting a science or mathematics teacher who holds both a license and a degree in the field taught."

Haber-Schaim, U., H.A. Pratt, R. Cutting, H.G. Kirksey. 1999. *Introductory Physical Science*. Science Curriculum Inc. < <http://www.sci-ips.com/sci.html> >.

Hake, R.R. 1998. "Interactive-engagement vs traditional methods in mechanics instruction," *APS Forum on Education Newsletter*, Summer, pp. 5-7; online as ref. 5c at < <http://www.physics.indiana.edu/~sdi/> >.

Hake, R.R. 2000a. "The General Population's Ignorance of Science Related Societal Issues: A Challenge for the University," *AAPT Announcer* **30**(2): 105 (2000); online as ref. 11 at < <http://www.physics.indiana.edu/~hake/> >.

Hake, R.R. 2000b. "Is it Finally Time to Implement Curriculum S?" *AAPT Announcer* **30**(4), 103; online as ref. 13 at < <http://www.physics.indiana.edu/~hake/> >. A large number of references relevant to the reform of P-16 education is given on pages 55-99.

Hake, R.R. 2002a. "Lessons from the physics education reform effort." *Conservation Ecology* 5(2): 28; online at < <http://www.consecol.org/vol5/iss2/art28> >. See also Hake (1998, 2002b).

Hake, R.R. 2002b. "Comment on 'How do we know if we're doing a good job in physics teaching?' by Robert Ehrlich [*Am. J. Phys.* 70 (1), 24-29 (2002)]," *Am. J. Phys.*, in press; online at < <http://www.physics.indiana.edu/~hake/> >.

Hake, R.R. 2002c. "Whence Do We Get the Teachers (Response to Madison)". PKAL Roundtable on the Future: *Assessment in the Service of Student Learning*, Duke University, March 1- 3; updated on 6/17/02; online at < <http://www.pkal.org/events/roundtable2002/papers.html> >.

Hammer, D. 1999. Physics for first graders? *Science Education* 83(6):797-799; online at: < <http://www2.physics.umd.edu/~davidham/1stgrdrs.html> >.

Hart-Rudman Commission. 2001a. [United States Commission on National Security/21st Century], *Road map for national security: Imperative for change, Phase III Report*; online at < <http://www.nssg.gov/> >: "The capacity of America's educational system to create a 21st century workforce second to none in the world is a national security issue of the first order. As things stand, this country is forfeiting that capacity. The facts are stark: (a) The American educational system needs to produce significantly more scientists and engineers, including four times the current number of computer scientists, to meet anticipated demand. (b) To do this, more than 240,000 *new and qualified* science and mathematics teachers are needed in our K-12 classrooms *over the next decade* (out of a total need for an estimate 2.2 million new teachers). (c) However, some 34 percent of public school mathematics teachers and nearly forty percent of science teachers *lack even an academic minor* in their primary teaching fields. (d) In 1997, Asia alone accounted for more than 43 percent of all science and engineering granted worldwide, Europe 34 percent, and North America 23 percent. In that same year, China produced 148,800 engineers, the United States only 63,000. (*Italics in the original*)

Hart-Rudman Commission. 2001b. *Journeys through the teacher pipeline: Recapitalizing American education, Partial cost estimates for road map for national security*; online at < <http://www.nssg.gov/addedumpage.htm> >.

Heller, K.J. 2001. "The time has come to make teaching a real profession." *APS Forum on Education Newsletter*, Spring; online at < <http://www.aps.org/units/fed/spring2001/index.html> >.

Heller, K.J. 2002. "No Child Left Behind? Teaching Science and the Department of Education Budget – Good Intentions, Political Realities, Unintended Consequences." *APS Forum on Education Newsletter*, Spring; online at < <http://www.aps.org/units/fed/spring2002/index.html> >.

Heubert & Hauser, eds. 1998. "High Stakes: Testing for Tracking, Promotion, and Graduation," Committee on Appropriate Test Use, National Research, National Academy Press; online at < <http://www.nap.edu/catalog/6336.html> >.

Hubisz, J.L. 2001a. "Physics? Yes, but when?" *AAPT Announcer* **31**(4): 8.

Hubisz, J.L. 2001b. "Serendipity Times Two," *AAPT Announcer* **31**(4): 8. *APS Forum on Education Newsletter*, Spring; online at < <http://www.aps.org/units/fed/spring2001/index.html> >.

Hubisz, J.L. 2001c. "Report on a Study of Middle School Physical Science Texts," *Phys. Teach.* **39**(5): 304-309. Unfortunately the relatively effective text by Haber-Schaim et al. (1999) was *not* reviewed, evidently because it was not one of the best sellers (see Raloff 2001b). The full report is online at < <http://www.science-house.org/middleschool/reviews/textreview.html> >

Joint Physics Societies. 1999. American Institute of Physics, American Physical Society, American Association of Physics Teachers, American Astronomical Society, Acoustical Society of America, American Association of Physicists in Medicine, American Vacuum Society) *Statement on the Education of Future Teachers*; online at < <http://www.aip.org/education/futeach.htm> >: "Many of us believe that teachers are one of the most important elements in the entire educational system, yet many teachers today are not receiving sufficient undergraduate preparation in science to enable them to do a good job once they graduate."

Jones, S. 2001. "Teachers as Professionals," *APS Forum on Education Newsletter*, Summer; online at < <http://www.aps.org/units/fed/summer2001/index.html> >.

- Jossem, E.L. 1964. "Undergraduate Curricula in Physics: A Report on the Princeton Conference on *Curriculum S*," *Am. J. Phys.* **32**(6), 491-497 (1964).
- Khoury, B. 2001. "Physics First, Physics for All, Physics for the Best," *AAPT Announcer* **31**(4): 6.
- Khoury, B. 2002. "The Preparation and Professional Development of Teachers," *AAPT Announcer* **32**(2): 4 & 7.
- Kozol, J. 1992. *Savage Inequalities: Children in America's Schools*. Harper Collins.
- Langenberg, D.N. 2000. *Rising to the challenge. Thinking K-16* **4**(1):19; online as "Honor in the Boxcar" at < <http://www.edtrust.org/main/main/reports.asp> >.
- Lederman, L.M. 1999. "A science way of thinking." *Education Week*, 16 June; 1999 < <http://www.edweek.org/ew/1999/40leder.h18> >.
- Lederman, L.M. 2000a. *Project Arise*, online at < <http://www-ed.fnal.gov/arise/> >.
- Lederman, L.M. 2000b. "A Plan, A Strategy for K-12," in NAP (2000), pp. 7- 11: "We hear that after the new sequence is installed, increases take place in fourth-year science electives, enrollment in AP science courses zooms up, college successes are recorded, and then, here is the funny thing, *there is a dramatic effect on women and minority students form poor families who come into high school without a strong positive science and math experience*. Many of these. . .(new sequence). . .schools tell us things like 'AP physics now has 53% women.' I remember AP physics as having one, two, or no women. What is going on?" (My *italics*.)
- Lederman, L. 2001a. "Physics First," *APS Forum on Education Newsletter*, Spring 2001; online at < <http://www.aps.org/units/fed/spring2001/index.html> >.
- Lederman, L. 2001b. "Revolution in Science Education: Put Physics First." *Physics Today* **54**(9): 11-12; online at < <http://physicstoday.org/pt/vol-54/iss-9/p11.html> >.
- Lederman, L. 2002. "A Vision for 21st-Century High School: Project Arise," plenary session, *AAPT Announcer* **32**(2): 136.

Livanis, O. (2000). *Physics First Home Page*; < <http://members.aol.com/physicsfirst/> >.

Lindenfeld, P. 2001. "We can do better: A Report on Some Teaching Innovations," *Forum on Physics and Society Newsletter*, July; online at < <http://www.aps.org/units/fps/jul01/701art1.html> > : "At Rutgers University we are trying to address several of the major problem areas: the declining number of physics majors, the dissatisfaction with the introductory courses, the barrier that physics courses represent for students who are not well prepared, the often marginal support system that we provide for our students, and the neglect of these problems by many members of the faculty. . . . *Some decades ago we added the 'general' major, with a less demanding curriculum, based on the premise that we can provide substantive science-based education to students who do not intend to pursue a research career in physics. . . This . . . (the 'general major,' two new full year post-introductory courses, a 5-year program in conjunction with the College of Engineering, and an applied physics major). . . puts us in the rarified range of 45 graduating seniors this year. . . . . Our efforts have to continue, for the sake of the students, and for our own. We can do better!*" (Our italics.) See also Lindenfeld 2002 and Etkina et al. 1999.

Lindenfeld, P. 2002. "Guest Comment: Format and content in introductory physics," *Am. J. Phys.* **70**(1): 12-13.

Lopez, R.E. & T. Schultz. 2001. "Two Revolutions in K-8 Science Education." *Physics Today* **54**(9): 44-49; online at < <http://physicstoday.org/pt/vol-54/iss-9/p44.html> >.

Love, L.E. 2001. "Physics in the Elementary School," *APS Forum on Education Newsletter*, Spring; online at < <http://www.aps.org/units/fed/spring2001/index.html> >.

Mahajan, S. & R.R. Hake. 2000. "Is it time for a physics counterpart of the Benezet/Berman math experiment of the 1930's?" *Physics Education Research Conference 2000: Teacher Education*; online as ref. 6 at < <http://wol.ra.phy.cam.ac.uk/sanjoy/benezet/> >.

NAP. 2000. National Academy Press. Committee on Women in Science and Engineering. *Who Will Do the Science of the Future? A Symposium on Careers of Women in Science*; online at < <http://www.nap.edu/catalog/10008.html> >. See especially the contribution by Lederman on pages 7-11.

Norton S.D., P.H. Hammer, R. Czujko. 2002. "Mastering Physics for Non-Academic Careers" on the web at < <http://www.aip.org/professionalmasters/profmshigh.htm> > and < <http://www.aip.org/professionalmasters/index.htm> >: "The authors define a Professional Master's Degree program as one that addresses the current needs of the economy as well as addresses the needs of students by providing both fundamental knowledge and specialized skills. Fundamental knowledge is the foundation on which students will be able to build throughout their working lives and the specialized skills will enable students to get their careers started immediately after graduation . . . Using these criteria, we have identified: 22 physics departments that have the strongest Professional Master's Degree programs. . . ."

NRC. 1996. National Research Council, *National Science Education Standards*. National Academy Press < <http://books.nap.edu/catalog/4962.html> >. See also NRC (1999) and NRC (2000).

NRC. 1999. National Research Council, *Improving Student Learning: A Strategic Plan for Education Research and its Utilization*. National Academy Press < <http://www.nap.edu/catalog/6488.html> >.

NRC. 2000. National Research Council, *Inquiry and the "National Science Education Standards": A Guide for Teaching and Learning*. National Academy Press < <http://www.nap.edu/catalog/9596.html> >.

NSF. 1996. Advisory Committee, *Shaping the future: new expectations for undergraduate education in science, mathematics, engineering, and technology*; online at < <http://www.nsf.gov/cgi-bin/getpub?nsf96139> >.

NSF. 1998. National Science Board. *Science and Engineering Indicators 1998* ; online at < <http://www.nsf.gov/sbe/srs/seind98/start.htm> >: ". . . it appears that only 11 percent of Americans can define the term 'molecule.' . . . A large proportion of the population knows that a molecule is a small piece of matter, but is unable to relate it to an atom or a cell, which are also small pieces of matter. And, despite substantial media attention to deep space probes and pictures from the Hubble Space Telescope, *only 48 percent of Americans know that the earth goes around the sun once each year. . . . Only 27 percent of Americans understand the nature of scientific inquiry well enough to be able to make informed judgments about the scientific basis of results reported in the media.* Public understanding of the nature of scientific inquiry was measured through questions about the meaning of scientific study and the reasons for the use of control groups in experiments." (My *italics*.)

NSF. 1999a. National Science Board. *Preparing Our Children: Math and Science Education in the National Interest*, (NSB 99-31); online at < <http://www.nsf.gov/cgi-bin/getpub?nsb9931a> >: "There are many signs that teachers in the classroom cannot rely on their undergraduate education when teaching mathematics or science. According to the National Commission on Teaching and America's Future, as many as one in four teachers is teaching 'out of field.' The National Association of State Directors of Teacher Education and Certification reports that only 28 states require prospective teachers to pass examinations in the subject areas they plan to teach, and only 13 states test them on their teaching skills. Many students who turned away from mathematics and science in college become elementary school teachers."

NSF. 1999b. Committee on Undergraduate Science Education, *Transforming Undergraduate Education in Science, Mathematics, Engineering, and Technology*. National Academy Press; online at < <http://www.nap.edu/catalog/6453.html> >: "Vision 4 - SME&T faculties would assume greater responsibility for the pre-service and in-service education of K-12 teachers. *Improving the SME&T education of both pre-service and in-service K-12 teachers is one of the most important challenges facing college and university faculties.* Scientists, mathematicians, engineers, and teacher educators all need to share responsibility for teacher preparation . . . If Vision 4 were to be realized, these faculty would provide integrated pre-service and in-service experiences that blend scientific knowledge with pedagogical methods and effective teaching practices." (My *italics*.)

NSF. 2002. National Science Board. *Science and Engineering Indicators 2002* (NSB-02-1); online at < <http://www.nsf.gov/sbe/srs/seind02/start.htm> >. See Dawson (2002).

Pelligrino, J.W., N. Chudowsky, R. Glaser, eds. 2001. *Knowing What Students Know: The Science and Design of Educational Assessment*. National Academy Press; online at < <http://www.nap.edu/catalog/10019.html> >.

Raloff, J. 2001a. "Errant Texts: Why some schools may not want to go by the book." *Science News* **159**(11), March 17; online at < <http://www.sciencenews.org/20010317/bob9.asp> >.

Raloff, J. 2001b. "Where's the Book? Science education is redefining texts." *Science News* **159**(12), March 24; online at < <http://www.sciencenews.org/20010324/bob12.asp> >.

Redish, E.J. 1999. "Millikan lecture 1998: building a science of teaching physics." *Am. J. Phys.* **67**(7): 562-573; online at < <http://www.physics.umd.edu/rgroups/ripe/perg/cpt.html> >.

Reif, F. 1974. "Educational Challenges for the University," *Science* **184**, 537-542.

Shavelson, R.J. & L. Towne. 2001. *Scientific Research in Education*, National Academy Press; online at < <http://www.nap.edu/catalog/10236.html> >.

Snyder, W. 2001. "Understanding and Appreciating Physics from Pre-school On (or The Search for Intelligent Life in the Universe Should Start Here on Earth)," *APS Forum on Education Newsletter*, Spring; online at < <http://www.aps.org/units/fed/spring2001/snyder.html> >.

Stein, F. 2001. "The Blame Game in Teacher Preparation," *AAPT Announcer* **31**(4): 10-11; *APS Forum on Education Newsletter*, Fall; online at < <http://www.aps.org/units/fed/fall2001/index.html> >.

Swartz, C.E. 1993. Editorial: "Standard reaction." *Phys. Teach.* **31**: 334-335.



Swartz, C.E. 1969. *Measure and Find Out: A Quantitative Approach to Science*. Scott, Foresman and Company. According to the Hubisz (2001c) report: "Clifford E. Swartz, then Director of the National Science Foundation Workshop on *Elementary School Science by a Quantitative Approach*, wrote the three volume *Measure and Find Out: A Quantitative Approach to Science* . . . . These books have what is missing from most of the books reviewed in this report."

Tyson-Bernstein, H. 1988. *America's Textbook Fiasco, A Conspiracy of Good Intentions*. Council for Basic Education.

UMPERG. 2002. *Curriculum Materials in Physics Based on Physics Education Research*; online at < <http://www.physics.umd.edu/perg/ecs/matper.htm> >.

U.S. Congress. 2001. Public Law PL 107-110, *No Child Left Behind Act of 2001*; online at < <http://www.ed.gov/legislation/ESEA02> >.

Wilson, K.G. & B. Daviss. 1994. *Redesigning education* (Henry Holt, 1994); description online at < <http://www-physics.mps.ohio-state.edu/~kgw/RE.html> >.

Wilson, J. 2002. "The Physics Major: An Endangered Species?" *APS Forum on Education Newsletter*, Spring 2002; online at < <http://www.aps.org/units/fed/spring2002/index.html> >.

Woolf, L. 1999. *Science Education Petition* of 22 December, online at < <http://www.sci-ed-ga.org/standards/petition.html> > : "the California Science Standards are *based on neither the spirit nor the letter of the National Science Education Standards developed by the National Academy of Sciences or the Benchmarks for Science Literacy*. . . many are incorrect, misleading, ambiguous, and age-inappropriate . . . the California Academic Standards Commission has approved a policy that *effectively prohibits the adoption of scientifically accurate, thoroughly tested, and highly regarded kit-based science curricula*, . . . (and) . . . has approved a policy that allows the adoption of materials that have never been thoroughly tested in classrooms." (My *italics*.) Material related to the petition is online at < <http://www.sci-ed-ga.org/standards/> >. Woolf's petition was signed by 330 Californians, among them: Andrew Sessler, past president of the APS; James Langer, then president of the APS; Jerry Pine, co-director of the Cal Tech Precollege Science Institute; Wendell Potter, vice chair of the Physics Dept., Univ. of California at Davis; Helen Quinn of the Stanford Linear Accelerator; Richard Shavelson, Professor of Education and Psychology at Stanford; J.M. Atkin, Chair of the Committee on Science Education K-12 at the National Research Council; Fred Goldberg, Professor of Physics, San Diego State University; Angelica Stacy, Professor of Chemistry, Univ. of California-Berkeley; and many California science teachers and educators from elementary-, middle- and high-schools