What Can We Learn From the Biologists About Research, Development, and Change in Undergraduate Education?*‡

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– What is REDCUBE?
– WWW and Educational Infrastructure
– Why Biology?
– Contents of REDCUBE
– Benefits of REDCUXE (X = Biology, Chemistry, etc.)
– Overviews of Undergraduate Biology Education Reform
– What Have We Learned?
– Epilogue
– Appendix: Phys. Ed. Needs Revitalization; Some Intro. Refs. on Undergrad. Biology Reform; Refs. and Footnotes for this Presentation

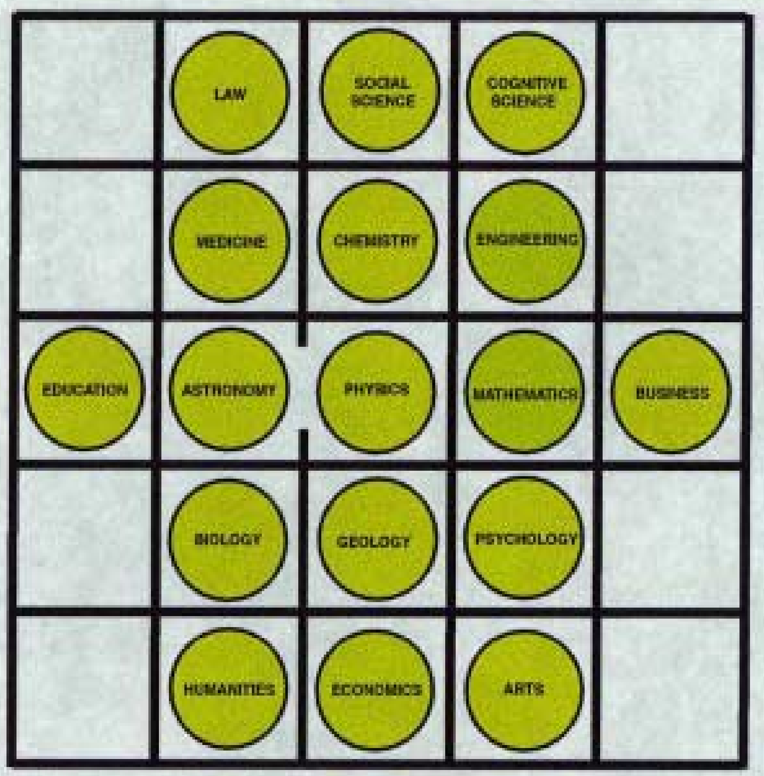
*Partially supported by NSF Grant DUE/MDR-9253965

‡ The literature reference is R.R. Hake, *AAPT Announcer* **29**(4), 99 (1999); on the web at <http://physics.indiana.edu/~hake/>.

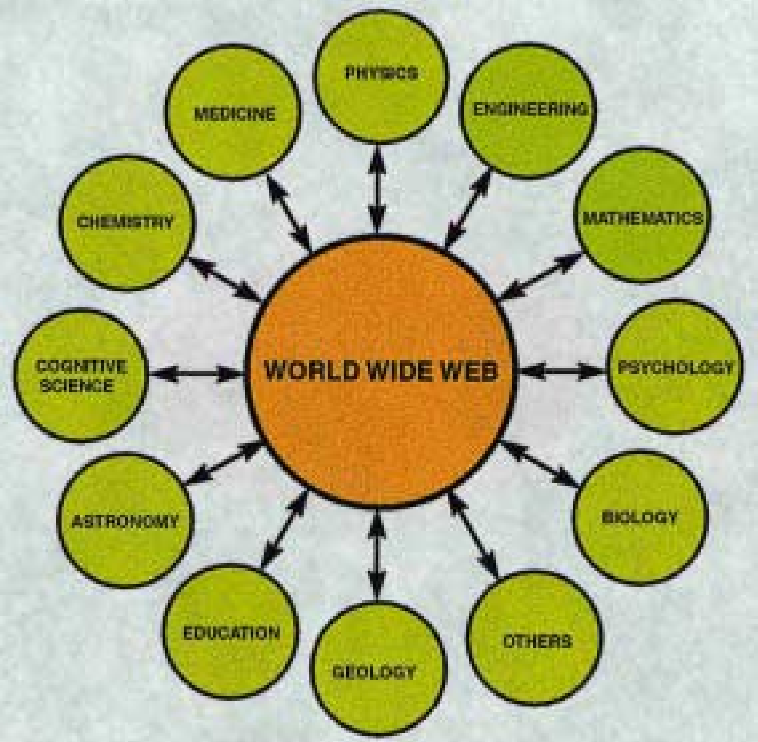
The REDCUBE Web Guide

- REsearch, Development, and Change in Undergraduate Biology Education (REDCUBE), A Webguide for Non-Biologists
  - On the web as a portable document file at <http://www.physics.indiana.edu/~redcube>
  - Provides a web window onto the world of biology-education reform

- May promote interdisciplinary synergy, thus hastening the glacial pace of educational reform



Present Education Researchers and Developers

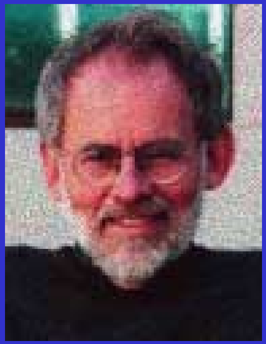


Future Education Research/Development *Community* ???

“Change requires ongoing interaction among communities of people and institutions that will reinforce and drive reform. ……. educators need to form 'invisible colleges’ resembling the national and international research communities."

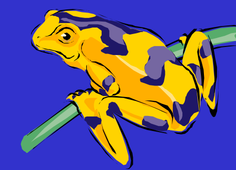
From Analysis to Action: Undergraduate Education in Science, Mathematics, Engineering, and Technology

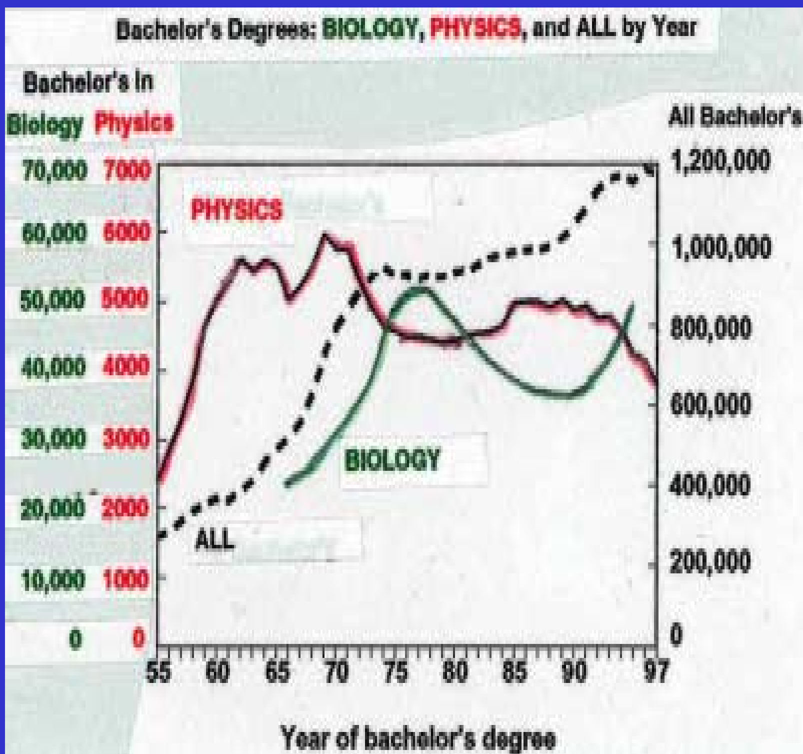
THE WWW: TOWARDS A POWERFUL EDUCATIONAL INFRASTRUCTURE



Roy Pea

- ”…..tools for learning communities must move beyond forums for exchanging tidbits and opinions, to structures which rapidly capture knowledge-value and foster rapid accumulation and growth of a community’s capability ……… tools to allow contributors to share partially completed resources, and enable others to improve upon them. A related direction is *‘knowledge mining’ - discovering efficient processes for quickly aggregating and collating the knowledge of a community on a particular topic.*” (My *italics*.)
  - – (Roy Pea & Jeremy Roschelle)

Why Biology? 



- Pace of reform probably more rapid than in physics
- Larger pool of experience - Biology Bachelor’s Per Year (Biology-BPY) 10 times greater than physics
- Biology-BPY rising rapidly over the past decade, while Physics-BPY falls rapidly (even while All-BPY rises) - Why??
- Many students in physics courses for captives are biology majors - might biologists, aware of ineffective physics teaching, decide to teach physics themselves?
- $335 million Hughes Medical Institute grants to 220 colleges has stimulated some model reforms

CONTENTS OF REDCUBE

(Version of 8 Sept. 1999)

- 47 biology-educator profiles,
- 446 references (124 relevant to general science-education reform),
- 490 hot-linked <URL's> on:
  - Biology Associations,
  - Biology Teacher's Web Sites,
  - Scientific Societies and Projects (not only Biology),
  - Higher Education,
  - Cognitive Science and Psychology,
  - U.S. Government, and
  - Searches and Directories.
- Updated about every 6 months with "linkrot" eradication

POSSIBLE BENIFITS OF REDCUXE (X = Biology, Chemistry, Engineering, Geology, Mathematics, etc.)

- References and <URL's> may be useful to teachers and education researchers
- May provide some ideas (both pedagogical and institutional/political) for speeding reform
- May stimulate other disciplines to:
  - construct a resource similar to the AAPT's *Physical Science Resource Center*
  - Produce a resource letter similar to that by McDermott and Redish
  - Devote more effort to *research* in education (in addition to development and implementation)

TWO GOOD OVERVIEWS ON RESEARCH, DEVELOPMENT, AND CHANGE IN UNDERGRADUATE BIOLOGY EDUCATION

- Howard Hughes Memorial Institute (Undergraduate Biology Education) <http://www.hhmi.org/grants/undergraduate/>
  - Beyond Bio 101 <http://www.hhmi.org/BeyondBio101/index.htm>

- C. D'Avanzo and A.P. McNeal, eds., *Student-Active Science: Models of Innovation in College Science Teaching* (Saunders, 1997); <http://www.saunderscollege.com/lifesci/studact/>

WHAT HAVE WE LEARNED FROM REDCUBE?

- Some biologists (*examples* of their locations are in "[…..]") are very active in developing and implementing non-traditional teaching methods
  - Collaborative Learning [Univ. of Wisconsin-Madison, Cal State Univ (Fresno), Beloit, Stanford, Drexel, Indiana Univ., Beloit, Hampshire, Portland State, Worcester Polytechnic, Univ. of Oregon]
  - Problem/project/case-based learning [Univ. of Delaware, Biological Sciences Curriculum Study, Beloit, Mercer University School of Medicine, University of Missouri - Columbia School of Medicine, Southeast Missouri State, Queens University (Canada) School of Medicine, SUNY-Binghamton, Portland State
  - Writing, speaking, ethics [Wesleyan]
  - Dealing with evolution (cf., The Big Bang) [San Diego State, Univ. of Tennessee, Delta State, Univ. of California- Riverside, Indiana University, Rensselaer, Mercer Univ. School of Medicine, Beloit College, Yale, Baruch College]

- Assessment [Louisiana State, UCLA, Univ. of Missouri-Columbia Medical School, Rensselaer, Univ. of Wisconsin-Madison, San Diego State]
- Mathematics in Biology [Beloit, Univ. of Tennessee]
- Advanced Technology [Vanderbilt, Rensselaer, Drexel, Beloit, MIT, Florida Institute of Technology, San Diego State, Concord Consortium, Trinity Univ., Cal State-Northridge, Mesa Community College]
- Concept Mapping [San Diego State, Cornell]
- Web Posting of Class Materials [MIT, Univ. of Illinois-Urbana]
- Undergraduate Research [Reed, Univ. of Arizona, Hampshire, SUNY-Binghamton, Portland State, Millikin Univ.]
- Workshop Biology [Univ. of Oregon]

• Biologists at some institutions (*examples* in "[…..]") have instigated institutional/political changes
  - Broad institutional support for reform of biology education [Univ. of Wisconsin-Madison, Univ. of Delaware]
  - Interdisciplinary courses and seminars [Notre Dame, Case, Haverford, Stanford, Baruch College, Radford University, Stockton College, Spelman College, Evergreen] "the walls...(between disciplines)... must come down....Students are typically interested in problems of modern society, and these problems often have multifaceted scientific and technological components. Discipline-specific introductory courses are well suited for already committed majors, but they are not able to tap the richness available in a discussion of issues dealing with the environment, health, or technological innovation." *The Freshman Year in Science and Engineering* (Alliance for Undergraduate Education, 1990)

- Integration with humanities and social sciences [SUNY- Binghamton, Portland State]
- Interactive Video Network [Univ. of North Dakota]
- Heavier weighting of teaching and educational contribution in tenure/promotion decisions [Univ. of Arizona]
- Recruitment and retention of women and minorities [Morehouse, Fort Lewis, Xavier Univ. of Louisiana, Univ. of Texas-San Antonio, Wellesley, University of Florida-Gainesville, Northern Arizona Univ., Michigan State, Georgia Tech. Spelman College]
- Personalization of instruction via the Internet [Univ. of Illinois-Urbana, Emery, Bates]
- Total redesign of introductory curriculum [Bryn Mawr]

EPILOGUE

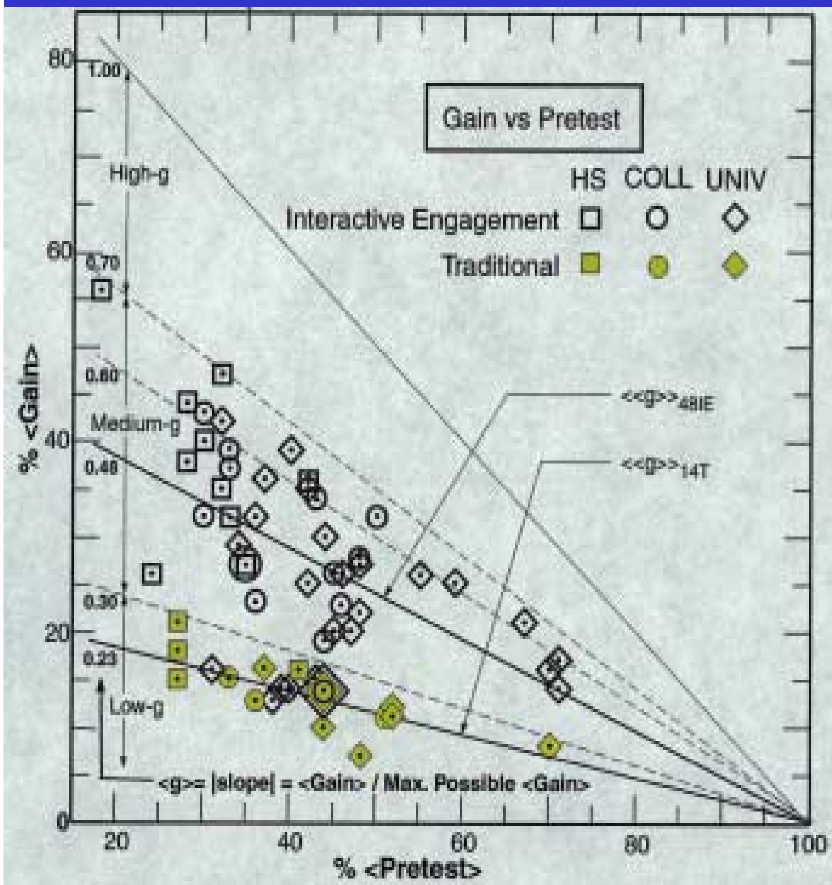
- History suggests that the present national educational reform effort may have little lasting impact. This would be most unfortunate, considering the current imperative to
  - *educate more effective science majors and science-trained professionals*
  - *raise the appallingly low level of science literacy among the general population*
  - *solve the monumental science-intensive problems (economic, social, political, and environmental) that beset us*

- Progress towards educational reform will probably require
  - *long-term classroom use, feedback, assessment, research analysis, and redesign of non-traditional educational methods and curricula*
  - *the interdisciplinary cooperation of instructors, departments, institutions, and professional organizations*

APPENDIX

- Undergraduate Physics Education Needs Revitalization
- Some Suggested *Introductory* REDCUBE References
- References and Footnotes for this Presentation

Undergraduate Physics Education Needs Revitalization



Average pre-to-post gain vs average pretest score on the Halloun-Hestenes tests of conceptual understanding of mechanics for 62 introductory courses enrolling 6542 students. Traditional courses cluster in the low-gain region. R.R. Hake, *Am. J. Phys.* **66**(1), 64-74 (1998).

- Bachelor's production in physics is at four-decade low and falling; in biology it's 10 times greater than in physics and rising rapidly (see Slide #5)
- Research in physics education strongly suggests that traditional courses fail to promote students' conceptual understanding, whereas interactive engagement courses are much more effective
- But few physics faculty have relinquished traditional methods of instruction.

- In addition to relatively ineffective physics teaching, Institutional and Political Factors Slow Reform
  - AP physics serves as a filter rather than a pump
  - In-class and standardized tests (MCAT, SAT, GRE) drive the curriculum in a traditional direction (but the test makers dispute this - see at <http://www.hhmi.org//BeyondBio101/tests.htm>)
  - Effectiveness of physics teaching has little effect on promotion/tenure decisions or on national departmental rankings
  - High-school physics is not required for college admission; many colleges require little or no science for graduation
  - Clients for physics aren't cultivated among those who do *not* wish to obtain a physics PhD (but see double-major and "3,2 programs" described by Erhlich; and the new M.S. programs for professional science-based careers at <http://www.ScienceMasters.com>)
  - Class sizes are too large

Sheila Tobias (with some minor editing)

Sheila Tobias

Robert Ehrlich

- Enrollments in classes for captives are in jeopardy. “Nationally 50% of the student credit hours generated by physics departments come from engineering students.” (Paul Zitzewitz)
  - “Under the new Accreditation Board for Engineering and Technology (ABET) ‘Engineering Criteria 2000’…. much greater emphasis is placed on ***measurable evidence of student learning***, rather than credit hours taken….. The ‘professional component’ …. will require only ‘one year of a combination of college level mathematics and basic sciences… appropriate to the discipline.’ ” (Robert Ehrlich)
  - In a survey of 86 engineering deans, Ehrlich found that 32% indicated that they would “seek to have physics taught within engineering, accreditation requirements permitting.”

SOME SUGGESTED *INTRODUCTORY* REDCUBE REFERENCES

- Howard Hughes Memorial Institute (Undergraduate Biology Education) <http://www.hhmi.org/grants/undergraduate/>
  - Beyond Bio 101 <http://www.hhmi.org/BeyondBio101/index.htm>

- University of Delaware Problem Based Leaning Program <http://www.udel.edu/pbl/>; D. Allen and B. Duch, *Thinking Towards Solutions: Problem-Based Learning Activities for General Biology* (Saunders, 1998).

- ASM American Society For Microbiology (cf. AAPT's Physical Science Resource Center) <http://www.asmusa.org/>)
  - Education <http://www.asmusa.org/edusrc/edu1.htm>
  - Curriculum Activities for Undergraduate Education <http://www.asmusa.org/edusrc/edu4d.htm>
  - Undergraduate Microbiology Education Conferences <http://www.asmusa.org/edusrc/edu4c.htm>
  - Parents, Students, and General Public Site <http://www.microbeworld.org>
  - Digital Library of Mircobiology Resources for Teaching and Learning <http://www.asmusa.org/edusrc/educ3.htm>

- Lou Gross's site on quantitative aspects of the life sciences <http://www.tiem.utk.edu/~gross/>.

- BioQUEST Curriculum Consortium - Beloit College <http://bioquest.ort>.

- Anton Lawson: scientific thinking patterns and neurological models of cognition <http://lsvl.la.asu.edu/biology/faculty/lawson.html>; *Science Teaching and the Development of Thinking* (Wadsworth, 1995); contains a test of critical thinking.

- Worcester Polytechnic site on collaborative learning at <http://www.wpi.edu/Academics/Depts/Bio/People/miller.html>.

- Univ. of Wisconsin - Madison’s Biology Education Center:
  - "Innovation in Teaching: Novel Approaches to Knotty Problems, Spotlight on Departments" <http://www.cals.wisc.edu/iic/innovation.html>,
  - "Undergraduate Research Opportunities in Biology at UW-Madison” <http://www.wisc.edu/cbe/research/>,
  - "Technology uses in biology education” <http://newmedia.doit.wisc.edu/bnmc/instruct/index.htm >,
  - J. Handlesman, B. Houser, and H. Kriegel, *Biology Brought to Life: A guide to teaching students to think like scientists* (Times Mirror, 1997).
- G.E. Uno, *Handbook on Teaching Undergraduate Science Courses: A Survival Training Manual* (Saunders, 1999, in press); <http://www.ou.edu/cas/botany-micro/faculty/uno-book.shtml >.

- Concord Consortium: simulations - GenScope(genetics), BioLogica (cellular structure) <http://genscope.concord.org/>, <http://www.concord.org/projects/index.html#mod>.

- J.A. Moore, *Science as a Way of Knowing: The Foundations of Modern Biology* (Harvard University Press, 1993).

- H. Roy, Rensselaer, “The Studio Genetics and Evolution Course” <http://www.rpi.edu/dept/bio/info/Biosimlab/genetics.html>.

- University of Oregon "Workshop Biology,” <http://www.hhmi.org/BeyondBio101/index.htm>, <http://biology.uoregon.edu/Biology_www/workshop_biol/wb.html>.

- C. D'Avanzo and A.P. McNeal, eds., *Student-Active Science: Models of Innovation in College Science Teaching* (Saunders, 1997); on the web at <http://www.saunderscollege.com/lifesci/studact/>:

  - D.E. Allen, "Bringing Problem-Based Learning to the Introductory Biology Classroom."

  - C. D'Avanzo and A.P. McNeal, "Research for all students: structuring investigation into first-year courses."

  - M. Flower, C. Ramette, and W. Becker, "Science in the Liberal Arts at Portland State University: A Curriculum Focusing on Science-in-the-Making."

  - S.E. Groh, B.A. Williams, D.E. Allen, B.J. Duch, S. Mierson, and H.B. White "Institutional Change in Science Education: A Case Study."

- J.R. Jungck, "Realities of Radical Reform: Reconstructing 'Chilly Climates' into 'CollaborativeCommunities' - Sharing BioQUEST Experience."

- A.P. McNeal, "Teacher-Active Workshops: Collaborative Structures for Curricular Reform."

- J.L. Narum, "Some Lessons Learned."

- G.S. Prince, Jr. and N. Kelly, "Hampshire College as a Model for Progressive Science Education."

- M.D. Sundberg, "Assessing the effectiveness of an investigative laboratory to confront common misconceptions in life science."

- G.E. Uno, " Learning About Learning Through Teaching About Inquiry."

REFERENCES AND FOOTNOTES FOR THIS PRESENTATION

SLIDE #2 - The REDCUBE Web Guide

1. Portable document files (pdf's) are transportable across nearly all platforms and now pervade the web. Downloading of PDF documents such as REDCUBE requires use of the FREE Adobe Acrobat (AA) "Reader," version 3 or later. Version 4.0 is downloadable at <http://www.adobe.com/prodindex/acrobat/readstep.html>. Recent versions of Netscape Navigator/Communicator and Internet Explorer (all can be downloaded for free) have the AA Reader built in, so that clicking on the pdf icon will download the file automatically.

SLIDE #3 - Interdisciplinary Synergy

1. *From Analysis to Action: Undergraduate Education in Science, Mathematics, Engineering, and Technology, Report of a Convocation* (National Academy Press, 1996), also at <http://www.nap.edu/readingroom/books/analysis/ >. A good set of references is appended.

2. The window between Astronomy- and Physics- education research and development appears to be a fortunate carryover from the traditional close links between those two disciplines in non-educational basic research.

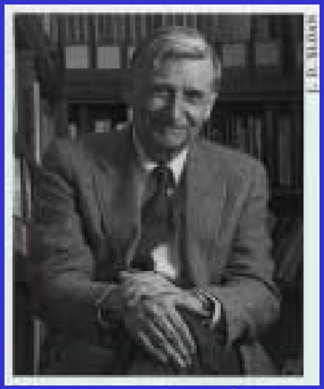
3. The case for *discipline-based* research in education has been made by E.F. Redish "Millikan Lecture 1998: Building a Science of Teaching Physics," *Am. J. Phys.* **67**(7), 562-573 (1999); on the web at <http://www.physics.umd.edu/rgroups/ripe/perg/cpt.html>.

4. Karl Pister (former Chancellor of UC - Santa Cruz), "Renewing the Research University," *University of California at Santa Cruz Review* (Winter 1996): "Three cultural shifts must occur if.... (public universities)......are to succeed...(in meeting the needs of the country).…. First, we need to encourage innovative ways of looking at problems, moving away from the increasing specialization of academia to develop *new interdisciplinary fields that can address complex real-world problems from new perspectives*. Second, the orientation of faculty effort and the faculty reward system in our universities must support the full range of institutional missions in a more balanced manner. Third, our society must be willing to make quality education, especially in science and technology, accessible at all levels for all students. Education must be seen more as an investment in society's well-being and less as a cost.” (My *italics*.)
<http://www.ucsc.edu/news_events/review/text_only/Winter-96/Win_96-Pister-Renewing_.html>

5. G.S. Prince, Jr. and N. Kelly, "Hampshire College as a Model for Progressive Science Education,” in *Student-Active Science: Models of Innovation in College Science Teaching*, A. P. McNeal and C. D'Avanzo, eds. (Saunders, 1997), see <http://www.saunderscollege.com/lifesci/studact/chapters/ch03.html>: "The combined success of a range of sound, well-conceived projects ..... have not changed the major indices measuring scientific literacy. The irony of discrete successes leading to little overall change is a result of two persistent beliefs within 'traditional' reform efforts themselves: *the belief that science is distinct from other fields of learning*, and the belief that patterning science education at all levels on a university model represents fundamental reform. 'Progressive'

efforts to reform science education, on the other hand, look at science as integral to a broader learning enterprise, and the effort to improve its teaching as one involving fundamental premises that underlie all learning .... If students are seen as active learners and given the chance to shape the questions and problems to be addressed, then assumptions about their ability to do the work become of necessity positive, and they respond by doing science. If the general underlying assumptions about the nature of education do not change, there will be no progress in science education reform." (My *italics*.)

6. E.O. Wilson, *Consilience: The Unity of Knowledge* (Knopf, 1998): "Then I discovered evolution. Suddenly …. I saw the world in a wholly new way…….. Natural history was validated as a real science. I had experienced the Ionian Enchantment…… a conviction….. that the world is orderly and can be explained by a few natural laws. Its roots go back to Thales of Miletus, in Ionia, in the sixth century B.C. ….. the spell of the Enchantment extends to other fields of science…. (besides physics)….. and in the minds of a few it reaches beyond into the social sciences, and still further…… to touch the humanities.



E.O. Wilson

7. *The Liberal Art of Science: Agenda for Action* (American Association for the Advancement of Science, 1990): "Education in science is more than the transmission of factual information: It must provide students with a knowledge base that enables them to educate themselves about the scientific and technological issues of their times; it must provide students with an understanding of the nature of science and its place in society; and it must provide them with an understanding of the methods and processes of scientific inquiry. To achieve these goals science should be taught as science is practiced at its best."

SLIDE #4 - The WWW: Towards a Powerful Educational Infrastructure

1. J. Roschelle and R. Pea, "Trajectories from Today's WWW to a Powerful Educational Infrastructure," *Educational Researcher*, June-July 1999, 22-25, 43.

2. Roy Pea, "New Media Communications Forums for Improving Education Research and Practice," in E. Condliff Lagemann and L.S. Shulman (eds.) *Issues In Education Research* (Jossey-Bass, in press); on the web at <http://www.sri.com/policy/ctl/html/contexthome.htm>.

3. R.D. Pea, "Augmenting the Discourse of Learning with Computer-Based Learning Environments," in *Computer-Based Learning Environments and Problem Solving*, ed. by E. DeCorte, M.C. Linn, H. Mandl, and L. Verschaffel (NATO ASI Series, series F, vol. 84, 1992).

SLIDE #5 - Why Biology?

1. AIP Publication #R-151.35, March 1999, *Enrollments and Degrees Report* <http://www.aip.org/statistics/trends/undtrends.htm>.

2. U.S. Dept. of Education, *Digest of Educational Statistics*, Chap. 3, "Postsecondary Education," <http://nces.ed.gov/pubs99/digest98/d98t250.html>.

3. Howard Hughes Medical Institute, *Beyond Bio 101: The Transformation of Undergraduate Biology Education*, Chapter 1, *Biology: A Hot Degree on Campus* <http://www.hhmi.org/BeyondBio101/degree.htm>.

4. R. Ehrlich, "What Can We Learn from Recent Changes in Physics Bachelor Degree Output?" *Phys. Teach.* **37**(3), 142-146 (1999).

5. R. Ehrlich, "Historical Trends in Physics Bachelor Output," *Phys. Teach.* **36**(6), 328-333 (1999).

6. R. Ehrlich, "Where are the physics majors?" *Am. J. Phys.* **66**, 79-86 (1998).

SLIDE #7 - Possible Benefits of REDCUXE (X = Biology, Chemistry, etc.)

1. American Association of Physics Teachers < http://www.aapt.org>; AAPT, *Physical Science Resource Center* <http://www.psrc-online.org/>.

2. L.C. McDermott and E.F. Redish, "RL-PER1: Resource Letter on Physics Education Research," *Am. J. Phys.* **67**, 755-767 (1999); <http://www.physics.umd.edu/rgroups/ripe/papers/rlpre.pdf>.

3. E.F. Redish, "Millikan Lecture 1998: Building a Science of Teaching Physics," *Am. J. Phys.* 67(7), 562-573 (1999); makes a case for the communal sharing of information on teaching and learning: "Why do we never seem to share and pass down to succeeding generations anything we learn in physics education?…….I believe the answer is clear. The problem is that many physics departments believe they have to create their own solutions …… Sharing of experiences and insights is rare even among faculty teaching the same course in succeeding years, especially at research universities. Treating education as a problem to be handled individually rather than scientifically by the community at large, instead of creating a community-consensus knowledge base, we continue to (in the felicitous phrase of Arnold Arons) 'reinvent the flat tire.' "
On the web at <http://www.physics.umd.edu/rgroups/ripe/perg/cpt.html>.

4. R.R. Hake, "Interactive-engagement vs traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses," *Am. J. Phys.* **66**, 64-74 (1998). On the web at <http://www.physics.indiana.edu/~sdi>.

5. R.R. Hake, "Towards Paradigm Peace in Physics Education Research," accepted for presentation at the AERA annual meeting in New Orleans, 4/2000, on the web at <http://www.physics.indiana.edu/~hake>. Lists recent physics-education research articles that are consistent with ref. 4, and discusses the complementarity of qualitative and quantitative research in physics education.

6. K. J. Heller, " Introductory Physics Reform in the Traditional Format: An Intellectual Framework," *AIP Forum on Education Newsletter*, Summer 1999, pp. 7-9 (1999); on the web at <http://webs.csu.edu/~bisb2/FEdnl/heller.htm>. Relates some non-traditional physics-teaching methods [Cooperative Group Problem Solving (Heller & Heller), Interactive Demonstrations (Sokoloff and Thornton), Overview Case Studies (van Heuvelen), Peer Instruction (Mazur), Socratic Dialogue Inducing Laboratories (Hake), and Tutorials (McDermott)) to "developmental theory" and "cognitive apprenticeship."

7. D. Hestenes, "Guest Comment: Who needs physics education research!? *Am. J. Phys.* **66**(6), 465-467 (1998): "Most of our colleagues have been oblivious to …..(physics education research)….. if not contemptuous of it. Some are beginning to realize that it is more than another 'educational fad.' It is a serious program to apply to our teaching the same scientific standards that we apply to physics research."

8. NSF's recent 8-million dollar *Research on Learning and Education* (ROLE) program "will support research along a four-quadrant continuum that includes (1) *brain research as a foundation for research on human learning*; (2) fundamental research on behavioral, cognitive, affective, and social aspects of human learning; (3) research on science, mathematics, engineering, and technological (SMET) learning in formal and informal educational settings; and (4) research on SMET learning in complex educational systems." (My *italics*.) <http://www.nsf.gov/cgi-bin/getpub?nsf0017>. [As indicated in refs. 9 & 10, some caution should probably be exercised in regarding "brain research as a foundation for research on human learning."

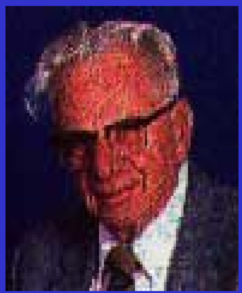
9. J.T. Bruer, "Education and the Brain: A Bridge Too Far," *Educational Researcher* **26**(8), 4-16 (1997). (Bruer heads the John T. McDonnell Foundation); *Schools for Thought: A Science of Learning in the Classroom* (MIT Press, 1994).

10. C. F. Chabris, "Prelude or requiem for the 'Mozart effect'?" *Nature* **400**, 826-827 (1999); on the web at <http://wjh-www.harvard.edu/~cfc/MozartNature.pdf>; W.J. Cromie, "Mozart Effect Hits Sour Notes," *Harvard Gazette*, 8/25/99; on the web at <http://www.news.harvard.edu/science/current_stories/25.Aug.99/mozart.html>.

SLIDE #12: Epilogue

I. Difficulties of Reform Movements

1. A. B. Arons, "Uses of the Past: Reflections on United States Physics Curriculum Development, 1955 to1990," *Interchange* **24**(1&2), 105-128 (1993); "Improvement of Physics Teaching in the Heyday of the 1960's," in *Conference on the Introductory Physics Course on the occasion of the retirement of RobertResnick*, Jack Wilson, ed. (Wiley, 1997), p. 13-20: "The problem now is how to make the insights being acquired achieve deeper and more lasting impact on existing delivery systems and, still more importantly, on sensible and realistic choice of subject matter, on intellectually digestible volume and pace of coverage, and on matching the impedance of different student populations …. A key issue still remains what I call 'honest' presentation. Honest presentation entails showing students *how we know, why we believe, why we accept, what is the evidence for, the concepts and theories we throw at them.* Deluging them as rapidly as possible in the end results of developmental sequences is not what I am willing to describe as honest; it is vulnerable to John Gardner's trenchant criticism of much of American education to the effect that we hand our students the cut flowers and forbid them to see the growing plants." (My *italics*.)



Arnold Arons

2. C. Swartz, "The Physicists Intervene," *Phys. Today* **44**(9), 22-28 (1991): "For over 150 years American physicists have been making forays into elementary and high school science teaching. Their novel approaches have usually worked - but the results have always been short-lived."

3. S. Tobias, "Guest Comment: Science Education Reform: What's wrong with the process?" *Am. J. Phys*. 60, 679-681 (1992).

4. S.B. Sarason, *The Predictable Failure of Educational Reform* (Jossey-Bass, 1990); *Revisiting "The Culture of The School and The Problem of Change"* (Teachers College Press, 1996).

5. G. Holton, "A Nation at Risk Revisited," in *The Advancement of Science and its Burdens* (Univ. of Cambridge Press, 1986): "If the Constitution and the Tenth Amendment are interpreted narrowly, as is now the fashion, one cannot be surprised by the movement to phase out most or all of the federal responsibility for education …… Thomas Jefferson, in asking Congress for a remedy, said 'An amendment of our Constitution must here come in aid of the public education. The influence on government must be shared by all the people.'........Without a device that encourages cumulative improvement over the long haul, without a built-in mandate to identify and promote the national interest in education as well as to 'help fund and support efforts to protect and promote that interest' …… we shall go to sleep again between the challenges of a Sputnik and a Honda."

6. W.P. Wolf, "Is Physics Education Adapting to a Changing World?" *Phys. Today* **47**(10), 48-55 (1994).

7. S. Tobias, "Science-Trained Professionals' – A New Breed for the New Century," *J. Sci. Ed. Technol.* **5**, 167-169 (1996).

8. *Daedalus* **127**(4), 1998 issue *Education yesterday, education tomorrow*. For a description see <http://daedalus.amacad.org/inprint.html>. Contains essays by researchers in education and by historians of more rapidly developing institutions such as power systems, communications, health care, and agriculture. Sets out to answer a challenge posed by Kenneth Wilson: "If other major American 'systems' have so effectively demonstrated the ability to change, why has the education 'system' been so singularly resistant to change? What might the lessons learned from other systems' efforts to adapt and evolve have to teach us about bringing about change - successful change - in America's schools?" For a partial answer see ref. 34.

SLIDE #12: Epilogue - II. Science Illiteracy

9. G. Holton, "The Anti-Science Phenomenon," (and citations therein) in *Science and Anti-Science* (Harvard University Press, 1993); *Einstein, History, and Other Passions: The Rebellion Against Science at the End of the Twentieth Century* (Addison Wesley, 1996) [Einstein's "Ionian Enchantment" (cf. Slide #3, ref. 6, E.O. Wilson) is discussed on pages 160-164.]

10. "Science literacy," as used here, does not mean the knowledge of science "facts" as measured by some "science literacy tests," but rather an understanding of the methods, history, and limitations of science; the relationship of science to society and to other disciplines; and a working knowledge of science in at least a few areas such as to allow further self-education as the need may arise. See A.B. Arons, *A Guide To Introductory Physics Teaching* (Wiley, 1990) pp. 289-290; reprinted with minor updates in *Teaching Introductory Physics* (Wiley, 1997).

11. *Benchmarks for Science Literacy - Project 2061*, AAAS (Oxford Univ. Press, 1993); see at <http://project2061.aaas.org/tools/benchol/bolframe.html>.

12. S. Bowen, “TIMSS - An Analysis of the International High School Physics Test,” *APS Forum on Education Newsletter*, Summer 1998, pp. 7-10, on the web at <http://www.research.att.com/~kbl/APS/aug98/TIMSS2.htm>.

13. M. Neuschatz, “What can the TIMSS teach us?” *The Science Teacher* **66**(1), 23-26 (1999)

14. *Science and Engineering Indicators* (NSF, 1998), Chap. 7, "Science and Technology”: "..... 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.” On the web at <http://www.nsf.gov/sbe/srs/seind98/start.htm>

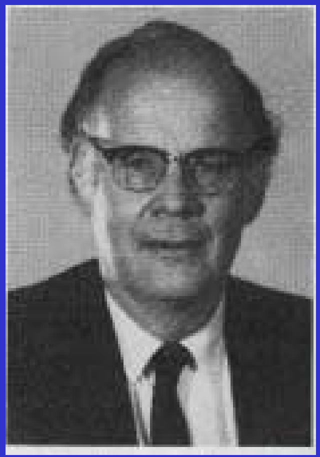
15. *The Nation’s Report Card*, National Assessment of Educational Progress (NAEP); on the web at <http://nces.ed.gov/nationsreportcard/site/home.asp>. C. Y. O'Sullivan, C. M. Reese, and J. Mazzeo *NAEP 1996 Science: Report Card for the Nation and the States*, on the web at <http://nces.ed.gov/nationsreportcard/96report/97497.shtml>: “Three percent of the nation's students reached the Advanced level at all three grade levels. Twenty-six percent of fourth- and eighth-grade students and 18 percent of the twelfth-grade\ students performed within the Proficient level, while 38 percent, 32 percent, and 36 percent performed within the Basic level for grades 4, 8, and 12, respectively.”

SLIDE #12: Epilogue - III. Science-Intensive Problems

16. R. Marshall and M. Tucker, *Thinking for a Living* (Basic Books, 1992).

17. A.A. Bartlett, “Forgotten fundamentals of the energy crisis,” *Am. J. Phys.* **46**(9), 876-888 (1978): “The greatest shortcoming of the human race is our inability to understand the exponential.”

18. A.A. Bartlett, "Reflections on Sustainability, Population Growth, and the Environment," *Population and Environment* **16**(1), 5-34 (1994); revised version, *Renewable Resources Journal* **15**(4), 6-23 (1997-98); on the web at <http://lahr.org/john-jan/growth/bartlett.html> “In the 1980’s it became apparent to thoughtful individuals that population, poverty, environmental degradation, and resource shortages were increasing at a rate that could not long be continued….(as indicated in)…. the book *Limits to Growth* (Meadows *et al.*, 1972) which simultaneously evoked admiration and consternation…... As the message of *Limits* faded, the concept of limits became an increasing reality with which people had to deal. ….. The use of the word ‘sustainable’ provided comfort and reassurance to those who may momentarily have wondered if possibly there were limits….. In the extreme case one reads about ‘sustainable growth.’ If we accept the idea that ‘sustainable’ means for long indefinite periods of time, then we can see that ‘sustainable growth’ implies ‘increasing endlessly,’ which means that the growing quantity will tend to become infinite in size.”



Albert Bartlett

19. A.A. Bartlett, “The Exponential Function, XI: The New Flat Earth Society,” *Phys. Teach.* **34**(6), 342-343 (1996); “Is There a Population Problem,” *Wild Earth* **7**(3), 88-90 (1997); "The Massive Movement to Marginalize the Modern Malthusian Message," *The Social Contract* **8**(3), 239-251 (1998). All are on the web at <http://lahr.org/john-jan/growth/bartlett.html>.

20. E.O. Wilson, *Consilience: The Unity of Knowledge* (Knopf, 1998), esp. Chap. 12 “To What End”: “The global population is precariously large, and will become much more so before peaking some time after 2050. Humanity overall is improving per capita production, health, and longevity. But it is doing so by eating up the planet’s capital, including natural resources and biological diversity millions of years old. Homo sapiens is approaching the limit of its food and water supply. Unlike any species before, it is also changing the world’s atmosphere and climate, lowering and polluting water tables, shrinking forests, and spreading deserts. *Most of the stress originates directly or indirectly from a handful of industrialized countries*. Their proven formulas for prosperity are being eagerly adopted by the rest of the world. The emulation cannot be sustained, not with the same levels of consumption and waste. Even if the industrialization of the developing countries is only partially successful, the environmental aftershock will dwarf the population explosion that preceded it.” (My *italics*.)

21. M. Gell-Mann, *The Quark and the Jaguar: Adventures in the Simple and the Complex* (W.H. Freeman, 1994), ch. 22, pp. 345 - 366.

22. G.E. Brown, "New Ways of Looking at US Science and Technology," *Phys. Today* **47**(9), 31-35 (1994).

23. R.W. Schmitt, "Public Support of Science: Searching for Harmony," *Phys. Today* **47**(1), 29-33 (1994).

24. K. W. H. Panofsky, “Physics in Arms Control,” *Physics and Society* **28**(4), 1-3 (1999); on the web at <http://physics.wm.edu/~sher/aoct99.html#a1>.

25. S. Fetter, “The Future of Nuclear Arms Control,” *Physics and Society* **28**(4), 8-10 (1999); on the web at <http://physics.wm.edu/~sher/aoct99.html#a4> “….. Ten years after the end of the cold war there are too many nuclear weapons, too ready for use. The threat of deliberate attack by an implacable, ideological adversary has been superseded by the threat of theft, anarchy, and erroneous or unauthorized use.”

26. K. Hasselmann, “Are We Seeing Global Warming?” *Science*, 9 May 1997, 914-915.

27. F.J. Dyson, “The Science and Politics of Climate,” *Physics and Society* **29**(1) (1999); on the web at <http://physics.wm.edu/~sher/ajan00.html#a1>.

28. G. Holton, “Scientists Organizing to Fulfill their Civic Responsibility,” *Physics and Society* **28**(4), 11-13 (1999); on the web at <http://physics.wm.edu/~sher/aoct99.html#a6>.

SLIDE #12: Epilogue - IV. Engendering Progress Towards Educational Reform

29. *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology* (Advisory Committee to the NSF Directorate for Education and Human Services chaired by Melvin George, 1996), on the web at <http://www.nsf.gov/cgi-bin/getpub?nsf96139>: "Many faculty in SME&T 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."

30. J.I. Goodlad, *Teachers For Our Nation's Schools* (Jossey-Bass, 1990) : "Few matters are more important than the quality of the teachers in our nation's schools. Few matters are as neglected.… A central thesis of this book is that there is a natural connection between good teachers and good schools and that this connection has been largely ignored …. It is folly to assume that schools can be exemplary when their stewards are ill-prepared." (My *italics*.)

31. *Shaping the Future, Volume II*: *Perspectives on Undergraduate Education in Science, Mathematics, Engineering, and Technology* at <http://www.nsf.gov/cgi-bin/getpub?nsf98128> (contains an extensive bibliography on SME&T undergraduate education which, unfortunately, omits most of the relevant physics literature).

32. "Preparing for the 21st Century: The Education Imperative," National Research Council, 1997, available at <http://www2.nas.edu/21st>.

33. *Unlocking Our Future: Toward a New National Science Policy*, A Report to Congress by The House committee on Science chaired by Vernon Ehlers, 9/24/98 at <http://www.house.gov/science/science_policy_study.htm>: "Currently, the U.S. spends approximately $300 billion a year on education and less than 30 million, 0.01% of the overall education budget, on education research. At a time when technology promises to revolutionize both teaching and learning, this miniscule investment suggests a feeble long-term commitment to improving our educational system." (cf. ref. 34)

34. K.G. Wilson and C.K. Barsky, "Applied Research and Development: Support for Continuing Improvement in Education," *Daedalus* 127(4), 233- 258 (1998): "We see the need for a launch of a research and development initiative in education, paralleling existing national research initiatives related to AIDS or global climate change ...... Today we have to think of education as demanding in multiple dimensions: as a science, as a design challenge, and as a performing art while still being an imperative for life in a democracy. Handed down traditions are no longer enough." See also <http://www.physics.ohio-state.edu/~redesign/>.

35. K.G. Wilson and B. Daviss, *Redesigning Education* (Henry Holt, 1994); see also at <http://www-physics.mps.ohio-state.edu/~kgw/RE.html>.

36. J.J. Duderstadt (president emeritus and Professor of Science and Engineering, Univ. of Michigan - Ann Arbor), "New Roles for the 21st-Century University: Changing times demand a new social contract between society and the institutions of higher education," *Issues* **16**(2), 37-51 (1999-2000): "….a 21st-century analog to the land-grant university might be a termed a 'learn-grant' university, designed to develop human resources as it top priority along with the infrastructure necessary to sustain a knowledge-driven society."

37. R.C. Hilborn, "Physics at the Crossroads: Innovation and Revitalization in Undergraduate Physics – Plans for Action," report on a College Park AAPT conference of 9/96, <http://www.aapt.org/events/events.html>; "Guest Comment: Revitalizing undergraduate physics – Who needs it?" *Am. J. Phys.* **65**, 175-177 (1997).

38. *Reinventing undergraduate education: A blueprint for America's Research Universities. The Boyer Commission on Educating Undergraduates in the Research University* (Carnegie Foundation for the Advancement of Teaching, 1998), also at <http://notes.cc.sunysb.edu/Pres/boyer.nsf >: "The university's essential and irreplaceable function has always been the exploration of knowledge. This report insists that the exploration must go on through what has been considered the 'teaching' function as well as the traditional 'research' function. The reward structures in the modern research university need to reflect the synergy of teaching and research - and the essential reality of university life: that baccalaureate students are the university's economic life blood and are increasingly self-aware."

39. *Transforming Undergraduate Education in Science, Mathematics, Engineering, and Technology* (National Academy Press, 1999); on the web at <http://www.nap.edu/readingroom/enter2.cgi?ED.html>.

40. *An Exploration of the Nature and Quality of Undergraduate Education in Science, Mathematics, and Engineering*, (Sigma Xi, 1989); see also *Entry-level Undergraduate Courses in Science, Mathematics and Engineering: An Investment in Human Resources* (Sigma Xi, 1989): "Undergraduate education in science, mathematics, and engineering has the potential to be the most effective leverage point in improving the quality of.… (these fields).… at all levels ....Reforming undergraduate education the natural sciences merits the highest priority on the national agenda."

SLIDE #14 - Physics Education Needs Revitalization

1. See references 2-7 for Slide #7.

2. R.C. Hilborn, "Guest Comment: Revitalizing undergraduate physics - who needs it? *Am. J. Phys.* **65**(3), 175-177 (1997): “All of us - students; physics faculty; the science, engineering, and technology communities; and indeed the general public - need the revitalization of undergraduate physics.”

3. D. Goodstein, “Now Boarding: The Flight from Physics,” *Am. J. Phys.* **67**(3), 183-186 (1999): “All across the country, the number of students majoring in physics is said to be at its lowest point since Sputnik, 40 years ago…..(see Slide #5)... The most important role of the college course seems to be to weed out a few poor souls who might otherwise make it to medical school or some other kind of quasi-scientific training. *If the profession of teaching physics were a business, we would be filing for bankruptcy.* On the other hand our assets include nothing less than the wisdom of the ages, the most important part of the body of human knowledge. Mastery of that knowledge, a fundamental grasp of how the world works, ought to be the best possible preparation for the coming century. ” (My *italics*.)

SLIDE #15 - Institutional and Political Factors Slow Reform

1. S. Tobias, "From Innovation to Change: Forging A Physics Education Agenda for the 21st Century," *APS Forum on Education Newsletter*, Summer 1999, <http://webs.csu.edu/~bisb2/FEdnl/TOBIASshort.htm>; for the complete version see <http://webs.csu.edu/~bisb2/FEdnl/Tobias.htm>. Another (much shorter) version is scheduled to appear as a "Guest Comment" in *Am. J. Phys.* **68**(2), February 2000.

2. S. Tobias and F. A. J. Birrer, "Who will study physics, and why?," *Eur. J. Phys.* **20**, 365-372 (1999).

3. S. Tobias, D.E. Chubin, and K. Aylesworth, *Rethinking Science as a Career* (Research Corp., 1995) esp. Chap. 6, "Reinventing the Master's Degree and Revitalizing Undergraduate Programs." Information on ordering Tobias’s books is at <http://www.Sheila.Tobias.net> under "Inquiries."

4. S. Tobias, "Guest Comment: Science Education Reform: What’s wrong with the process?” *Am. J. Phys.* **60**, 679-681 (1992); *Revitalizing Undergraduate Science: Why Some Things Work and Most Don’t* (Research Corporation, 1992).

5. S. Tobias, " ’Science-Trained Professionals’ – A New Breed for the New Century," *J. Sci. Ed. Technol.* **5**, 167-169 (1996).

6. M. Jensen, "Reinventing the Science Master's Degree, *Science* **284**, 1610-1611 (1999).

7. J. Kumagai, "Professional Master's Degrees Promise Quicker Entry Into Industry Jobs," *Phys. Today* **52**(6), 54-55 (1999).

8. Sheila Tobias, "Conceptualizing a New Degree," *APS News* **8**(11), 5 (1999); on the web at <http://www.aps.org/apsnews/1299/129908.html>

9. K.R. Weiss, "Stirring Things Up: Universities are blending together some traditional areas of study - and making the master's degree of tomorrow," *Los Angeles Times*, 24 October 1999, Special Education Supplement.

10. R. Ehrlich, "What Can We Learn from Recent Changes in Physics Bachelor Degree Output?" *Phys. Teach.* **37**(3), 142-146 (1999).

11. W.P. Wolf, "Is Physics Education Adapting to a Changing World?" *Phys. Today* **47**(10), 48-55 (1994).

SLIDE #16 - ABET “Engineering Criteria 2000”

1. P. Zitzewitz, “Engineering Accreditation Changes: a Threat or an Opportunity for Physics Programs,” *APS Forum on Education Newsletter*, Spring 1998, pp. 1, 3 (1998); on the web at <http://www.research.att.com/~kbl/APS/apr98/>

2. R. Ehrlich, "Engineering Deans' Opinions of Physics Courses," *APS Forum on Education Newsletter*, Summer 1998, pp. 2-4 (1998).

3. The ABET homepage is at <http://www.abet.org/>