RESEARCH, DEVELOPMENT, AND CHANGE IN UNDERGRADUATE BIOLOGY EDUCATION (REDCUBE): A WEB GUIDE FOR NON-BIOLOGISTS *

R.R. Hake, Physics Department, Indiana University (Emeritus), 8 Sept. 1999

I. INTRODUCTION

Research and development in undergraduate science, mathematics, engineering, and technology education would probably benefit from more exchange of information among workers in different disciplines. For example, non-biologists (e.g., astronomers, chemists, educators, engineers, geologists, mathematicians, physicists, psychologists) may have something to learn from biologists and vice versa. However, there are evidently no biological counterparts to the physicists' (A) "Physical Sciences Resource Center,"[1] (B) "Resource Letter on Physics Education Research,"[2a] or (C) "Physics Education Research Papers on the Web."[3] Until such become available, this incomplete survey may suffice to (a) give non-biologists a point of entry to the vast literature and web resources relevant to research, development, and change in undergraduate biology education, (b) stimulate efforts by biologists to produce biological counterparts of "A," "B," and "C." Starting points for this survey were: (1) a report[4] of a 1994 NSF conference on disseminating innovation in undergraduate education, (2) James Stewart's[6a] review of biology education research, (3) the Eison/Bonwell bibliography[7] on active learning (see Sec. VI), and (4) feedback from those† who received preliminary drafts of this compendium. All errors of omission and commission are mine alone. This "portable document file," [8a] at < http://physics.indiana.edu/~redcube > enables clicking on URL's (all verified on 9/7/99 except for those labeled NR = No Response) to bring them up in a browser.[8b]

The report consists of seven sections:

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†Robert Abrams, Deborah Allen, Amy Chang, David Clark, Charlene D'Avanzo, Ingrith Deyrup-Olsen, Diane Ebert-May, Kathleen Fisher, Michael Flower, Jeffrey Fox, Lou Gross, Joel Hagen, Jo Handelsman, Ethelynda Harding, William Hayes, Paul Horwitz, Paul DeHart Hurd, John R. Jungck, Jane Butler Kahle, Brad Kincaid, Ann Kindfield, Wayne Magee, George Malacinski, Ann McNeal, Judith Miller, John Moore, Deborah Morris, M. Patricia Morse, Craig Nelson, Joseph Novak, Shelly Peretz, Hugh Pross, Harry Roy, Paul Saltman, Mike Smith, James Stewart, Marshall Sundberg, Barbara Thorne, Lillian Tong, Dan Udovic, D. Tom Vernon, Nancy Wadleigh, John Wahlert, and Margaret Waterman.

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II. SOME BIOLOGISTS ACTIVE IN RESEARCH, DEVELOPMENT, AND CHANGE IN UNDERGRADUATE EDUCATION (The investigators listed below are primarily those whose work was reported in ref. 4, or who were suggested in feedback on drafts of this survey. They represent, of course, only a minute fraction of the workers active in the field. Only a few representative references are given for each investigator. Quotes - sometimes with minor editing - are from web sites, from ref. 4, or from private communications from the individuals themselves.)

A. *Deborah Allen*[9-14] of the University of Delaware's Department of Biological Sciences < http://www.udel.edu/bio > has developed, implemented, and assessed a two-semester introductory biology sequence that incorporates problem-based learning strategies, and uses advanced undergraduates as facilitators for the problem-solving groups (the course materials and associated teaching notes have recently been published[9]). With colleagues at the University of Delaware (UD), she has developed a university-wide program (along with a course, Tutorial Methods of Instruction) for in-service support and preparation of the undergraduate facilitators, who help faculty to preserve the essential features of PBL in classrooms with multiple student groups < http://www.udel.edu/pbl >. These peer group facilitators are part of a larger Science Fellows Program (which she helped to initiate and co-directs with colleagues in UD's Mathematics and Science Education Resource Center) that involves basic science and secondary science education majors in K-12 outreach activities. She is one of the co-founders and -leaders of an award-winning institute that assists interested faculty in incorporating PBL and other active learning strategies into their courses, along with effective use of technology < http://www.udel.edu/inst >. Current interests include (a) leadership of a departmental project to develop and assess a PBL curriculum in the biological sciences, (b) the design and implementation of a large enrollment course in physiology that uses PBL strategies, and (c) design and implementation of a summer course for high-school teachers in "Molecular Biology Through Inquiry." See Sec. IIID, Web Addresses for the University of Delaware.

B. *American Society of Zoologists - Education Committee*

"Science As A Way of Knowing" (SAAWOK)[15] was developed under the aegis of the Education Committee of the American Society of Zoologists (ASZ - now the Society for Integrative and Comparative Biology, SICB, see listing in Sec. IIIA, "Web Addresses"), with contributions from more than 100 eminent biologists. The goals of the project were to improve (a) the teaching of biological science at the university level, and, ultimately (b) the general understanding of the progress and issues of modern biology. Rather than being process oriented (as are many efforts in biology education) SAAWOK was substantive, formulating the major concepts and research directions in the rapidly expanding field of biological science. Each of the eight components[15] of SAAWOK is comprised of (1) a major essay developing the conceptual structure and background of the field; (2) a review and summary description of relevant audiovisual and other teaching aids; and (3) a coordinated symposium on current trends by leaders in the various biological fields. Volumes VI and VII include special sections by John Moore on the conceptual framework of biology. Support from the Carnegie Corporation made possible the distribution of the SAAWOK series to hundreds of scientists and teachers in the U.S. and worldwide.

C. *Rodger Bybee*[16-19,200] is now Executive Director of the *Center for Science, Mathematics, and Engineering Education* of the National Research Council. He chaired the "Content Working Group" of the development team for the *National Science Education Standards* (ref. 58 of Sec. IV). In his former association with the *Biological Sciences Curriculum Study* (BSCS) he contributed to a book "*Biological Perspectives* ...utilized in a ground breaking new college program that offers students and faculty a concrete framework for building biological literacy and for moving to an instructional style that requires students to organize information, use biological concepts in solving problems, and communicate their understanding in writing and discussion .... the text provides many opportunities for students to develop the skills associated with biological literacy by emphasizing important concepts and relationships, rather than rote memorization; demonstrating connections between biology and students' daily lives; recommending specific strategies (such as marginal notes and structured debates) that promote active student engagement; including text annotations and discussion questions graded from simple to complex." The lab manual *Thinking Biologically* contains 14 investigations keyed to chapters in the student text. The investigations are primarily guided inquiries, designed to promote student participation in and reflection about the processes of science, including hypothesis formation, experimental design, model building, and field study. Each investigation also includes a section titled 'Make Connections' that helps students connect the biology they are learning to aspects of their daily lives."
< http://www.bscs.org/ >
< http://www4.nas.edu/csmee/center.nsf >

D. *Amy Chang*[20] "as director for the Office of Education and Training, American Society for Microbiology (ASM), oversees all aspects of the Society's educational programs from policy and program development to implementation and evaluation. In 1991 she helped found the Coalition for Education in the Life Sciences (CELS) and served as the executive secretary for the Coalition until 1993. Today she works with the ASM Board of Education and Training and in collaboration with other national organization in the life sciences and/or education. She is responsible for advising and directing these national leadership groups regarding issues in science, biology, and microbiology education; kindergarten through high-school education, higher education, and graduate education; as well as minority, distance, and international education. The Board offers (a) an annual undergraduate education conference, (b) summer institutes for kindergarten through high-school teachers, (c) triannual newsletter, (d) curriculum guidelines, (e) education product reviews, (f) digital library for microbiology resources for teaching and learning, (g) multimedia resources, (h) telecourses in microbiology for distance learners, (i) career information, (k) student and faculty fellowships, and (l) travel grants. One of ASM's strategic goals is to conduct and support education, training and public information and to facilitate the dissemination and application of new microbiological knowledge addressing scientific matters affecting the public interest. It is through the Board, in partnership with the professional staff, that this goal is advanced and promoted. The ASM website is < http://www.asmusa.org >. The educational initiatives are described at a site for teachers and professionals at < http://www.asmusa.org/edusrc/edu1.htm >; and at a site for parents, students and the general public at < http://www.microbeworld.org >."
See also the listings under ASM in Sec. IIIA, "Web Addresses".

E. The late *Kerry B. Clark* of the Florida Institute of Technology was "involved in investigation of the use of computers in undergraduate and graduate education in biological sciences, particularly advanced computer graphics for visualization, conceptualization, and documentation. His expertise in this area included video/computer interfaces, video/computer conversion, 3-D modeling, CD-ROM technology, and hypertext." He constructed *Metazoa: Vanishing Kingdom*, a 330 MB CD-ROM featuring multimedia and 3-D graphics (Ocellus Productions, Palm Bay, FL., 1993).
< http://www.bio.fit.edu/Faculty/clark.htm >

F. *Charlene D'Avanzo*,[21-25] professor of ecology at Hampshire College, received her ..... Ph.D. from Boston University Marine Program, Marine Biology Lab, Woods Hole. She is particularly interested in marine ecology, returns to the Marine Biological Laboratory in Woods Hole each summer to continue her research on coastal pollution, and directs student aquaculture research in the Hampshire bioshelter. Her main focus in science education has been on developing investigation-based courses in the environmental sciences and running faculty development workshops. She is co-PI on two NSF grants designed to help faculty use more student-active approaches in introductory science and math courses. She and Ann McNeal edited the landmark book *Student-Active Science: Models of Innovation in College Science Teaching*,[21] which has had a wide impact on undergraduate biology education (see refs. 10, 11, 22, 32, 64, 105, 106, 128, 184, 197 in this section and ref. 39 in Sec. IV, "General References").
< http://www.hampshire.edu/academics/ns/faculty.shtml >
< http://helios.hampshire.edu/~cdNS/ >
< http://www.hampshire.edu/academics/ns/NS.shtml >

G. *Diane Ebert-May*,[26] is now at Michigan State University (MSU) where she is a professor in the Department of Botany and Plant Pathology, and director of the Lyman Briggs School, MSU's residential science program. While at Northern Arizona University (NAU) she was engaged in a project "designed to increase the scientific literacy of undergraduate non-majors at NAU and community colleges in Arizona with large numbers of under-represented rural students ..... (with) .... four major foci: (1) To restructure an introductory biology course for non-majors so that it enhances student's biological literacy and their understanding of multidisciplinary approaches to real-world problems. The laboratory component for the course provides students the opportunity to do inquiry-based and research-oriented science. (2) Effect systemic change at NAU and .... three community colleges by developing and implementing professional development seminars and practical workshops for graduate teaching assistants and faculty..... (3) Test the restructuring of introductory biology through an experimental design that will enable professionals to determine what is the most effective design for two kinds of academic communities, a state comprehensive university and a sample of community colleges in Arizona. (4) Follow faculty and their students in a longitudinal study of the course's impacts. This project represents an experimental approach to curriculum development that will determine 'what works' in non-majors' biology courses." Diane is now continuing similar work at Michigan State University.
< http://www.nau.edu/smlc/slice/slice.html >
< http://www.msu.edu/unit/lbs/people/fac_bios/ebert-may.html >

H. *Kathleen Fisher*[27-31] at San Diego State University contributed to the design and development of the SemNet© semantic[31] networking software. "She and her collaborators are currently developing a cross-platform, Java-based version of this software in English, Spanish, and German. She is also "developing a test for conceptual understanding of evolution ....(and).... is publishing biology lessons with accompanying knowledge-mapping exercises, related AAAS Benchmarks, and teachers' guides at < http://www.biologylessons.sdsu.edu >. The lessons are (a) designed for teaching biology to prospective elementary school teachers, typically in their senior year of college, but can be readily adapted for teaching K - 8 students, and (b) aim to promote personal knowledge construction and to foster conceptual change." In addition, she is working with biologists and biology educators nationwide as part of the NSF-funded Project FIRST - Faculty Institutes for Reforming Science Teaching Through Field Stations.
SemNet© Software < http://trumpet.sdsu.edu/semnet.html >
< http://public.sdsu.edu/CRMSE/kfisher.html >
< http://public.sdsu.edu/NaturalSciences/professors/fisher.html >

I. *Michael Flower* [32-34] of Portland State University (PSU) is interested in " 'science and society' issues: in vitro fertilization, genetic screening and the future of gene therapy, and the rise of biotechnology and the commercialization of advances in molecular biology.....Since coming to Portland State University in 1992 he has been co-author and co-director of large science curriculum reform grants - an NSF grant with William Becker.... to develop a 'Science in the Liberal Arts' (SLA) curriculum for students not majoring in the sciences; and an NEH/NSF grant with Lawrence Wheeler....to create a cluster of interdisciplinary Sciences-Humanities courses.....The 'Portland Today' project ...(is) ..... an example of the sort of open-ended project engaged in by our students. Indeed, it is a part of just one of the courses, Natural Science Inquiry, in the SLA curriculum. ..... There are several other biology-oriented courses characterized by a variety of 'science as practice' projects, not all of which are ecological..... Our goal in SLA is to have the students experience 'science-in-the-making' (science as practice), lecturing to them as little as possible about 'science made.' We all know that established facts - those knowledge claims about which we are most certain - are the foundation from which we explore, ask new questions, and produce new answers; we build upon what we already know. What is different in SLA is that the questions we ask and the problems we tackle dictate a significant portion of the factual scientific information students have to learn ..... we are interested in students learning and experiencing the scientific process by 'doing science' and learning the necessary content, background knowledge as they go."
PSU Center for Science Education < http://hope.cse.pdx.edu/ >
Portland Today project < http://hope.cse.pdx.edu/pdxtoday/index.html >
Cornerstones Project (includes several biology-oriented courses) < http://corners.pdx.edu >
Michael Flower < http://cse.pdx.edu/webbios/pages/flowerm.html >.

J. *Lou Gross*[35-37] at the University of Tennessee - Knoxville (UTK) is Professor of Ecology and Evolutionary Biology and Mathematics. He is Director of *The Institute for Environmental Modeling* at UTK and is a leader of the ATLSS (*Across Trophic Level System Simulation*) Project to assess the impacts of alternative management plans on the Everglades biota. In addition to his research in computational ecology, he has ongoing research projects in photosynthetic dynamics, landscape ecology, and has a long-term interest in enhancing the mathematics training of biologists. With NSF funding, he has coordinated several Workshops for quantitative scientists and biologists with a goal of developing a quantitative curriculum for life-science undergraduates. These Workshops have led to further gatherings at several other institutions, as well as the development of a variety of new mathematics for the life sciences courses. Currently, he is developing a *Primer of Quantitative Biology* as a set of modules for use as an adjunct to the general biology courses typically taken by first-year undergraduates. He has co-directed several courses and workshops in Mathematical Ecology at the *International Center for Theoretical Physics* in Trieste, Italy; has edited or co-edited four books; and is the moderator for the Life Sciences Section of the Mathematics Archives WWW site. He has one of the largest web sites on quantitative aspects of the life sciences (see Sec. IIID, UTK addresses).
< http://www.tiem.utk.edu/~gross/ >

K. *Joel B. Hagen* and his associates at Radford University have published a text[38] that uses historical case studies to humanize biological concepts. With Charles Kugler and other faculty at Radford he has developed "a nontraditional two-semester general biology course for nonmajors called *Contemporary Issues in Biology*. In this course we try to teach the major principles of biology by starting with issues of importance to students and pursing the biology we need to learn in order to deeply understand those issues. In BIOL 111, we approach biological concepts through environmental issues. In BIOL 112, we start with medical issues. Throughout both semesters we also give students readings and personal experiences that teach various methods of science and ways science and society interact. We also explicitly strive to develop students' reading skills, critical thinking skills, communication skills, teamwork skills, and creativity."
< http://www.runet.edu/~jhagen >
< http://www.runet.edu/~ckugler >.

L. *Jo Handelsman* of the Univ. of Wisconsin - Madison (UWM) "teaches biology to non-majors through hands-on experimentation; cooperative learning and problem-solving; and interactive lecturing that teaches students to pose hypotheses, design experiments to test them, and to interpret data."
She and others at UWM have authored a text[39] designed to teach students to think like scientists. Her work is described in "Beyond Bio 101" at:
"Changes In The Classroom," < http://www.hhmi.org/BeyondBio101/class.htm >
"Active Learning," < http://www.hhmi.org/BeyondBio101/learning.htm >.
< http://www1.bocklabs.wisc.edu/profiles/Handelsman,Jo.html >

M. *Ethelynda Harding*[40] of Cal State Univ (Fresno) describes her work as follows:
"Introductory biology laboratory was presented to students with diverse preparations and abilities as a series of modules, each centered on a single theme or concept (water, energy inputs, etc.). Within each module, students selected the laboratory activities they performed. The available activities addressed the central concept from the molecular to the ecological level, included microbes, plants and animals, varied in complexity and directedness, but generally emphasized inquiry. Student-originated experimentation was supported and rewarded. Students were assigned to groups, and group assessment was used to reward collaborative efforts. A student attitudes inventory, a course evaluation survey and student self-assessments were used to determine the effectiveness of the approach and to guide improvements. Students' concerns about their partners' effects on their grades were largely relieved by mastery grading of laboratory reports. Students reported that group assessment motivated them to work harder. Over half of the students felt comfortable designing their own experiments; 59% said that the opportunity to do so was important to them. Independent exploration helped the students understand concepts and made them feel like scientists rather than just students. Students preferred selecting their own activities to working in unison with the rest of the class; on the other hand, they preferred that laboratory topics correspond with and reinforce lecture content."
< http://www.csufresno.edu/cetl/Harding/harding.html >

N. *John Harte* of UC-Berkeley was a special advisor to the NRC Committee on High School Biology Education which authored a landmark study of U.S. high-school biology education[41]: "the infrequent use of creative inquiry or of strategies for cooperative learning in high-school biology classrooms is probably related to their absence in most college programs." Harte has written extensively on the environment and biological conservation.[42-45]
< http://socrates.berkeley.edu/erg/ >

O. *William Hayes* at Delta State University thinks that "education is more than training, that it involves the growth of the individual into increasingly complex knowledge and skills which he or she can apply meaningfully to life....(and is concerned that).... science majors be able to think as scientists upon graduation." He has constructed a web site for biology education which features valuable "Links to Information," "Big Ideas," and an Ethology Listserve. Links to "Information"/"Collected Writings" contains his essays on "Scientific Habits"; "Concepts, Principles, and Theories"; "Asking Good Scientific Questions"; "Scientific Thinking Skills"; "Approach to Evolution"; "Becoming a Scientific Thinker"; and "Scientific Attitudes."
< http://www.geocities.com/~doc_hayes/ >

P. *Paul Horwitz*[46-51] of the Concord Consortium is one of the originators of GenScope©, "a novel scriptable modeling environment that links four levels of a simulated system to make genetics accessible" to students. He is currently involved in the "BioLogica project, ...a new approach to biology using an extension of the GenScope© ideas into cellular structure."
< http://genscope.concord.org/ >
< http://www.concord.org/projects/index.html#mod >

Q. *Paul DeHart Hurd*,[52-60] Emeritus Professor at Stanford, was a special advisor to the NRC's Committee on High-School Biology Education which authored the influential study of U.S. high-school biology education.[41] Hurd has been a long-time critic[59-60] of science-education reform movements and science-education research.[55] He is a champion[52-54,56-60] of the "Science, Technology, and Society" (STS) approach to pre-college science education.

R. *John R. Jungck*[61-72] at Beloit College is one of the principle investigators of the *BioQUEST Curriculum Consortium (Quality Undergraduate Education Simulations and Tools in Biology)*, a national team of biologists and computer scientists..... developing software to simulate biological research....(situations in which students) .....develop research strategies in a series of open-ended investigations." From 1988 to 1997 he was editor of *Bioscene: Journal of College Biology Teaching*. His primary focus "has been to try to help students learn long-term strategies of research and to promote problem solving, collaborative learning, constructivist learning, and peer review." He brings in roughly forty professors each summer for nine days to develop curricular materials, now adopted at over 150 college campuses. He is particularly interested in increasing the use of mathematics and is chair of the Education Committee of the Society for Mathematical Biology.
See BioQUEST addresses in Sec. IIIA.
< http://bioquest.org >
< http://www.beloit.edu/~biology/jungck.html >
According to John Jungck, others at Beloit active in BioQUEST are:

(a) *Ethel Stanley*: in addition to being the Director of the BioQUEST Curriculum Consortium, she is currently co-editor of *Bioscene: Journal of College Biology Teaching* and vice-chair of the Teaching Section of the Botany Society of America. A former botany and environmental biology professor at Millikin University, she is a specialist on visual literacy in science and educational technology.

(b) *Patti Soderberg*: editor of *BioQUEST News*, which is sent out free to between five and six thousand subscribers. She is well known for her activity "Rebops" (see at
< http://www.wisc.edu/cbe/Publications/Reebops.pdf >) for learning meiosis and for several genetics software packages. She has promoted feminist critiques of science education and more inclusive approaches to diversity.

(c) *Robin Greenler*: a restoration ecologist has been active in "Bottle Ecology," "Wisconsin Fast Plants," (see under "RR. *Paul Williams*" below) and "Agri-Life Science" - an attempt to combine agricultural education with biology education.

S. *Jane Butler Kahle*[73-79] of Miami University (Ohio) is active in the Ohio Systemic Initiative - *Discovery* and was a member of the National Research Council Committee on High School Biology Education which authored ref. 41 on high-school biology education (see under "N. *John Harte*" above). She has published extensively on gender issues and systemic change in science education, and has recently been appointed director of the NSF's Division of Elementary, Secondary, and Informal Education (ESIE).
< http://www.discovery.k12.oh.us/ >

T. *W. Brad Kincaid* [80-81] of Mesa Community (MCC) uses computer technology to enhance learning-cycle instruction in biology. He is involved in MCC's "BioApps Project ..... funded by the NSF to develop, evaluate, and implement computer applications to enhance inquiry-oriented instruction in biology."
< http://www.mc.maricopa.edu/academic/life_sci/kincaid/ >
< http://www.mc.maricopa.edu/academic/life_sci/kincaid/bioapps/index.htm >

U. *Ann Carol Hildebrand Kindfield*,[82-88] formerly a professor of Biology & Molecular at Montclair State University, now works as a Biology Education Specialist at “Educational Designs Unlimited.” She is currently engaged in a project entitled "Student Reasoning in Basic Mendelian Genetics" under a Sokol Faculty Student Research (FSR) grant. She is also a consultant for the (a) "Barriers to Learning Genetics" project under the direction of Dr. Carol I. Barash, Genetics, Ethics & Policy Consulting, Boston, MA, and (b) GenScope© Evaluation Project. From 1994 to 1997 she was a research scientist at the Center for Performance Assessment, Educational Testing Service, which included years 1 and 2 of the GenScope© Evaluation Project and participation in a MISE (Merck Institute for Science Education)-funded project designed to assist K-8 teachers in the systematic development of methods for assessing student science learning. From 1990 to 1994, she did post-doctoral research on understanding/reasoning about biology with a focus on subcellular processes and domain-specific diagrams at the EMST/School of Education at UC-Berkeley, while serving as a lecturer in the Department of Molecular and Cell Biology.

V. *Anton Lawson*[89-95] of Arizona State University is interested in "the nature and development of scientific thinking patterns such as hypothetico-deductive, probabilistic, proportional, combinatorial, analogical, and correlational reasoning. Major interests involve determination of factors that influence the development of these thinking patterns during childhood and adolescence and determination of their relationship to each other and to scientific concept acquisition. The goal is to generate and test explanatory theories of the development of thinking patterns and develop neurological models of cognition. Classroom implications are sought with the intent of improving science instruction."
< http://lsvl.la.asu.edu/biology/faculty/lawson.html >.

W. *Sharon Long's* collaborative learning methods have been described at
< http://www.hhmi.org/BeyondBio101/index.htm > and in ref. 96 (p. 10, 13): "One important tool I use to engage students is to create opportunities for thought and active pursuit of an unknown during the class period. If I give a lecture for which I provide notes - a common practice - I always leave blanks in critical parts of the notes. On the board or transparency, I indicate the unknown. I pause while I talk about it, drawing students' attention to the hole in the notes. If possible, I ask for suggested answers or for a vote among the possibilities. By arranging the pause in your lecture you can give students the chance to puzzle out the question themselves and to preview their ability to work on the questions independently. And only by attending the class can a student gain all the information - an important draw to encourage class attendance."
< http://www.stanford.edu/dept/biology/faculty/long.html >

X. *Thomas Lord* of Indiana University of Pennsylvania (IUP) has been concerned "with the failing quality of contemporary education .... (which) has led to ..... several studies on effective teaching strategies in post primary grades.[97] Much of this educational research has focused on the role spatial aptitude plays in science learning... (and) has led to.... cooperative investigations with .... cognitive theoreticians.... (His interest in)... environmental and ecological issues... (has led to)..... the development of a liberal studies course in environmental science at IUP.... (His interest in).... bilaterality of human beings.....has led to research studies on handedness, neural hemisphere dominance, and lateral preference asymmetry.
< http://www.iup.edu/bi/filot.htmlx >

Y. *Wayne Magee*[98-100] of Drexel University "has a major interest in improving science education for undergraduates and is the principal investigator on the NSF-supported project entitled the 'Enhanced Bioscience Education Program (EBE)' and the NSF's 'Digital Imaging for Inquiry-Based Bioscience Laboratories.' The EBE project has involved major changes in the way the life sciences are taught to undergraduate students majoring in biological or environmental sciences and to students interested in becoming biology teachers. Major features of EBE are to provide a sequence of courses beginning in the freshman year that build upon one another and emphasize: (a) hands-on, active learning; (b) students working in collaborative learning groups and designing their own experiments; (c) extensive integration of computers and technology into all phases of the laboratory; (d) demonstrated skills in oral and written communication; (e) meaningful interactions between students and faculty; and (f) effective student support services. The program has been in place since the Fall of 1993 and has the demonstrated outcomes of increased (1) student retention, (2) students' involvement in their own learning, and (3) students' communication, computer, and laboratory skills. Recently, the program was adopted as the standard curriculum for the Department of Bioscience and Biotechnology."
< http://www.sciences.drexel.edu/biology/faculty/cvs/magee.html NR>
< http://bst2.bioscience.drexel.edu/biology/ebe/dickstein/ >
< http://bst2.bioscience.drexel.edu/biology/ebe/ebelabs >

Z. *George Malacinsk*i at Indiana University (IU), along with Paul Zell of IU, has developed collaborative-learning methods[101] for introductory courses and discussed[102] the severe institutional impediments to their implementation in large public research universities (such as IU).
< http://www.bio.indiana.edu/people/faculty/Malacinski.html >

AA. *Ann P. McNeal,*[103-110] is a professor of physiology at Hampshire College. "In 1993-4 she served as a Program Director in the Division of Undergraduate Education at the National Science Foundation. Ann's research is on the control of posture and movement in humans. She especially enjoys introducing beginning students to this accessible area of research. She is co-editor with Charlene D'Avanzo of the landmark book *Student-Active Science: Models of Innovation in Undergraduate Education,*[105] published by Saunders College Publishing in 1997 (see Sec IIIA "Web Addresses" under Saunders). Ann has conducted numerous faculty workshops for *Project Kaleidoscope* and other organizations; she enjoys using the same active-learning techniques with faculty as with students.
< http://www.hampshire.edu/academics/ns/faculty.shtml >
< http://helios.hampshire.edu/~apmNS/ >

BB. *Judith Miller*[111-118] of Worcester Polytechnic Institute (WPI) has piloted the use of undergraduate Peer Learning Assistants (PLA's) in large courses (including her own) that are taught in a cooperative learning (CL) mode. In a five-year project to develop, pilot, implement, assess, and disseminate the model, she has shown that PLA-assisted CL is not only feasible in large classes, but that it results in measurable increases in student learning, student satisfaction, and faculty productivity. With John Wilkes of WPI she has researched the relationship among cognitive style, group dynamics, satisfaction, and task type in a CL course. She consults and gives workshops nationally on the use of CL in technical courses.
< http://www.wpi.edu/Academics/Depts/Bio/People/miller.html >

CC. *John A. Moore*,[119-121,190] Emeritus Professor of Biology at the University of California-Riverside, was (a) a member of the National Research Council (NRC) Committee on High School Biology Education which authored ref. 41 on high-school biology education (see under "N. John Harte" above); (b) a member of the NRC Committee on Undergraduate Science Education which wrote *Science Teaching Reconsidered: A Handbook* (Nat. Acad. Press, 1997), ref. 96; (c) listed as "one who lent support to the project" which developed NRC's *National Science Education Standards* (Natl. Acad. Press, 1996), ref. 58 in Sec. IV, "General References"; (d) a member of the NRC Working Group on Teaching Evolution which produced *Teaching About Evolution and the Nature of Science* (Nat. Acad. Press, 1998), ref. 15 in Sec. IV; and (e) a contributor to the NRC's *Transforming Undergraduate Education in Science, Mathematics, Engineering, and Technology*, ref. 2 in Sec. IV. Moore is well known for his efforts to promote cultural and scientific literacy,[119,120] to improve undergraduate biology education,[185] and for spear-heading the *Science As A Way Of Knowing* (SAAWOK) Project.[15] Four of those essays (V, I, III, and IV in that order) were revised and published as a book,[121] described by *Book News* as "...wonderful.... clear, interpretive, nontechnical yet inclusive .... written for nonspecialists seeking a deeper understanding of how modern molecular biology, ecology, and biotechnology came to be. Moore..... interweaves case studies, hypotheses, deductions, and chronological narrative to convey the history of biology and give a sound introduction to the procedures and values of science."
< http://cnas.ucr.edu/~bio/faculty/Moore.html >

DD. M. Patricia Morse, now at the University of Washington, collaborated with Barbara Thorne of the University of Maryland in a sequel to the "Science as a Way of Knowing" Series[15] to organize "Science as A Way of Knowing: Biodiversity,"[122] utilized to enrich content in biology courses. The essay by E.O. Wilson along with research compilations from active research scientists can be readily utilized to enrich content in biology and environment courses. Trish comments that "It...(the "Science as a Way of Knowing" series)....was the first and most influential set of materials created by a professional scientific society and they are still in use today."

EE. *Jeanne Narum*[123-128] is the Director of the *Independent Colleges Office* (ICO) in Washington, D.C. The ICO serves as the Washington representative for the *Associated Colleges of the Midwest* and for a select group of liberal arts colleges across the country. Narum has been Director of *Project Kaleidoscope* (PKAL) since its inception in 1989. Although not a professional biologist, Narum is included in this survey because of the impact of *Project Kaleidoscope* on the reform of undergraduate biology education in the United States (see 'PKAL" in Sec. IIIC, "Web Addresses"). She has over twenty years of experience with faculty, curriculum, and institutional development projects, having served as Vice President for Development and College Relations at Augsburg College (1985-88), Director of Foundation Relations at St. Olaf College (1974-83). She serves as publisher for *Project Kaleidoscope* reports and was editor-in-chief for Volume 2,[126] *What Works: Building Natural Science Communities. Resources for Reform. Strengthening Undergraduate Science and Mathematics*; and for Volume 3,[125] *Structures for Science: A Handbook on Planning Facilities for Undergraduate Natural Science Communities*. In the context of coordinating the work of PKAL, she has spoken widely on PKAL and the reform of undergraduate science and mathematics.
< http://www.pkal.org/people/narum.html >

FF. *Craig Nelson*[129-139] at Indiana University acquired his interest in pedagogy in higher education from trying to more effectively teach evolution and environmental science. His initial efforts focused on classroom applications of William Per's ideas (see ref. 124 in Sec. IV "General References) on intellectual development to critical thinking in evolution[138] and in science generally,[137] and on the development of curricula for environmental science.[139] Subsequent work expanded in focus to include more active approaches to learning,[135] the impacts of pedagogical choices on the success of students from diverse backgrounds[134,136] and the integration of these themes.[130,131] For the past decade he has collaborated with Martin Nickels (Anthropology, Illinois State University) and Jean Beard (Biology, San Jose State University) in exploring how the integration of the nature of science and evolution can lead to a better understanding of both,[129,131,133] explorations supported by a series of NSF grants. His efforts to improve college teaching have also included (a) Chautauqua Short Courses for College Science Faculty on "Fostering Critical Thinking in Science" and on "Creation, Evolution, or Both: A Multiple-Model Approach" (annually since 1989; 3 days each; sponsored by NSF), (b) numerous invited presentations at national and international meetings, and (c) workshops on individual campuses in some 35 states on subjects such as "Fostering Critical Thinking & Mature Valuing Across the Curriculum."
< http://www.bio.indiana.edu/people/faculty/Nelson.html >

GG. *Joseph Novak*,[140-152] Emeritus Professor at Cornell, is a pioneer in research on misconceptions in science and the use of Concept Maps and Vee Diagrams. He has organized and edited the proceedings of the landmark interdisciplinary seminars *Misconceptions and Educational Strategies in Science and Mathematics*[140-143] at Cornell. The fourth such conference was in honor of his retirement.
< http://www.cals.cornell.edu/dept/education/faculty/novak/Novak.html >
Meaningful Learning Research Group (with *Robert Abrams*)
< http://www2.ucsc.edu/mlrg/mlrghome.html >

HH. *Herbert Posner*[153-156] of SUNY-Binghamton is "director of the undergraduate biology program and is co-principal investigator on (a) two educational initiative grants from the Howard Hughes Medical Institute to improve the undergraduate biology curriculum, and (b) a grant from the National Science Foundation to integrate the natural sciences and mathematics with the humanities and social sciences."
< http://biology.binghamton.edu/Posner.html >

II. *Sue Rosser*[157-163] formerly served as Director for the Center for Women's Studies and Gender Research at the University of Florida-Gainesville, where she was also a Professor of Anthropology. "In 1995, she was Senior Program Officer for Women's Programs at the National Science Foundation. From 1986 to 1995 she served as Director of Women's Studies at the University of South Carolina, where she also was a Professor of Family and Preventive Medicine in the Medical School. She has edited collections and written approximately 80 journal articles on the theoretical and applied problems of women and science and women's health." Recently she was named Dean of the Ivan Allen College - the humanities and social sciences arm of the Georgia Institute of Technology. Dean Rosser will be the first woman to serve as a dean of an academic college in Georgia Tech's 110-year history.
< http://www.news-info.gatech.edu/html/news_releases/rosser.html >

JJ. Harry Roy[164-166] of Rensselaer Polytechnic Institute (RPI) writes that he is "using...(his version)... the 'studio method'[167] to teach a sophomore Genetics and Evolution course.[164] This method de-emphasizes lecturing in favor of laboratory simulations using Visual Genetics[165] and BioQuest software,[61] working problems, and carrying out longer term projects with BioQuest programs. I have found that an effective sequence consists of a short presentation using a projector with on-line notes or animations, followed by interactive work by teams of students using laboratory simulations or an assigned problem. Once this is done, another topic may be presented by the instructor, and the process repeated with new material ..... I like the studio method far better than lecturing since it allows: (a) a better understanding on my part of student difficulties and means to overcome them, (b) better interactions with the students, and (c) more intense involvement of students in the class ..... The class has been taught three times a year for several years, with enrollments ranging from 6 to 50. Class averages were negatively correlated with class size ($r = -0.53$).[166] Pre/post testing with the automated testing function of WebCT[166] to administer pre- and post-tests to students in the latest class yielded a normalized average gain,[168] $\langle g \rangle \equiv (\%posttest - \%pretest)/(100 - \%pretest)$ of $0.54 \pm .32$ sd. As suggested by the large standard deviation, this $\langle g \rangle$ is based on a very small class size ($N = 13$) and remains to be confirmed by further data. Normalized gains in traditional introductory-physics lecture classes average about 0.2 nationwide.[168] For RPI physics courses using "Interactive Lecture Demonstrations"[169] and "Cooperative Group Problem Solving"[170] the normalized gain is about 0.33.[171] The latter two numbers are based on much larger sample sizes and much smaller standard deviations than for my class. In my opinion, pre/post testing is a reasonable method for assessing the effectiveness of teaching in circumstances where controlled experiments are impractical. The value of $\langle g \rangle$, while it may or may not be directly comparable between disciplines, at least is based on information that the instructor considers relevant to the goals of the course, unlike student evaluations, which arguably can be susceptible to other influences."
< http://www.rpi.edu/dept/bio/info/Staff/roy.html >

KK. *Paul Saltman*[172-174] of the University of California - San Diego (UCSD) has: (a) served as Provost of Revelle College as well as Vice Chancellor for Academic Affairs, (b) taught the large introductory courses in biology, biochemistry, and nutrition; (c) developed new interdisciplinary courses called "Frontiers of Science" for non-science majors; (d) served on many national and international boards editorial boards for scientific journals, (e) been a consultant to the National Institutes of Health, the Academy of Sciences, National Science Foundation, and many other local and regional agencies, (f) received many awards, including the first "Career Teaching Award" from the Academic Senate at UCSD, and the Caltech Distinguished Alumni Award, (g) is the recipient of an NIH Research Career Development Award and was a Lady Davis Professor at the Hebrew University in Jerusalem, Israel. Saltman's course Biology 22, "Food and Nutrition" for lower division non-majors requires no prerequisites, is the most popular non-major science course at UCSD, and might serve as a model for other university biology departments. Under his direction UCSD has developed summer programs to enhance the scientific knowledge and skills of elementary and secondary science teachers. [175,176] Saltman's concern to communicate, in the broadest possible way, recent important scientific developments in the context of their social and ethical importance has led to: (a) the production of a large number of radio and television programs including a thirteen half-hour series called "Patterns of Life" for National Educational Television, and a six-part series for the Public Broadcasting System, (b) the "Course by Newspapers" sequence for the National Endowment for the Humanities entitled "America and the Future of Man," and (c) numerous articles in popular magazines and newspapers. His work on nutrition[173,174] was used as part of national course through an on-line network called "The New Nutrition" offered through the University of California Extension in collaboration with Genetech and Mars, Inc. at < http://www.accessexcellence.org/TC/ >.
< http://www-biology.ucsd.edu/shadow/sa/newbrochure/saltman.html >

LL. *Mike Smith*[177-182] at the Mercer University School of Medicine has described his work as follows: "I am interested in genetics problem solving, teaching problem solving and thinking, the nature of expertise (particularly in genetics), and think-aloud interviewing as a research tool. More recently, my interests have focused on teaching and learning about mitosis and meiosis and evolution. I have also written about issues involved in the nature of science. In my current position, I focus on facilitating health behavior change, particularly on the development and evaluation of peer-educator training curricula for pregnancy and STD/HIV prevention. I also continue to teach introductory genetics for our first-year medical students." Smith was a member of the NRC Working Group on Teaching Evolution which produced *Teaching About Evolution and the Nature of Science* (Nat. Acad. Press, 1998), ref. 15 in Sec. IV, "General References."

MM. *Marshall Sundberg*[183-191] at Emporia State University "is a plant anatomist/morphologist interested in ontogeny adaptation. Areas of current research include the evolutionary origin of the maize ear and development of the separation zone in Tabasco pepper fruits. He is also interested in science education and has published on curriculum design and assessment."
< http://www.emporia.edu/biosci/sundbiol.htm >

NN. *Lillian Tong* at the University of Wisconsin-Madison's Center for Biology Education (CBE) coordinates various teaching/learning faculty enrichment activities among many biological science departments across campus. Lillian promotes sharing of successful teaching innovations and facilitates cross-departmental cooperation and access to resources. Her programs focus on effective use of technology, active learning, teaching non-majors, and engagement of women in science. The CBE website < http://www.wisc.edu/cbe/ > contains some of these efforts, which might serve as models for other large research universities:
(1) "Innovation in Teaching: Novel Approaches to Knotty Problems, Spotlight on Departments"
< http://www.cals.wisc.edu/iic/innovation.html >
(2) "Undergraduate Research Opportunities in Biology at UW-Madison"
< http://www.wisc.edu/cbe/research/ >
(3) "Technology uses in biology education"
< http://newmedia.doit.wisc.edu/bnmc/instruct/index.htm >.
Others contributing to the CBE are Alan Wolf, biology consultant on new media, and Jan Cheetham, undergraduate research opportunities coordinator.

OO. *Dan Udovic*[192-194] at the University of Oregon has developed "Workshop Biology," a "project ... focused on developing a nationwide network of college biology teachers and providing resources and assistance for curriculum development and assessment." Udovic's project is discussed at < http://www.hhmi.org/BeyondBio101/index.htm >. Among resources developed are: Course Design Overview and Syllabi, Concept & Investigation Lab Activity Packet, Issues Activities Packet , Assessment Packet, Workshop Biology Testbank, Science Literacy Survey, Science Course Attitudes Inventory, Mid-and-End-of-Term Course, and Student Background Survey. Project coordinator *Deborah Morris* "developed the instruments used in the curriculum evaluation, conducted the data analysis, and has organized and participated in most of the presentations on Workshop Biology."
< http://biology.uoregon.edu/Biology_www/workshop_biol/wb.html >
< http://biology.uoregon.edu//HHMI/ >
Deborah Morris is now at Portland State, where she is the project coordinator for the "Oregon Collaborative For Excellence in the Preparation of Teachers" < http://www.mth.pdx.edu/OCEPT >, and conducts a course "Social Foundations of Education"
< http://odin.cc.pdx.edu/~bydm/EPFA551/syllabus.html >.

PP. *Gordon Uno*[185,195-205] of the Department of Botany and Microbiology at the University of Oklahoma is currently serving as a Program Director in the Division of Undergraduate Education (DUE) at the NSF. He has (a) served as President of the National Association of Biology Teachers, (b) taught over 5,000 undergraduates, (c) published an ecology text[202] and papers on education,[185,197,198,200,204,205] (d) authored or co-authored several inquiry-oriented high school biology texts[202,203] and supplements as well as the college curriculum guide *Developing Biological Literacy*,[199] (e) established a discussion site "Bioboard"[196] (address below and in Sec. IIIA). He is also preparing a "handbook[195] for finishing Ph.D.'s and young faculty members who are seeking or have taken an academic position in which teaching is their main responsibility. This handbook is a guide for the development of a contemporary undergraduate course in biology....(or other sciences)..... and contains everything you wanted to know about teaching science but were afraid to ask. The handbook focuses on how students learn, inquiry instruction, critical thinking skills, and assessment strategies as well as how to improve lectures, discussions, and laboratories. It also includes case studies of the first year of teaching for several faculty members."
< http://www.ou.edu/cas/botany-micro/faculty/uno.html >
< http://www.ou.edu/cas/botany-micro/ug-ed/wwwboard/bioboard.shtml >.

QQ. *D. Tom Vernon*[206-208] of the University of Missouri - Columbia medical school, now retired, has been concerned with problem-based learning (PBL) in medical schools. Although he is actually a psychologist, he is listed here because of his work in the biologically popular PBL. Vernon and R.L. Blake have published a meta-analysis[196] of "all evaluative research from 1970 through 1992 that compares PBL with more traditional methods of medical education. Five separate meta-analyses were performed on 35 studies representing 19 institutions……..the results generally supported the superiority of the PBL approach over more traditional methods."

RR. *John H. Wahlert* of Baruch College (CUNY) has developed a seminar "Darwin and Darwinism: Scientific Theory and Social Construction." According to Wahlert "Education is improved by showing the connections that help students to interrelate knowledge in various fields rather than to store it in separate mental compartments. The subject - Darwin and Darwinism - has broad and deep effects in the several disciplines of the arts and humanities and in contemporary culture, and it presents an opportunity to improve the science literacy of future business people, educators, and citizens."
< http://w3.baruch.cuny.edu/slas/departments/natural_science/faculty/wahlert.html >
< http://www.baruch.cuny.edu/slas/darwin/index.html >

SS. *Margaret Waterman*[209-216] at Southeast Missouri State University has written extensively on case-based teaching in biology. She uses "realistic problem 'cases' as a way to help students develop their own scientific investigations, using either real materials or computer software, such as that included in the BioQUEST Library." She was formerly associated with the problem-based learning project at Harvard Medical School,[213] "working on teaching, curriculum and assessment with some scientists and physicians who were very committed to student-centered case-based learning, ... (has) ..... made many presentations on case-based learning nationwide, and has consulted with colleges interested in initiating the approach in the sciences." She now works with "preservice and inservice science teachers and continues her scholarship on investigative case-based learning." For an example of one of Waterman's case-based learning scenarios as used by high-school students see "*Shelly Peretz's* On-line Biology Projects" in Sec. IIIA, "Web Addresses."
< http://cstl.semo.edu/waterman/ >

TT. *Paul Williams*[217-219] of the University of Wisconsin - Madison investigates the development of rapid cycling brassicas as models for research and education: "Using rapid cycling stocks of six brassica species, which have up to 10 reproductive cycles per year, and various brassica pathogens, I am exploring the genetics of various interesting brassica phenotypes including host-pathogen interactions. I have an interest in bringing my research on rapid cycling brassicas into instructional materials for teachers and students of all ages. Seed stocks of rapid cycling brassicas, various pathogen isolates, and information documents on the growth and uses of the organisms for research and education, available through the Crucifer Genetics Cooperative and the Wisconsin Fast Plants Program, are distributed world-wide. The Wisconsin Fast Plants, Bottle Biology, and Crucifer Genetics Cooperative programs are derivatives of my research that are impacting widely in classrooms and education programs nationally and internationally."
< http://fastplants.cals.wisc.edu/ >

UU. *Debrah Wygal*[220] and her colleagues at the College of Saint Catherine have developed a biology course "based on two themes: (a) the biology of women and women's health, and (b) the biology of the environment. The goal is to spark student interest in biology by teaching cellular, molecular, and physiological details in the context of their own bodies and in the larger social frameworks surrounding these issues."

References (Am. Inst. of Physics format - articles for each author are in *reverse* chronological order.)

1. "Physical Science Resource Center" (PSRC) at the American Association of Physics Teachers (AAPT) site < http://aapt.org >, click on the "PSRC" sign to bring up < http://www.psrc-online.org/ >.

2. (a) L.C. McDermott and E.F. Redish, "Resource Letter on Physics Education Research" *Am. J.Phys.*, to be published and on the web < http://www.physics.umd.edu/rgroups/ripe/papers/rlpre.pdf >. See also (b) E.F. Redish and R.N. Steinberg, "Teaching Physics: Figuring Out What Works," *Phys. Today* **52**(1), 24-30 (1999) and on the web at < http://www.physics.umd.edu/rgroups/ripe/papers/PT/pt.htm >; (c) E.F. Redish, "Millikan Lecture 1998: Building a Science of Teaching Physics," *Am. J. Phys.* **67**(7), 562-573; on the web at < http://www.physics.umd.edu/rgroups/ripe/perg/cpt.html >.

3. University of Maryland (UMD) Physics Education Research (PER) Group web site at < http://www.physics.umd.edu/rgroups/ripe/perg/ >; the UMD-PER's listing of PER papers is on the web at < http://www.physics.umd.edu/rgroups/ripe/perg/perow.html >.

4. *Project Impact: Disseminating Innovations in Undergraduate Education* (NSF Reports 95-69 (Proceedings) & 95-70 (Abstracts), 1995), see esp. J.L. Fox, "Current Trends in Undergraduate Biology," NSF 95-69, p. 44-49: ".....biology lacks a central clearing-house for evaluating, recognizing, and rapidly distributing outstanding new ideas about teaching as well as new teaching materials that spring up at the hundreds of universities, colleges, community colleges, and other higher education facilities around the country." See, however, ref. 5; the Sec. IIIA web addresses for ABLE, BioQUEST, CELS, HHMI, Science Junction, UTK; and the "Teacher's Web Sites" of Sec. IIIB.

5. (a) "The Coalition for Education in the Life Sciences" (CELS), a "national coalition of professional societies in the biological sciences that have joined together in an effort to improve undergraduate education in the life sciences" at < http://www.wisc.edu/cels/ >. (b) CELS monograph *Professional Societies and the Faculty Scholar: Promoting Scholarship and Learning in the Life Sciences*, Louise Liao, ed., 1998, on the web at < http://www.wisc.edu/cels/ >, see, esp. J. R. Jungck, "Professional Biological Societies as Communities of and for Faculty Scholars: Opportunities and Challenges," p. 16-22.

6. (a) J. Stewart, "Biology Education Research: A View from the Field," in *Toward a scientific practice of science education*, ed. by M. Gardner, J.G. Greeno, F. Reif, A.H. Schoenfeld, A. diSessa, and E. Stage (Lawrence Erlbaum, 1990). See also (b) R. Hafner and J. Stewart, "Revising explanatory models to accommodate genetic phenomena: Problem solving in the "context of discovery" *Science Education* **79**(2), 111-146 (1995); (c) J. Lythcott and J. Stewart, "Teaching Science in a multicultural perspective," in C. Grant & M. Gomez, eds., *Making Schooling Multicultural: Campus and Classroom* (1995); (d) E. Finkel and J. Stewart, "Strategies for model-revision in a high school genetics classroom," in *Mind, Culture, and Activity* **1**(3), 168-195 (1994); (e) J. Stewart and R. Hafner, "Research on Problem Solving: Genetics" in *Handbook of Research on Science Teaching and Learning*, D.L. Gabel, ed. (Macmillan, 1994).

7. J.A. Eison *et al.* "Bibliography of Active Learning in Science" at < http://www.cte.usf.edu/resources/res_def.html >. See also C.C. Bonwell and J.A. Eison, *Active learning: Creating excitement in the classroom.* (ASHE-ERIC Higher Education Reports, 1991); J.A. Eison and C.C. Bonwell, "Recent Works on Using Active Strategies Across the Disciplines," ERIC document ED364135, 1993; "Enhancing Teaching and Learning in Post Secondary Science Courses" (includes "Enhancing Students' Critical and Creative Thinking Skills"), unpublished. I thank Craig Nelson for pointing out these valuable resources.

8. (a) The present document is in the form of an Adobe Acrobat (AA) portable document file (PDF). Such files are transportable across nearly all platforms and now pervade the web. Downloading of PDF documents such as this one requires use of the FREE 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. (b) The present PDF has been constructed so that clicking on web addresses [or Uniform Resource Locators (URL's), e.g., < http://www.udel.edu/pbl >**]** will bring up the address in your browser. In some cases clicking will bring up an Adobe panel which requests that you specify a browser. For more information, when viewing the PDF file, click on the Help/Reader Online Guide/Viewing PDF documents/Opening and printing PDF documents/Opening PDF documents in a Web browser window.

9. D. Allen and B. Duch, *Thinking Towards Solutions: Problem-Based Learning Activities for General Biology* (Saunders, 1998).

10. D.E. Allen, "Bringing Problem-Based Learning to the Introductory Biology Classroom," 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/ch15.html >.

11. 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," 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/ch05.html >.

12. D.E. Allen, "Teaching with tutors: Can undergraduates effectively guide student problem-based learning groups?" *About Teaching* **50**,1-2 (1996).

13. D.E. Allen, B. J. Duch, and S. E. Groh, "The power of problem-based learning in teaching introductory science courses, *New Directions for Teaching and Learning* **68**, 43-52 (1996).

14. D. E. Allen and H. B. White III, "A few steps ahead on the same path: Using peer tutors in the cooperative learning classroom - a multilayered approach to teaching," *J. College Science Teaching* March/April, p. 299-302 (1999).

15. American Society of Zoologists - Education Committee, "Science As a Way of Knowing:"
I. Organized by J.A. Moore, "Evolutionary Biology," *American Zoologist* **24**, 421-534 (1984);
II. Organized by J.A. Moore, "Human Ecology," *ibid.* **25**, 377-641 (1985);
III. Organized by J.A. Moore, "Genetics," *ibid.* **26**, 569-918 (1986);
IV. Organized by J.A. Moore, "Developmental Biology," *ibid.* **27**, 411-732 (1987);
V. Organized by J.A. Moore, W.V. Mayer, and I. Deyrup-Olsen, "Form and Function," *ibid.* **28**, 441- 808 (1988);
VI. Organized by B.M Alberts, "Cell and Molecular Biology," *ibid.* **29**, 481-817 (1989);
VII. Organized by E.S. Hodgson, "Neurobiology and Behavior," *ibid.* **30**, 401-860 (1990); *ibid.* **31**, 349-471 (1991).
VIII. Organized by M.P. Morse and B.L. Thorne, "Biodiversity," *ibid.* **34**, 1-171 (1994).

16. R.W. Bybee, "Improving Science Education: The Role of Scientists," American Physical Society *Forum on Education Newsletter*, Fall, 1998, p. 6-8; "The Sputnik Era: Why is this Educational Reform Different from all other Reforms?" *ibid.* Spring 1998, p. 4-6.

17. R.W. Bybee and A. Champagne, "The National Science Education Standards," *Science Teacher* **62**(1), 40-45 (1995).

18. R.W. Bybee, *Reforming Science Education: Social Perspectives & Personal Reflections* (Teachers College Press, 1993);

19. R.W. Bybee, "Planet Earth in Crisis: How Should Science Educators Respond?" *American Biology Teacher* **53**(3), 146-153 (1991).

20. A. Chang, "The Origins of CELS," in ref. 5b, p. 14-15.

21. C. D'Avanzo and A.P. McNeal, eds., *Student-Active Science: Models of Innovation in College Science Teaching* (Saunders, 1997). Saunders is advancing the cause of education reform: (a) "professionals" may order a *free* copy by calling 1-800-782-4479; (b) the entire book will soon be available electronically as an Adobe Acrobat portable document file! See Saunders listings in Sec. IIIA, "Web Addresses"; and refs. 10, 11, 22, 32, 64, 105, 106, 128, 184, and 197.

22. C. D'Avanzo and A.P. McNeal, "Research for all students: structuring investigation into first-year courses" in *Student-Active Science: Models of Innovation in College Science Teaching*, A. P. McNeal and C. D'Avanzo, eds. (Saunders, 1997),
< http://www.saunderscollege.com/lifesci/studact/chapters/ch16.html >.

23. C. D'Avanzo, "Three ways to teach ecology," *Bulletin of the Ecological Society of America* **77**, 92-93 (1996).

24. C. D'Avanzo, "Inquiry in the Undergraduate Science Classroom," *BioScience* **37**, 540 (1987).

25. C. D'Avanzo, "Involving freshmen in research," *Education Section of the Ecological Society of America* **3**(1), 7-8 (1992).

26. D. Ebert-May, C. Brewer, S. Allred, "Innovation in Large Lectures - Teaching for Active Learning" *Bioscience* **47**(9), 601-607 (1997).

27. K. M. Fisher, J. H. Wandersee, and D. Moody, *Mapping Biology Knowledge* (Dordrecht, Netherlands: Kluwer, in press).

28. K. M. Fisher & R. G. Christianson, "Comparison of student learning about diffusion and osmosis in constructivist and traditional classrooms" to appear in *From Misconceptions to Constructed Understanding - Proceedings of the Fourth International Misconceptions Seminar* (in honor of the retirement of Joseph Novak), R. Abrams, ed. (Meaningful Learning Research Group, 1999), on the web at
< http://www2.ucsc.edu/mlrg/mlrghome.html >.

29. K. M. Fisher, "Supporting knowledge construction and reflection," *Vivek: A Quarterly in Artificial Intelligence* **9**(2), 18-34 (1996).

30. K. M. Fisher & M. Kibby, eds., *Knowledge Acquisition, Organization, and Use in Biology* (Springer Verlag, 1996).

31. M. Gorodetsky, K. M. Fisher, B. Wyman, "Generating Connections and Learning with SemNet©, a Tool for Constructing Knowledge Networks," *J. Sci. Ed. Tech.* **3(**3**)**, 137-144 (1994).

32. M. Flower, C. Ramette, and W. Becker, "Science in the Liberal Arts at Portland State University: A Curriculum Focusing on Science-in-the-Making" in *Student-Active Science: Models of Innovation in College Science Teaching*, A. P. McNeal and C. D'Avanzo, eds. (Saunders, 1997) < http://www.saunderscollege.com/lifesci/studact/chapters/ch12.html >.

33. M. Flower, "Technoscientific Politics: Cui Bono?" (A review of Donna Haraway's <Modest_Witness@Second_Millenium.FemaleMan_Meets_OncoMouse>), *Theory and Event* **1.3** (1997), an electronic journal. The table of contents of issue 1.3 is at < http://muse.jhu.edu/journals/theory_&_event/toc/archive.html#1.3 >.

34. M. Flower and D. Heath, "Micro-anatomo politics: mapping the Human Genome Project" *Culture, Medicine and Psychiatry* **17**, 27-41 (1993)

35. L.J. Gross, "Mentoring in a distributed world," *D-Lib Magazine*, September 1998, at < http://www.dlib.org/dlib/september98/09editorial.html >.

36. L.J. Gross, "Quantitative training for life-science students," *BioScience* **44**, 59 (1994).

37. D.L. DeAngelis and L.J. Gross, eds., *Individual-Based Models and Approaches in Ecology* (Routledge, Chapman, and Hall, 1992).

38. J.B. Hagen, D. Allchin, and F. Singer, *Doing Biology* (Harper Collins, 1996).

39. J. Handlesman, B. Houser, and H. Kriegel, *Biology Brought to Life: A guide to teaching students to think like scientists* (Times Mirror Higher Education Group, 1997).

40. E. E. Harding, M. Key, and C.C. Loving, "Themes, Inquiry, and Collaboration in College Introductory Biology Laboratory," presentation at Lily West, Lake Arrowhead, CA, 1995.

41. *Fulfilling the Promise: Biology Education in the Nation's Schools* (National Academy Press, 1990), for a description see < http://www.nap.edu/bookstore/isbn/0309051479.html >, or the listing in Sec. VB.

42. J. Harte, "Feedbacks, Thresholds, and Synergies in Global Change: Population as a Dynamic Factor," *Biodiversity and Conservation* **5**, 1069-1083 (1996).

43. R. Socolow, D. Anderson, J. Harte, eds. *Annual Review of Energy and the Environment* **21** (Annual Reviews, Inc., 1996).

44. J. Harte, "The Central Scientific Challenge for Conservation Biology," in *The Ecological Basis of Conservation: Heterogeneity, Ecosystems, and Biodiversity*, eds., S. Pickett, R. Ostfeld, M. Shachak, and G. Likens (Chapman and Hall, 1996), p. 187-192.

45. J. Harte, *Consider a Spherical Cow: A Course in Environmental Problem Solving* (University Science Books, 1988).

46. P. Horwitz and M. A. Christie, "Computer-Based Manipulatives for Teaching Scientific Reasoning: An Example," in *Learning the Sciences of the 21st Century: Research, Design, and Implementing Advanced Technology Learning Environments* (Lawrence Erlbaum, to be published).

47. P. Horwitz, "Designing Computer Models that Teach" in *Computer Modeling and Simulation in Pre-College Science Education*, Nancy Roberts, Wallace Feurzeig, and Beverly Hunter, eds., (Springer Verlag, to be published).

48. P. Horwitz, E. Neumann and J. Schwartz, "Teaching Science at Multiple Levels: the GenScope Program," *Communications of the ACM* **39**(8), 1996.

49. P. Horwitz and B. Barowy, "Designing and Using Open-Ended Software to Promote Conceptual Change," *Journal of Science Education and Technology* **3**(3), 161-85 (1994).

50. P. Horwitz and W. Feurzeig, " Computer-Aided Inquiry in Mathematics Education, *Journal of Computers in Mathematics and Science Teaching* **13**(3), 265-301 (1994).

51. P. Horwitz. E.F. Taylor, and P. Hickman, " 'Relativity Readiness' Using the RelLab Program," *Physics Teacher* **32**(2), 81-86 (1994).

52. P.D. Hurd, *Inventing Science Education for the New Millennium* (Ways of Knowing in Science Series, Teachers College Press, 1997).

53. P.D. Hurd, "New Minds for a New Age: Prologue to Modernizing the Science Curriculum," *Science Education* **78**(1), 103-116 (1994).

54. P.D. Hurd, "Technology and the Advancement of Knowledge in the Sciences," *Bulletin of Science, Technology & Society* **14**(3), 125-131 (1994).

55. P.D. Hurd, "Comment on Science Education Research: A Crisis of Confidence," *Journal of Research in Science Teaching* **30**(8), 1009-1011 (1993).

56. P.D. Hurd, "Closing the Educational Gaps between Science, Technology, and Society," *Bulletin of Science, Technology and Society* **12**(3), 127-35 (1992).

57. P.D. Hurd, "Why We Must Transform Science Education," *Educational Leadership* **49**(2), 33-35 (1991).

58. P.D. Hurd, "The Emergence of a New Synthesis for Biology Education," *Bulletin of Science, Technology & Society* **7**, 585-588 (1988).

59. P.D. Hurd, "Perspectives for the Reform of Science Education," *Phi Delta Kappan* **67**(5), 353-358 (1986).

60. P.D. Hurd, "Problems and issues in science-curriculum reform and implementation," in *High School Biology Today and Tomorrow*, W.G. Rosen, ed. *(*National Academy Press, 1986), p. 291-297.

61. J.R. Jungck, ed. *The BioQUEST Library* V. (Academic Press, 1986-1999); co-author of seven modules: (1) Genetics Construction Kit (with J. Calley), (2) Microbial Genetics Construction Kit (with J. Calley), (3) Inherit (with P. Soderberg and B. Jones), (4) Pedigree Construction Kit (with J. Calley), (5) Introduction to BioQUEST: Problem Posing, Problem Solving, and Persuasion in Biological Investigations (with J. Stewart and N. Peterson), (6) BIRDD - Beagle Investigation Returns with Darwinian Data: Darwin Finch Data Resource (with F. Price, S. Donovan, and J. Stewart); (7) Benzer: Ordering Food Webs, Restriction Maps, and Sequences (with V. Streif and I. Ceraj).

62. J.R. Jungck, "Digital Libraries for Educational Reform: Instantiation, Ignorance, and Information," in *Developing a Digital National Library for Undergraduate Science, Mathematics, Engineering, and Technology Education,* (National Academy Press, 1998), p. 78-83, at < http://www.nap.edu/readingroom/books/dlibrary/ >, see also the listing and quote from Jungck's paper in Secs. VA and VII.

63. J.R. Jungck, P. Soderberg, E. Stanley, and V. Vaughan, "Computer-Enhanced Collaborative Learning," in *Methods of Effective Teaching and Course Management,* E. D. Siebert, M. W. Caprio, and C. M. Lyda, eds., (Kendall/Hunt, 1997), p. 173-188.

64. J.R. Jungck, "Realities of Radical Reform: Reconstructing 'Chilly Climates' into 'Collaborative Communities' - Sharing BioQUEST Experience," in *Student-Active Science: Models of Innovation in College Science Teaching,* A. P. McNeal and C. D'Avanzo, eds., (Saunders, 1997), p. 21-45. < http://www.saunderscollege.com/lifesci/studact/chapters/ch02.html >.

65. J.R. Jungck, "Ten Equations that Changed Biology: Mathematics in Problem-Solving Biology Curricula," *Bioscene: Journal of College Biology Teaching* **23**(1), 11-36 (1997).

66. J.R. Jungck, "Ignorance, Error, and Chaos: Local Learning/Global Research," published in Japanese as "Muchi, shippai soshite konnton" in Gendai shisou (Japanese Journal of Modern Thought) **24**(11), 363-376 (1996), also at < http://www.beloit.edu/~biology/jungck.html >.

67. J.R. Jungck, "A Problem Posing Approach to Biology Education," *American Biology Teacher* **47**(5), 264-266 (1985), reprinted in *Problem Posing: Reflections and Applications*, S. Brown and M. Walter, eds., (Lawrence Erlbaum, 1993).

68. J.R. Jungck, "Constructivism, Computer Exploratoriums, and Collaborative Learning: Constructing Scientific Knowledge," *Teaching Education* **3**(2), 151-170 (1991).

69. J.R. Jungck, "The Three I's: Interdisciplinary, Investigative, and Independent study," in *How Ought Science Be Taught?,* R.K. Gibbs and P.A. Taylor, eds., (MSS Educational Publishers, 1972) p. 209-210.

70. J.R. Jungck and N.S Peterson, "Problem-Posing, Problem-Solving, and Persuasion in Biology Education," *Academic Computing* **2**(6), 14-17, 48-50 (1988).

71. J.R. Jungck and J.N. Calley, "Strategic Simulations and post-Socratic pedagogy: Constructing software to develop long-term inference through experimental inquiry," *American Biology Teacher* **46**(8), 464-467 (1985).

72. J.R. Jungck and C. Dyke, "Evolution, Economics and Education: Understanding the Consequences of Natural Selection in Health and Disease," *American Biology Teacher* **47**(3), 138-141 (1985).

73. J.B Kahle, "Equitable systemic reform in science and mathematics: Assessing progress," *Journal of Women and Minorities in Science and Engineering* 4(2-3), 91-112 (1998).

74. J.B. Kahle, "Reaching equity in systemic reform: How do we assess progress and problems?" Research Monograph No. 5 (National Institute for Science Education, University of Wisconsin-Madison, 1998).

75. J.B. Kahle, "Introduction," in *Women in the biological sciences: A bibliographic sourcebook,* L. S. Grinstein, C. A. Biermann, & R. K. Rose, eds., (Greenwood Press, 1997), p. xxi-xxii.

76. J. B. Kahle, "Systemic Reform: Challenges and Changes," *Science Educator* **6**(1), 1-6 (1997).

77. J.B. Kahle, "Equitable science education: A discrepancy model," in *Gender, science and mathematics: Shortening the shadow,* B. Fraser, L.H. Parker, & L.J. Rennie, eds. (Dordrecht: Kluwer, 1996) p. 129-139).

78. J.B. Kahle and J. Meece, "Research on Gender Issues in the Classroom, in *Handbook of Research on Science Teaching and Learning,* D.L. Gabel, ed. (Macmillan, 1994).

79. J. B. Kahle and L.J. Rennie, "Ameliorating Gender Differences in Attitudes about Science: A Cross-National Study," *Journal of Science Education and Technology* **2**(1), 321-334 (1993).

80. l. P. Johnson and B. Kincaid, *Investigating Biology* (Organpipe Publishers, 1994).

81. W. B.Kincaid, "Using the Learning Cycle to Teach Biology Concepts and Basic Skills," in *Vision '90: The Maricopa Community Colleges Journal of Teaching and Learning*, **2** (1-2), (1990).

82. D.T. Hickey, E.W. Wolfe, and A.C.H. Kindfield, "Assessing learning in a technology-supported genetics environment: Evidential and systemic validity issues," *Educational Assessment* (in press).

83. A.C.H. Kindfield, "Generating and using diagrams to learn and reason about biological processes. *Journal of Structural Learning and Intelligent Systems* (in press).

84. P. Horwitz, J. Schwartz, A.C.H. Kindfield, L.M. Yessis, D.T. Hickey, A. Heidenberg, and E.W. Wolfe, "Implementation and evaluation of the GenScope© learning environment: Issues, solutions, and results," in M. Guzdial, J. Kolodner, A. Bruckman, and A. Ram. eds., *Proceedings of the Third Annual International Conference of the Learning Sciences* (Association for the Advancement of Computers in Education; Charlottesville, VA, 1998), p. 6-10.

85. A.C.H. Kindfield, "Genetics beyond the textbook," *Science Education* **81**(5), 609-610 (1997), review of the book *The DNA mystique: The gene as a cultural icon*.

86. A.C.H. Kindfield, "Assessing understanding of biological processes: Elucidating students models of meiosis," *The American Biology Teacher* **56**(6), 367-371 (1994).

87. A.C.H. Kindfield, "Biology Diagrams: Tools to Think With," *Journal of the Learning Sciences* **3**(1), 1-36 (1993/1994).

88. A.C.H. Kindfield, "Understanding a Basic Biological Process: Expert and Novice Models of Meiosis" *Science Education* **78**(3), 255-283 (1994).

89. A.E. Lawson, "Introducing Mendelian genetics through a learning cycle," *The American Biology Teacher* **58**(1), 38-42 (1996).

90. A.E. Lawson, *Science Teaching and the Development of Thinking* (Wadsworth, 1995). Contains a student test of critical thinking.

91. A.E. Lawson, "Epistemological foundations of cognition," in D. Gabel, ed. *Handbook of Research on Science Teaching and Learning* (Macmillan, 1994).

92. A.E. Lawson, "Deductive reasoning, brain maturation, and science concept acquisition: Are they linked?" *Journal of Research in Science Teaching* **30**(9), 1029-1052 (1993).

93. A.E. Lawson, "Neural Principles of Memory and a Neural Theory of Analogical Insight," *Journal of Research in Science Teaching* **30**(10), 1327- 1348 (1993).

94. A.E. Lawson, W.P. Baker, L. DiDonato, M.P. Verdi, and M.A. Johnson, "The role of physical analogues of molecular interactions and hypothetico-deductive reasoning in conceptual change," *Journal of Research in Science Teaching* **30**(9), 1073-1086 (1993).

95. A.E. Lawson, ed. "Special Issue on the Role of Analogy in Science and Science Teaching," *Journal of Research in Science Teaching* **30**(10), 1211-1364, (1993).

96. *Science Teaching Reconsidered: A Handbook* (Nat. Acad. Press, 1997), see < http://www.nap.edu/readingroom/books/str/ >, see also the listing in Sec. VA.

97. T.R. Lord, "A Comparison Between Traditional and Constructivist Teaching in College Biology, "*Innovative Higher Education* **21**(3), 197-216 (1997).

98. W. E. Magee and P. Martin, "Beyond Hands-On" (submitted, 1999).

99. W. E. Magee and P. Martin, "The Enhanced Bioscience Education (EBE) Program," paper presented at the AIBS meeting, Seattle, WA, August, 1996.

100. R. Mutharasan, W. E. Magee, M. Wheatley, and Y. Lee, "Thematic introduction to engineering biotechnology: Gateway experience," *ASEE Annual Conference Proc.* (1995).

101. G.M. Malacinski and P.W. Zell, "Learning molecular biology means more than memorizing the formula for tryptophan," *J. Coll. Sci. Teaching* **25**, 198-202 (1996).

102. P.W. Zell and G.M. Malacinski, "Impediments to developing collaborative learning strategies: The input vs. output conflict." *J. Sci. Ed. Tech.* **3**, 107-114 (1994).
Science Education, **81**(5), 609-610 (1997).

103. A.P. McNeal, "Death of the Talking Heads: participatory structures for faculty workshops," *College Teaching* **46**(3), 90 (1998).

104. A.P. McNeal, D.U. Silverthorn, and D.B. Stratton, "Involving students in experimental design: three approaches," *Advances in Physiology Education* **20**(1) (1998).

105. A.P. McNeal and C. D'Avanzo, eds., *Student-Active Science: Models of Innovation in College Science Teaching*, (Saunders, 1997) Saunders is advancing the cause of education reform: (a) "professionals" may order a *free* copy by calling 1-800-782-4479; (b) the entire book will soon be available electronically as an Adobe Acrobat portable document file! See Saunders listings in Sec. IIIA, "Web Addresses"; and refs. 10, 11, 21, 22, 32, 64, 106, 128, 184, and 197, < http://www.saunderscollege.com/lifesci/studact/ >.

106. A.P. McNeal, "Teacher-Active Workshops: Collaborative Structures for Curricular Reform," in A.P. McNeal and C. D'Avanzo, eds., *Student-Active Science: Models of Innovation in College Science Teaching*, (Saunders, 1997), < http://www.saunderscollege.com/lifesci/studact/chapters/ch26.html >.

107. A.P. McNeal, "Introduction" in *Project Impact: Disseminating Innovations in Undergraduate Education* (NSF Report 95-69, Proceedings, 1995).

108. A.P. McNeal and M. Murrain, "Drugs in the nervous system: a course in learning to learn science," *College Teaching* **42**(2), 47-50 (1994).

109. A.P. Woodhull-McNeal, "Project Labs in Physiology," *Advances in Physiology Education* **8**(1), 29-32 (1992).

110. A.P. Woodhull-McNeal, "Teaching science as inquiry: a course example," *College Teaching* **37**(1), 3-7 (1989).

111. J. E. Groccia and J. E. Miller, "Enhancing Productivity: Administrative, Instructional, and Technological Strategies," in *New Directions for Higher Education* #103 (Jossey-Bass, 1998).

112. J.E. Miller and J.E. Groccia, "Are Four Heads Better Than One? A Comparison of Cooperative and Traditional Teaching Formats in an Introductory Biology Course," *Innovative Higher Education* **21**(4), 253-273 (1997).

113. J. E. Miller and others, "Providing Structure: The Critical Element," *New Directions for Teaching and Learning* **67**, 17-30 (1996).

114. J. E. Groccia and J. E. Miller, "Collegiality in the Classroom: The Use of Peer Learning Assistants in Cooperative Learning in Introductory Biology" in *Innovative Higher Education* **21**(2), 87-100 (1996).

115. J. E. Miller and others, "Group Dynamics: Understanding Group Success and Failure in Collaborative Learning," *New Directions for Teaching and Learning* **59**, 33-44 (1994).

116. J. E. Miller, J. M. Wilkes, R. D. Cheetham, and L. Goodwin, "Tradeoffs in Student Satisfaction: Is the 'Perfect' Course an Illusion," *Journal on Excellence in College Teaching* **4**, 27-47 (1993).

117. L. Goodwin, J.E. Miller, and R. D. Cheetham, "Teaching freshman to think - does active learning work?," *BioScience* **41**(10), 719-722 (1991).

118. J.E. Miller and R. D. Cheetham, "Teaching Freshman to Think - active learning in introductory biology," *BioScience* **40**(5), 388-391 (1990).

119. J.A. Moore, "Cultural and Scientific Literacy" *Molecular Biology of the Cell* **6**, 1-6 (1995).

120. J.A. Moore, "We need a revolution - teaching biology for the twenty-first century," *Bioscience* **43**(11), 782-786 (1993).

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

122. M.P. Morse and B.L. Thorne, "Science as a way of knowing: Biodiversity," *American Zoologist* **34**, 1-171 (1994) - see also ref. 15.

123. J.L. Narum, "A Better Home for Undergraduate Science," *Issues in Science and Technology* **13**(1), 78-84 (1996).

124. J.L. Narum, *Project Kaleidoscope* (*Project Kaleidoscope*, Washington, DC, 1996).

125. J.L. Narum, ed., *Structures for Science: A Handbook for Planning Facilities for Undergraduate Natural Science Communities*, Vol. 3 (*Project Kaleidoscope*, Washington, DC, 1995).

126. J.L. Narum, ed., *What Works: Building Natural Science Communities. Resources for Reform. Strengthening Undergraduate Science and Mathematics*, Vol. 2 (*Project Kaleidoscope*, Washington, DC, 1992).

127. J.L. Narum, ed, *What Works: Building Natural Science Communities. A Plan for Strengthening Undergraduate Science and Mathematics*, vol. 1 (*Project Kaleidoscope*, Washington, DC, 1991).

128. J.L. Narum, "Some Lessons Learned," 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/ch01.html >.

129. J. Beard, M.K. Nickels, C.E. Nelson, "Making a Difference in the Classroom: Effects of an Inservice Institute for High School Biology Teachers," submitted for publication, 1/99.

130. C.E. Nelson, "On the Persistence of Unicorns: The Tradeoff Between Content and Critical Thinking Revisited," in *The Social Worlds of Higher Education: Handbook for Teaching in a New Century*, B. A. Pescosolido and R. Aminzade, eds. (Pine Forge Press, 1999), Ch. 14.

131. M.K. Nickels, J. Beard, "The Nature of Science as a Foundation for Teaching Science: Evolution as a Case Study," in *The Nature of Science in Science Education*, W.F. McComas, ed. (Kluwer Academic Publishers, 1998), Ch. 20, p. 315-328.

132. C.E. Nelson, "Tools for Tampering with Teaching's Taboos," in *New Paradigms for College Teaching*, ed. by W.E. Campbell and K.A. Smith (Interaction Book, 1997), p. 51-77.

133. M.K. Nichels, C.E. Nelson, J. Beard, "Better Biology Teaching by Emphasizing Evolution and the Nature of Science," *The American Biology Teacher* **58(6)**, 332-336 (1996).

134. C.E. Nelson, "Student Diversity Requires Different Approaches to College Teaching, Even in Math and Science," *American Behavioral Scientist* **40**(2), 165-175 (1996).

135. C.E. Nelson, "Critical Thinking and Collaborative Learning, *New Directions for Teaching and Learning* **59**, 45-58 (1994).

136. C.E. Nelson. "Every Course Differently: An Outline," p. 94-100 and (with 12 others) "Valuing Diversity in the Educational Process," p. 71-74; both in *Role of Faculty from Science Disciplines in the Undergraduate Education of Science and Mathematics Teachers*, J. Lanier & W. Sibley, eds. (National Science Foundation, 1994) NSF Publication 93-108.

137. C.E. Nelson, "Skewered on the Unicorn's Horn: The Illusion of Tragic Tradeoff Between Content and Critical Thinking in the Teaching of Science," in *Enhancing Critical Thinking in the Sciences*, L.W. Crow, ed. (Society for College Science Teachers/National Science Teachers Association, 1989), p. 17-27.

138. C.E. Nelson, "Creation, Evolution, or Both? A Multiple Model Approach," in *Science and Creation*, R.W. Hanson, ed. (Macmillian, 1986), p. 128-159.

139. C.E. Nelson, "Environmental Studies Programmes, Indiana University," in *Environmental Education at Post Secondary Level* (Centre for Educational Research and Innovation, Organization for Economic Cooperation and Development, Paris, 1974), p. 97-110. Reprinted as "Environmental Studies Program at Indiana University," in *Selected Environmental Education Programs in North American Higher Education*, A.L. Pratt, ed. (National Assoc. Environmental Educ.), p. 79-88.

140. *From Misconceptions to Constructed Understanding - Proceedings of the Fourth International Misconceptions Seminar* (in honor of the retirement of Joseph Novak), R. Abrams, ed. (Meaningful Learning Research Group, in press, 1999), on the web at < http://www2.ucsc.edu/mlrg/mlrghome.html >.

141. *The Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics*, J. Novak and R. Abrams, ed. (Meaningful Learning Research Group, 1993), on the web at < http://www2.ucsc.edu/mlrg/mlrghome.html >.

142. *The Proceedings of the Second Misconceptions in Science and Mathematics Conference Proceedings*, J. Novak. ed. (Cornell University, 1987); also available on Macintosh CD ROM in Quick Time Format. Information on titles, authors, and page numbers is at < http://www2.ucsc.edu/mlrg/mlrghome.html >.

143. *Proceedings of the International Seminar on Misconceptions in Science and Mathematics,* H. Helm and J. Novak, eds., (Cornell University, 1983), p. 282-291, abstracts are on the web at < http://www2.ucsc.edu/mlrg/mlrghome.html >.

144. J.D. Novak, J.J. Mintzes, and J.H. Wandersee, eds. *Teaching Science for Understanding - A Human Constructivist View* (Academic Press, 1998).

145. J.D. Novak, *Learning, Creating, and Using Knowledge: Concept Maps as Facilitative Tools in Schools and Corporations* (Erlbaum, 1998).

146. J. Wandersee, J. Mintzes, and J. Novak, "Research on Alternative Conceptions in Science" in D. Gabel, ed. *Handbook of Research on Science Teaching and Learning* (Macmillan, 1994).

147. J.D. Novak, "Concept Maps and Vee Diagrams: Two Metacognitive Tools to Facilitate Meaningful Learning," *Instructional Science* **19**(1), 29-52 (1990).

148. J.D. Novak, "Concept Mapping Brings Long-Term Movement toward Meaningful Learning, *Science Education* **74**(4), 461-472 (1990).

149. J.D. Novak, "Concept Mapping: A Useful Tool for Science Education," *Journal of Research in Science Teaching* **27**(10), 937-947 (1990).

150. J.D. Novak and D.B. Gowin, *Learning How to Learn* (Cambridge University Press, 1985).

151. J.D. Novak," Applying Learning Psychology and Philosophy of Science to Biology Teaching," *American Biology Teacher* **43** (1), 12-20 (1981).

152. J.D. Novak, "An Alternative to Piagetian Psychology for Science and Mathematics Education," *Studies in Science Education* **5**, 1-30 (1978).

153. H.B. Posner and J.A. Markstein, "Student-Directed Investigations in Enzymology for Introductory College Biology," *American Biology Teacher* **60**(1), 54-58 (1998).

154. H.B. Posner, "Teaching introductory cell and molecular biology - a historical and empirical approach," *The American Biology Teacher* **58**, 272-274 (1996).

155. H.B. Posner, T. O'Brien, and J.A. Markstein, "A teaching scholars program to develop problem-solving molecular biology experiments," in J.A. Chambers, ed., *Selected Papers from the Fifth National Conference on College Teaching and Learning*, pp. 129-140. (Center for the Advancement of Teaching and Learning, Jacksonville, Florida, 1994).

156. H.B. Posner and J.A. Markstein, "Cooperative Learning in Introductory Cell and Molecular Biology," *Journal of College Science Teaching* **23**(4), 231-233 (1994).

157. S. Rosser, *Teaching Science and Health from a Feminist Perspective: A Practical Guide* (Pergamon Press, 1986).

158. S. Rosser, *Re-engineering Female Friendly Science* (Teachers College Press, 1997).

159. S. Rosser, *Teaching the Majority* (Teachers College Press, 1995).

160. S. Rosser, *Women's Health: Missing from U.S. Medicine* (Indiana University Press, 1994).

161. S. Rosser, *Feminism and Biology: A Dynamic Interaction* (Twayne Macmillan, 1992).

162. S. Rosser, *Female-Friendly Science* (Pergamon Press, 1990).

163. S. Rosser, *Feminism within the Science and Health Care Professions: Overcoming Resistance* (Pergamon Press, 1988).

164. H. Roy, "The Studio Genetics and Evolution Course," 1996, at < http://www.rpi.edu/dept/bio/info/Biosimlab/genetics.html >.

165. H. Roy and A. Day, Visual Genetics - in progress, 1999, computer programs containing problem sets, simulations of many genetic experiments, and animations that describe numerous topics in genetics and evolution.

166. H. Roy, "Automated Testing and Measurement of Student Progress in Genetics and Evolution," 1999, at < http://www.rpi.edu/~royh/AutomatedTestingAndMeasurement.html >.

167. J.M. Wilson, "The CUPLE Physics Studio," *Phys. Teach*. **32**, 518-523 (1994); "Physics Education in the Next Century," *APS Forum on Education Newsletter*, Spring 1999, p. 5-7.

168. 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) and on the web at < http://www.physics.indiana.edu/~sdi >.

169. D.R. Sokoloff and R.K. Thornton, "Using Interactive Lecture Demonstrations to Create an Active Learning Environment," *Phys. Teach*. **35**, 340-347 (1998).

170. P. Heller, R. Keith, S. Anderson, "Teaching problem solving through cooperative grouping, Part 1: Group vs individual problem solving," *Am. J. Phys*. **60**, 627-636 (1992); P. Heller and M. Hollabaugh "Teaching problem solving through cooperative grouping, Part 2: Designing problems and structuring groups," *ibid*., p. 637-644. See < http://www.physics.umn.edu/groups/physed/index.html >.

171. K. Cummings, J. Marx, R. Thornton, and D. Kuhl, "Evaluating innovations in studio physics," *Physics Ed. Res*., supplement 1 to the *Am. J. Phys*. **67**(7), S38-S44.

172. P. D. Saltman, "Rediscover Teaching, Service During This Academic Year," *The Scientist*, 1 October 1989.

173. P. D. Saltman, I. Mothner, and J. Gurin, *The University of California San Diego Nutrition Book* (Little Brown, 1993).

174. P. D. Saltman, "The *Yang* of Nutrition .... The *Yin* of Food," *Engineering and Science* (California Inst. of Technology), Summer, 1995, p. 29-36.

175. Anon, "When Teachers Go Back To School," *UCSD Perspectives*, Winter 1993-94, p. 18-19.

176. J. Berlfein, "Summer Program Trains Schoolteachers to Teach Elementary Science," *The Scientist*, p. 16, October 1989.

177. M.U. Smith, "Foundational Issues in Evolution Education," *Science and Education* **4**(1), 23-46 (1995).

178. M.U. Smith, "Doing Research on College Science Instruction - Planning Data Analysis," *Journal of College Science Teaching* **23**(4), 252-256 (1994).

179. M.U. Smith, "Comments and Criticism: Comment on 'Identification of Student Misconceptions in Genetics Problem Solving via Computer Program,' " *Journal of Research in Science Teaching* **28**(4), 383-384 (1994).

180. M. U. Smith and P.E. Simmons, eds., *Teaching Genetics: Recommendations and Research: Proceedings of a National Conference* (National Science Foundation, Cambridge, Mass, March 18-21, 1992). (Published in house by the University of Georgia, 1994).

181. M.U. Smith, "Cognitive Development, Genetics Problem Solving, and Genetics Instruction: A Critical Review," *Journal of Research in Science Teaching* **29**(7), 701-713 (1992).

182. M.U. Smith, "Expertise and the Organization of Knowledge: Unexpected Differences among Genetic Counselors, Faculty, and Students on Problem Categorization Tasks," *Journal of Research in Science Teaching* **29**(2), 179-205 (1992).

183. M.D. Sundberg, J. Armstrong, M. Dini, and B. Wischusen, "Tips for designing and implementing investigative laboratories," *J. Coll. Sci. Teach*., accepted for publication.

184. M.D. Sundberg, "Assessing the effectiveness of an investigative laboratory to confront common misconceptions in life science," in *Student-Active Science: Models of Innovation in College Science Teaching*, A. P. McNeal and C. D'Avanzo, eds. (Saunders, 1997).
< http://www.saunderscollege.com/lifesci/studact/chapters/ch09.html >.

185. M.D. Sundberg, J. Carter, D. Galitz, B. Kirchoff, R. Moore, and G. Uno, "Executive Summary of the Education Committee and Teaching Section," in *Botany for the Next Millennium* (Botanical Society of America, 1995).

186. M.D. Sundberg, M.L. Dini, and E. Li, "Improving student comprehension and attitudes in freshman biology by decreasing course content," *Jour. Res. Sci. Teach.* **31**, 679-693 (1994).

187. M.D. Sundberg and G.J. Moncada," Creating Effective Investigative Biology Laboratories for Undergraduates," *BioScience* **44**, 698-704 (1994).

188. M.D. Sundberg and M.L. Dini, "Science Majors vs Nonmajors: Is There a Difference?" *Journal of College Science Teaching*, 22 (5),299-304 (1993).

189. M.D. Sundberg and J.E. Armstrong, "The Status of Laboratory Instruction for Introductory Biology in U.S. Universities," *American Biology Teacher* **55**(3), 144-46 (1993).

190. M.D. Sundberg, E.J. Kormondy, J.L. Carter, J.A. Moore, S.N. Postlethwait, and J.W. Thornton, "Education: Reassessing the Commission on Undergraduate Education in the Biological Sciences," *BioScience* **42**, 442-447 (1992).

191. M.D. Sundberg, "Are we reinventing the wheel?" *BioScience* **41**, 779-783 (1991).

192. D. Udovic, D. Morris, A. Dickman, J. Postlethwait, and P. Wetherwax, "What matters in non-majors biology: I. Development of the Workshop Biology project, and II. Insights and lessons from the Workshop Biology project," intended for submission to the *Journal of College Science Teaching*.

193. D. Udovic, D. Morris, A. Dickman, J. Postlethwait, and P. Wetherwax, *The Workshop Biology Curriculum Handbook*, (draft version distributed by the Workshop Biology Program, Department of Biology, University of Oregon, 1996).

194. D. Udovic and W. Goodwin, *Epidemiology* (Computer software and manual; current version is 2.1), in J.R. Jungck, ed., *The BioQUEST Library* V. (Academic Press, 1986-1999).

195. G.E. Uno, *Handbook on Teaching Undergraduate Science Courses: A Survival Training Manual* - a handbook for young faculty members teaching undergraduate courses in science (Saunders College Publishing, 1999, in press); a description and table of contents are at < http://www.ou.edu/cas/botany-micro/faculty/uno-book.shtml >.

196. G.E. Uno, "Biology Initiative" posted on 7/30/97 on the "Bioboard" (see Sec. IIIA, "Web Addresses"): "The biologists at NSF's Division of Undergraduate Education (DUE) want to know if the 'biology community' is ready to talk about starting a biology initiative in the country and if biologists are willing to make the effort to reform their courses ..... are we too disparate a group to do what the mathematicians, chemists, and physicists have done?" [Note: I would guess that on a national scale less than 0.1% of physicists have substantively reformed their undergraduate courses. Survey information on the extent of educational change for various disciplines would be of value (R. Hake)]

197. G.E. Uno, " Learning About Learning Through Teaching About Inquiry," 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/ch11.html >.

198. G.E. Uno, "The State of Precollege Botanical Education," *American Biology Teacher* **56**(5), 263-67 (1994).

199. G.E. Uno (principal author), *Developing Biological Literacy*, Biological Sciences Curriculum Study - BSCS (Kendall/Hunt,1994).

200. G.E. Uno and R.W. Bybee, "Understanding the dimensions of biological literacy," *BioScience* **44**(8), 553-557 (1994).

201. L.E. Watson, G.E. Uno, N. A. McCarty, and A. B. Kornkven, "Conservation biology of a rare plant species, Eriocaulon kornickianum (Eriocaulaceae)", *American Journal of Botany* **81**(8), 980-986 (1994).

202. G.E. Uno (co-author and editor), *Biological Science: An Ecological Approach* (BSCS text) (Kendall/Hunt, 7th ed., 1992).

203. G.E. Uno, *Investigating the Human Environment: Land Use* (BSCS text) (Kendall/Hunt, 1984).

204. G.E. Uno, "Teaching College and College-Bound Biology Students," *American Biology Teacher* **50**(4), 213-216 (1988).

205. G.E. Uno, "A Push-Button Electronic System to Promote Class Discussion," *American Biology Teacher* **46**(4), 229-232 (1984). Uno was a pioneer of "electronic classroom communication systems," see "ECCS's" in Sec. IIIC, "Web Addresses," and ref. 24 in Sec. IV, "General References." An even earlier system, called a "Scholarater" (because it effectively rated the quality of instructor's questions and thus the quality of the instructing scholar) was described by physicist H. R. Crane, "An experiment toward establishing communication from audience to lecturer," *IRE Transactions on Education* **4**, 162-166 (1961).

206. D.T.A. Vernon, M.C. Hosokawa," Faculty Attitudes and Opinions about Problem-Based Learning" *Academic Medicine* **71**(11), 1233-38 (1996).

207. D.T.A. Vernon, "Attitudes and Opinions of Faculty Tutors about Problem-Based Learning," *Academic Medicine* **70**(3), 216-223 (1995).

208. D.T.A. Vernon and R.L Blake, "Does Problem-Based Learning Work? A Meta-Analysis of Evaluative Research," *Academic Medicine* **68**(7), 550-563 (1993).

209. M.A. Waterman and E.D. Stanley, "Investigative Cases and Case-Based Learning in Biology," in *The BioQUEST Library* V (Academic Press, 1986-1999), J.R. Jungck, ed.

210. M.A. Waterman, "Investigative Case Study Approach for Biology Learning," *Bioscene - Journal of College Biology Teaching* **24**(1), 3-10 (1998).

211. T. Glick, E.G. Armstrong, M.A. Waterman, E. Hundert, and S. Hyman, "An Integrated Preclerkship Curriculum in Neuroscience, Psychiatry, and Neurology," *Academic Psychiatry*, **21**(4), 212-218 (1997).

212. A. Feins, M.A. Waterman, A.S. Peters, and M. Kim, "The teaching matrix: a tool for organizing teaching and promoting professional growth" *Academic Medicine* **71**(11), 1200-03 (1996).

213. P.B. Martin and M.A. Waterman, "Advice for using closed malpractice claims as teaching tools," *Forum* **15**(3), 1-3 (1994) (Journal of the Harvard Risk Management Foundation).

214. M.A. Waterman, "Teaching strategies for the life sciences - CELS III" in *Strategies for Success*, Vol. 11, (Benjamin Cummings, 1993).

215. M.A. Waterman, "Alternative conceptions of the tentative nature of scientific knowledge," in *Proceedings of the International Seminar on Misconceptions in Science and Mathematics*, H. Helm and J. Novak, eds., (Cornell University, 1983), p. 282-291, abstracts are on the web at < http://www2.ucsc.edu/mlrg/mlrghome.html >.

216. M.A. Waterman and J.F. Rissler, "Use of scientific research reports to develop higher-level cognitive skills," *Journal of College Science Teaching* **11**, 336-340 (1982).

217. P. H. Williams, *Bottle Biology* (Kendall/Hunt, 1993).

218. P. H. Williams, *Exploring with Wisconsin Fast Plants* (Dept. of Plant Pathology, U.W.-Madison, 1989).

219. P. H. Williams and C. B. Hill, "Rapid cycling populations of Brassica, *Science* **232**, 1385-1389 (1986).

220. C.G. Norton, L.H. Gildensoph, M. Phillips, D.D. Wygal, K.H. Olsen, J.J. Pelligrini, and K. Tweeten, "Reinvigorating Introductory Biology: A Theme-based, Investigative Approach To Teaching Biology Majors," *Journal of College Science Teaching* **27**(2), 121-26 (1997).

III. SOME WEB ADDRESSES RELEVANT TO UNDERGRADUATE BIOLOGY EDUCATION (in addition to those indicated above)

A. BIOLOGY ASSOCIATIONS AND SOCIETIES

ABLE - Association for Biology Laboratory Education
< http://www.zoo.utoronto.ca/able/ >
a. Hot Biology Web Sites
< http://www.zoo.utoronto.ca/able/hotsites/hotsites.htm >

ACUBE - Association of College and University Biology Educators
< http://papa.indstate.edu/amcbt/index.html >
a. *Bioscene: Journal of College Biology Teaching*
< http://papa.indstate.edu/amcbt/bioscene.html >

AIBS - American Institute of Biological Sciences
< http://www.aibs.org >
a. Education
< http://www.aibs.org/latitude/latmap.html >
b. *Bioscience Magazine*
< http://www.aibs.org/biosciencemagazine/index.html >

ASM American Society For Microbiology
< http://www.asmusa.org/ >
a. Education
< http://www.asmusa.org/edusrc/edu1.htm >
b. Curriculum Activities for Undergraduate Education
< http://www.asmusa.org/edusrc/edu4d.htm >
c. Undergraduate Microbiology Education Conferences
< http://www.asmusa.org/edusrc/edu4c.htm >
d. Parents, Students, and General Public Site
< http://www.microbeworld.org >
e. Digital Library of Mircobiology Resources for Teaching and Learning
< http://www.asmusa.org/edusrc/educ3.htm >

American Society of Cell Biology
< http://www.faseb.org/ascb/ >
a. Citeline.com Search
< http://www.faseb.org/ascb/ >
b. Education Committee
< http://www.faseb.org/ascb/ >

BCN - BioChemNet
< http://schmidel.com/bionet.cfm >
a. General Biology
< http://schmidel.com/bionet/biology.htm >

Bioboard (Gordon Uno)
< http://www.ou.edu/cas/botany-micro/ug-ed/wwwboard/bioboard.shtml >
< http://www.ou.edu/cas/botany-micro/ug-ed/index.shtml >

Biology Labs On-Line (California State University)
< http://www.apple.com/education/hed/aua0101/applets/ >
< http://www.apple.com/education/hed/aua0101/evolveit/ >

BioLab (Clemson University)
< http://biowww.clemson.edu/biolab/home.html >

BIOPI-L - email list server for Biology teachers and professionals from kindergarten to university, managed by Tom Manney, Physics Department, Kansas State University.
a. Homepage
< http://www.dsuper.net/~missus/biopi/ >
b. Archives
< http://listserv.ksu.edu/archives/biopi-l.html >

BioQUEST Curriculum Consortium - Beloit College
< http://bioquest.org >
a. Library
< http://www.apnet.com/bioquest/ >
b. Web Sites with Projects of Interest (including some in chemistry, physics, and mathematics)
< http://bioquest.org/websites.html >
c. Bioscene: Journal of College Biology Teaching
< http://acube.org/bioscene.html >
d. John R. Jungck's homepage
< http://www.beloit.edu/~biology/jungck.html >
e. Art of Mathematical Biology Gallery
< http://www.beloit.edu/~biology/jungck.html >

Biosciences
< http://mcb.harvard.edu/BioLinks.html >

BSA - Botanical Society of America
< http://www.botany.org/ >
a. Teaching Section
< http://www.botany.org/bsa/sections/teaching/index.html >

BSCS - Biological Sciences Curriculum Study (BSCS)
< http://www.bscs.org/ >

CELS - Coalition for Education in the Life Sciences
< http://www.wisc.edu/cels/ >
a. Monograph "Professional Societies and the Faculty Scholar"
< http://www.wisc.edu/cbe/cels/monograph/cover.htm >
b. Educational Activities Links
< http://www.wisc.edu/cbe/cels/edulinks.html >
c. Educational Organizations
< http://www.wisc.edu/cels/eduorg.html >

Computational Molecular Biology and Molecular Bioinformatics Workshop
< http://juno.ucsd.edu/~sje/thailand.html >

HHMI - Howard Hughes Memorial Institute (Undergraduate Biology Education)
< http://www.hhmi.org/grants/undergraduate/ >
a. Beyond Bio 101
< http://www.hhmi.org/BeyondBio101/index.htm >
b. Beyond Bio 101 - Institutions Mentioned (some also appear in this survey)
< http://www.hhmi.org/BeyondBio101/appear.htm >

NABT - National Association of Biology Teachers
< http://www.nabt.org/ >

Saunders College Publishing's *BioWeb: The Online Life Sciences Magazine*
< http://www.saunderscollege.com/lifesci/ >

Saunders College Publishing's *Student-Active Science*. Saunders is to be congratulated for advancing the cause of education reform: (a) "professionals" may order a *free* copy by calling 1-800-782-4479; (b) the entire book will soon be available electronically as an Adobe Acrobat portable document file!
< http://www.saunderscollege.com/lifesci/studact/ >
a. Resources
< http://www.saunderscollege.com/lifesci/studact/resources.html >
b. Hot Tips
< http://www.saunderscollege.com/lifesci/studact/tips.html >
c. Participants
< http://www.saunderscollege.com/lifesci/studact/participants.html >

Science Junction - North Carolina State University - A "cyber -community for teachers, students, and researchers of science"
< http://www.ncsu.edu/sciencejunction/ >
a. Instructional Material and Science Education
< http://www.ncsu.edu/sciencejunction/terminal/imse/lowres/index.htm >
b. Selected Mega Biology Web Sites
< http://www.ncsu.edu/sciencejunction/terminal/imse/lowres/1/megabiology.htm >
c. Al Bodzin's Home Page for Science Educators - many good links
< http://www.ncsu.edu/servit/bodzin >

Shelly Peretz's On-line Biology Projects (Designed for high-school students but probably useful at the postsecondary level)
< http://207.63.195.19/projects >
a. How Do We Inherit Our Biological Characteristics? (Funded by Fermi Lab)
< http://207.63.195.19/projects/inherit > (Under Resources/Case Studies: The Sickle Cell Classroom Scenario was written by Margaret Waterman - See Sec. II, SS)

SICB- Society for Integrative and Comparative Biology (formerly the American Zoological Society)
< http://www.sicb.org/ >
a. Related Scientific Community Information
< http://www.sicb.org/public/about/related.html >

SMB- Society for Mathematical Biology
< http://www.smb.org/ >

UTK - University of Tennessee - Knoxville, Louis Gross
< http://www.tiem.utk.edu/~gross/ >

a. Mathematical Life Sciences Page for Education
< http://www.tiem.utk.edu/~harrell/main.html >

b. Mathematical Life Sciences Archives WWW Servers
< http://archives.math.utk.edu/mathbio/ >

c. Institute for Environmental Modeling
< http://www.tiem.utk.edu/ >

d. Louis Gross Homepage
< http://www.tiem.utk.edu/~gross/ >

e. Quantitative Curriculum for Life Science Students
< http://www.tiem.utk.edu/~gross/quant.lifesci.html >

B. SOME BIOLOGY TEACHER'S WEB SITES WITH ESPECIALLY VALUABLE LINKS

Alan Cairns's Biology Education Resources (Cairns is actually a renaissance-man high-school physics teacher)
< http://www-hpcc.astro.washington.edu/scied/bioindex.html >

Louis Gross Homepage
< http://www.tiem.utk.edu/~gross/ >

William Hayes's Homepage
< http://www.geocities.com/~doc_hayes/ >

John R. Jungck's Homepage
< http://www.beloit.edu/~biology/jungck.html >

Craig Nelson's Biology Education Resources
< http://php.indiana.edu/~nelson1/#MORE WWW BIOLOGY >

Margaret Waterman's Science Education Links for Teachers
< http://cstl.semo.edu/waterman/bookmarks/index.htm >

Al Bodzin's Home Page for Science Educators
< http://www.ncsu.edu/servit/bodzin >

C. SCIENTIFIC ASSOCIATIONS, SOCIETIES, AND PROJECTS (not confined to biology)

AAAS - American Association for the Advancement of Science
< http://www.aaas.org/ >
a. *Science* online
< http://www.sciencemag.org/ >
b. Essays on Science and Society
< http://www.sciencemag.org/feature/data/150essay.shl >
c. Project 2061 - a long term initiative to reform K - 12 science education nationwide
< http://project2061.aaas.org/ >
d. Benchmarks for Science Literacy: Project 2061
< http://project2061.aaas.org/tools/benchol/bolframe.html >
e. Blueprints for Reform On-Line
< http://project2061.aaas.org/tools/bluepol/blpframe.html >

American Journal of Physics and *The Physics Teacher*, Searchable Indices
< http://www.phy.nau.edu/~danmac/AAPTDB/index.html >

American Academy of Arts and Sciences
< http://www.amacad.org/ >
a. *Daedalus* magazine
< http://daedalus.amacad.org/daehome.html >

American Geological Institute
< http://www.agiweb.org/ >
a. Education
< http://www.agiweb.org/ehr.html >

American Geophysical Union
< http://www.agu.org/ >
a. Shaping the Future of Undergraduate Earth Science Education: Innovation and Change Using an Earth System Approach - Report of Workshop of 11/96
< http://www.agu.org/sci_soc/spheres/ >

Annenberg/CPB Projects Learner Online
< http://www.learner.org/ >
a. Educational Technology
< http://www.learner.org/edtech/ >
b. Research and Evaluation
< http://www.learner.org/edtech/rscheval/ >

Carnegie Institution of Washington
< http://www.ciw.edu/ >
a. Academy for Science Education (K-6)
< http://www.ciw.edu/case/ >

Concord Consortium Projects
< http://www.concord.org/projects/index.html#mod >
a. GenScope
< http://genscope.concord.org >

CREN - Corporation for Research and Educational Networking (commercial)
< http://www.cren.net/index.html >

CUR - Council on Undergraduate Research
< http://www.cur.org/ >

Distance Learning Sites
ADEC - American Distance Education Consortium
< http://www.adec.edu/ >
ADEPT -Assessment of Distance Education Pedagogy and Technology
< http://www.users.csbsju.edu/~tcreed/adept/ >
Annenberg/CPB Projects - Distance Learning
< http://www.learner.org/edtech/distlearn/ >
Distance Education Clearinghouse - Univ. of Wisconsin
< http://www.uwex.edu/disted/home.html >
Lucent Technologies - Center for Excellence in Distance Learning (CEDL)
< http://www.lucent.com/cedl/ >
United States Distance Learning Association
< http://www.usdla.org/ >

ECCS's - Electronic Classroom Communication Systems
a. Classtalk (*Better Education* of Yorktown, VA)
< http://www.pcs.cnu.edu/~fhartlin/graphics/ClasstalkProj.html#anchor419081 >
< http://www.bedu.com >
b. Personal Response System (*EduCue* of Hong Kong)
< http://www.educue.com/ >

ER - *Education Review* (publishes review articles of recently published books in 16 educational fields including evaluation, learning and instruction, methodology, and technology education.
< http://coe.asu.edu/edrev/ >

EDUCAUSE (formerly EDUCOM)
< http://www.educause.edu/ >
a. *Educom Review*
< http://www.educause.edu/pub/er/erm.html >
b. *Cause/Effect* ("....journal for college and university managers and users of information resources...")
< http://www.educause.edu/pub/ce/cause-effect.html >
c. NLII - National Learning Infrastructure Initiative
< http://www.educause.edu/nlii/ >

EJSE - *The Electronic Journal of Science Education* - Archive Page
< http://unr.edu/homepage/jcannon/ejse/ejse.html >

Richard Felder's Resources in Engineering and Science Education (North Carolina State University)
< http://www2.ncsu.edu/unity/lockers/users/f/felder/public/RMF.html >

Gell-Mann's Santa Fe Institute (".... seeks to catalyze new multidisciplinary projects that break down the barriers between the traditional disciplines, to spread its ideas and methodologies to other individuals, and encourage the practical applications of its results."
< http://www.santafe.edu/ >
a. Education
< http://www.santafe.edu/sfi/education/index.html >

HTML tutorial links (Aron Titus while at North Carolina State University)
< http://www4.ncsu.edu/unity/users/t/titus/www/Research/HTMLGuide.html >

James S. McDonnell Foundation - headed by John T. Bruer (see Sec. IV, refs. 48, 80).
< http://www.jsmf.org/ >

NISE - National Institute for Science Education
< http://www.wcer.wisc.edu/nise >
a. College Level One
< http://www.wcer.wisc.edu/nise/CL1/ >
b. Project FLAG (Field-Tested Learning Assessment Guide for SME&T)
< http://newtraditions.chem.wisc.edu/FLAG/nt-flag.htm >
c. NISE - Collaborative Learning (CL) & Small Group Learning [under "Resources" is an annotated bibliography of CL articles which may be searched by discipline (including biology)].
< http://www.wcer.wisc.edu/nise/CL1/CL/clhome.asp >

NSTA - National Science Teachers' Association
< http://www.nsta.org/ >
a. Journal of College Science Teaching
< http://www.nsta.org/pubs/jcst/ >
b. Building a Presence for Science - bringing standards-based teaching and learning into schools
< http://www.nsta.org/BaP/ >

Pew Charitable Trust
< http://www.pewtrusts.com/ >
a. Director Russell Edgerton's Insightful White Paper on Higher Education
< http://www.pewtrusts.com/Frame.cfm?Framesource=programs/edu/eduindex.cfm >

Philosophy of Education Yearbook
< http://www.ed.uiuc.edu/COE/EPS/PES-Yearbook/index.html#CONTENTS >

PKAL - *Project Kaleidoscope*
< http://www.pkal.org/ >
a. Workshop: Enhancing Learning-Centered Environments: The Biology Department of the Future
< http://www.pkal.org/curricul/bio/agenda2.html >
b. Biology and Biochemistry Resources
< http://www.pkal.org/curricul/3links.html#bio >
c. Leaders in Undergraduate SMET Education (Presenters at PKAL Conferences by Topic)
< http://www.pkal.org/people/index.html >

Rand Institute for Education
< http://www.rand.org/centers/education/ >

Science Junction - North Carolina State University - A "cyber -community for teachers, students, and researchers of science"
< http://www.ncsu.edu/sciencejunction/ >
a. Instructional Material and Science Education
< http://www.ncsu.edu/sciencejunction/terminal/imse/lowres/index.htm >
b. Selected Mega Biology Web Sites
< http://www.ncsu.edu/sciencejunction/terminal/imse/lowres/1/megabiology.htm >
c. Al Bodzin's Home Page for Science Educators - many good links
< http://www.ncsu.edu/servit/bodzin >

SEA - Science Education Associations (Univ. of West Florida)
< http://science.coe.uwf.edu/ >

Sci-Seek (commercial)
< http://www.sciseek.com/cgi-bin/hyperseek/directory.cgi >

Sigma Xi, The Scientific Research Society
< http://www.sigmaxi.org/ >
a. Science Resources
< http://www.sigmaxi.org/scienceresources/scienceresources.htm >
b. 1999 Forum - *Reshaping Undergraduate Science and Engineering Education: Tools for Better Learning*, 11/4-5/99, Minneapolis, MN
< http://www.sigmaxi.org/forum/1999Forum/forum99.htm >

TEC - The Education Coalition (a non -profit organization working "to promote systemic educational reform through the use of multiple technologies. TEC includes elementary, secondary, post-secondary schools, educational agencies, broadcast agencies, and high-tech industry corporations."
< http://www.tecweb.org/ >

TERC - Technical Education Research Center
< http://www.terc.edu >

Tomorrow's-Professor Listserv - postings of special interest to university graduate students, postdocs, and faculty. (Rick Reis, Stanford University Learning Laboratory)
a. listing of previous posts
< http://sll-6.stanford.edu/projects/tomprof/listserver.html >
b. Reis's book "Tomorrow's Professor" (IEEE Press, 1997)
< http://cis.stanford.edu/structure/tomorrowprof.html >
c. Reis's homepage
< http://cis.stanford.edu/structure/reis.html >

Web Programming and Design (commercial)
< http://www.STARS.com >

D. HIGHER EDUCATION

AAHE - American Association of Higher Education
< http://www.aahe.org/ >

a. TLT - Teaching , Learning, and Technology Affiliate (Includes the nearly 10,000 member AAHESGIT electronic discussion group moderated by Steven Gilbert)
< http://www.tltgroup.org/ >

b. Listserv and Forums
< http://www.tltgroup.org/listserv/index.html >

c. PPIC - Program for the Promotion of Institutional Change
< http://www.aahe.org/ppic/inst_change.htm >

c. Assessment Forum
< http://www.aahe.org/assessment/assessnw.htm >

d. 2000 National Conference on Higher Education - Diversity and Learning
< http://www.aahe.org/nche/ >

e. Teaching Initiatives
< http://www.aahe.org/teaching/Teaching_Initiative_Home.htm >

ACE - American Council on Education ("...the nation's coordinating higher education association...")
< http://www.acenet.edu/ >

a. Eye on Washington
< http://www.acenet.edu/washington.html >

b. News
< http://www.acenet.edu/news.html >

c. Issues
< http://www.acenet.edu/issues.html >

d. Events
< http://www.acenet.edu/events/home.html >

e. Initiatives
< http://www.acenet.edu/initiatives.html >

AERA - American Education Research Association
< http://www.aera.net >

a. Divisions
< http://aera.net/divisions/ >

b. List service information
< http://lists.asu.edu/cgi-bin/wa >

c. List archives at LISTS.ASU.EDU
< http://lists.asu.edu/archives/index.html >

d. AERA-C - Learning & Instruction
< http://aera.net/divisions/c/ >
< http://lists.asu.edu/archives/aera-c.html >

e. AERA-D - Measurement and Research Methodology
< http://www.aera.net/divisions/d/ >
< http://lists.asu.edu/archives/aera-d.html >

f. AERA-J - Postsecondary Education
< http://aera.net/divisions/j/ >
< http://lists.asu.edu/archives/aera-j.html >

g. Special Interest Groups (SIG's)
< http://aera.net/sigs/ >

h. List of SIG's
< http://aera.net/sigs/siglst.htm >
i. AERA -SIG-EST: Special Interest Group on Education in Science and Technology
< http://www.ls.sesp.nwu.edu/sig-est/index.html >
j. AERA-SIG-ATL: Special Interest Group on Advanced Technologies for Learning
< http://www.ls.sesp.nwu.edu/sig-atl/index.html >
k. AERA-SIG-Brain & Education
< http://cctr.umkc.edu/user/adc/brain.html >
l. AERA-SIG- SMKCC: Subject Matter Knowledge and Conceptual Change
< http://soe.csusb.edu/smkcc/ >

ASEE- American Society for Engineering Education
< http://www.asee.org/ >
a. *Prism* magazine on-line
< http://www.asee.org/prism/ >

ASP - Astronomical Society of the Pacific
< http://www.aspsky.org/ >

Brussels Free University - "Radical Constructivism" by Alex Reigler
< http://www.univie.ac.at/cognition/constructivism/ >.

Harvard
a. Smithsonian Center for Astrophysics (Science Education Dept.)
< http://cfa-www.harvard.edu:80/cfa/sed/ >
1. Private Universe Project - all grades
< http://cfa-www.harvard.edu:80/cfa/sed/privateuniv.html >
2. Private Universe Project in Mathematics - grades K - 12
< http://cfa-www.harvard.edu:80/cfa/sed/pupmath.html >
3. Universe! Education Forum - all grades
< http://cfa-www.harvard.edu:80/cfa/sed/saonasa.html >

b. Project Zero (Harvard Graduate School of Education) - investigates "the development of learning processes in children, adults, and organizations" - directed by David Perkins and Howard Gardner
< http://www.pz.harvard.edu/ >

c. Educational Technology Center (Harvard Graduate School of Education) - Staff includes Judah Schwartz and David Perkins
< http://edetc1.harvard.edu/ >
1. Journal of Science Education and Technology
< http://edetc1.harvard.edu/jset/jset.html >

IHRE - Institute for Research on Higher Education (University of Pennsylvania, analysis of postsecondary education in the United States)
< http://www.irhe.upenn.edu/pp/pp-main.html >

MAA - Mathematical Association of America
< http://www.maa.org/ >
a. Teaching and Learning
< http://www.maa.org/t_and_l/index.html >
b. A. and J. Seldon's "Glossary of Constructivism"
< http://www.maa.org/t_and_l/sampler/rs_glossary.html >
c A. and J. Seldon's "Research Sampler"
< http://www.maa.org/t_and_l/sampler/research_sampler.html >

MCTP - Maryland Collaborative for Teacher Preparation - Essays on constructivism and education (some addresses are outdated)
< http://www.inform.umd.edu/UMS+State/UMD-Projects/MCTP/WWW/Essays.html >

MIT
a. Media Lab
< http://www.media.mit.edu/ >
b. Center for Biological and Computational Learning
< http://www.ai.mit.edu/projects/cbcl/ >
c. Center for Educational Computing Initiatives
< http://www-ceci.mit.edu/ >

NCSA- National Computational Science Alliance
< http://www.ncsa.uiuc.edu/ >

POD Network - Professional and Organizational Development in Higher Education
< http://www.podnetwork.org/main.html >
a. Discussion Group Information
< http://www.podnetwork.org/elec/maillist.html >
b. Discussion Group Homepage
< http://www.podnetwork.org >

Queens University (Canada) School of Medicine, Problem-Based Learning Program, coordinated by Hugh Pross, Professor of Oncology
< http://meds.queensu.ca/medicine/pbl/pblhome.htm >

Scholarly Societies Project (Univ. of Waterloo)
< http://www.lib.uwaterloo.ca/society/overview.html >

Stanford University
a. Research in the School of Education
< http://www.stanford.edu/dept/SUSE/navigation/researchnavfrm.html >

University of California - Berkeley
a. Instructional Technology Program
< http://www.itp.berkeley.edu/ >
b. Graduate School of Education
< http://www-gse.berkeley.edu/ >

University of Colorado at Denver - School of Education - Education Theory Sources
< http://www.cudenver.edu/~mryder/itc_data/theory.html >

UD-PBL - Univ. of Delaware, Problem Based Learning
< http://www.udel.edu/pbl/ >
a. Problem Based Learning Sites
< http://www.udel.edu/pbl/others.html >

UD-ITUE - Univ. of Delaware, Institute for Transforming Undergraduate Education
< http://www.udel.edu/inst/ >
a. Online Resources
< http://www.udel.edu/inst/resources.html >

USF-CTE University of South Florida- Center for Teaching Enhancement
< http://www.cte.usf.edu/ >
a. "Bibliography of Active Learning in Science"
< http://www.cte.usf.edu/resources/res_def.html >

Washington Higher Education Secretariat (".....composed of 42 national, higher education associations representing the different sectors and functions in postsecondary institutions.")
< http://www.whes.org >

E. COGNITIVE SCIENCE AND PSYCHOLOGY

Most listings are from: Stanford's "Cognitive and Psychological Sciences on the Internet" at
< http://www-psych.stanford.edu/cogsci/ >

University of Arizona -Learning Theory (by Chris Johnson, Modern Languages)
< http://www.coh.arizona.edu/inst/edp512s97/learningtheory.html >

Athabasca - Canada's Open University - Cognitive Psychology
< http://server.bmod.athabascau.ca/html/aupr/cognitive.htm >

Athabasca - Canada's Open University - Biological and Physiological Psychology
< http://server.bmod.athabascau.ca/html/aupr/biological.htm >

Boston University - Department of Cognitive and Neural Systems and Center for Adaptive Systems
< http://cns-web.bu.edu/CNS.html >

Brown University - Cognitive & Linguistic Sciences
< http://www.cog.brown.edu/netscape4.html >

University of California - San Diego - Cognitive Science
< http://cogsci.ucsd.edu/ >

University of California at Santa Barbara - Cognitive Science - Philosophy, Linguistics, and Experimental Psychology (by Francis F. Steen, Department of English)
< http://humanitas.ucsb.edu/users/steen/CogSci/ >

Carnegie Mellon - Center for Innovative Learning
< http://cil.andrew.cmu.edu/ >

Carnegie Mellon - Department of Psychology
< http://www.psy.cmu.edu/ >

Carnegie Mellon University & The University of Pittsburgh - Center for the Neural Basis of Cognition
< http://www.cnbc.cmu.edu/ >

University of Colorado - The Institute of Cognitive Science
< http://psych-www.colorado.edu/ics/home.html >

Indiana University- Learning and Cognition (by David Perry, School of Education, Indiana Univ.)
< http://education.indiana.edu/~p540/webcourse/web.html#top >

Indiana University - Center for Research on Concepts and Cognition - directed by D. Hofstadter
< http://www.cogsci.indiana.edu/ >

Indiana University - Cognitive Science Department
< http://www.psych.indiana.edu/ >

Johns Hopkins - Department of Cognitive Science
< http://www.cogsci.jhu.edu/ >

Massachusetts Institute of Technology - Department of Brain and Cognitive Sciences
< http://web-bcs.mit.edu/ >

Univ. of Michigan - Cognition and Perception
< http://www.umich.edu/~psycdept/ >

Northwestern University - Institute for the Learning Sciences - Directed by Roger C. Schank
< http://www.ils.nwu.edu/ >

Northwestern University - Learning Sciences (School of Education and Social Policy - Publications)
< http://www.ls.sesp.nwu.edu/papers/papers.html >

Ohio State - Center for Cognitive Science
< http://www.cog.ohio-state.edu/ >

University of Pennsylvania - Institute for Research in Cognitive Science
< http://www.cis.upenn.edu/~ircs/homepage.html >

University of Pittsburg - Learning Research and Development Center
< http://www.lrdc.pitt.edu/ >

University of Rochester - Brain and Cognitive Sciences
< http://www.bcs.rochester.edu/ >

Rutgers University Center for Cognitive Science
< http://ruccs.rutgers.edu/ruccs.html >

F. UNITED STATES GOVERNMENT

DOD - Federal Information Exchange
< http://www.rams-fie.com/ >
a. Education Services
< http://www.rams-fie.com/education/index.htm >

FedWorld.gov (Dept. of Commerce) -U.S. Government Sites
< http://www.fedworld.gov/#usgovt >

Fermi Lab Education Homepage
< http://www-ed.fnal.gov/ >
a. University Programs
< http://www-ed.fnal.gov/ed_univ.html >
b. Pre-college Programs
< http://www-ed.fnal.gov/ed_precol.html >
c. Lederman Science Center
< http://www-ed.fnal.gov/ed_lsc.html >
d. Engaged learning projects (K-12)
< http://www-ed.fnal.gov/trc/projects/project_index.html >
e. *Handbook of Engaged Learning Projects* - Designed by K-12 teachers to demonstrate engaged learning and effective use of technology. The teachers worked closely with a staff of experienced educators and computer specialists at Fermilab's Lederman Science Center.
< http://www-ed.fnal.gov/help/cover.html >

HCS - House Committee on Science
< http://www.house.gov/science/welcome.htm >
a. SciEd - Improving Math and Science Education (see also Sec. IV., ref. 20 “Ehlers Report”)
< http://www.house.gov/science/education.htm >

IITF - Information Infrastructure Task Force
< http://iitf.doc.gov >

NAS - National Academy of Sciences (see also under NRC below)
< http://www.nas.edu/ >
a. NAS Press (National Academy Press (“read over 1350 books online”)
< http://www.nap.edu/ >
b. “Issues in Science and Technology Online”
< http://bob.nap.edu/issues/ >
c. Links to Cool Science Sites
< http://bob.nap.edu/catalog/faq/dspphp.phtml?fuseaction=bookmark&val1=month >

NASA - Education and Public Outreach
< http://www.hq.nasa.gov/office/oss/education/index.htm >

NCO - National Coordination Office for Computing, Information, and Communications
< http://www.hpcc.gov/ >

NIH - National Institutes of Health
< http://www.nih.gov/ >
a. Scientific Resources
< http://www.nih.gov/science >

NIST - National Institute of Standards and Technology
< http://www.nist.gov/ >

NLE - National Library of Education
< http://www.ed.gov/NLE/ >

NRC - National Research Council (operating agency of both the National Association of Science (NAS) and the National Academy of Engineering(NAE) - the NRC is administered jointly by the NAS, the NAE, and the Institute of Medicine
< http://www.nas.edu/nrc/ >

a. Center for Science, Mathematics, and Engineering Education
< http://www4.nas.edu/csmee/center.nsf >

b. CUSE - Committee on Undergraduate Science Education
< http://www2.nas.edu/cusehome/ >

c. Library (with links to the life sciences)
< http://www4.nas.edu/nrclibr.nsf >

d. Board on Biology
< http://www2.nas.edu/bbhome/ >

e. The Health of Biology and Biology Education
< http://www2.nas.edu/bbhome/210a.html >

NSF - EHR National Science Foundation - Education and Human Resources
< http://red.www.nsf.gov/ >

a. REC - Research, Evaluation, and Communication
< http://www.ehr.nsf.gov/EHR/REC/ >

b. Science Links
< http://www.nsf.gov/home/external/start.htm >

c. Search
< http://www.nsf.gov/home/search.htm >

d. DUE - Division of Undergraduate Education
< http://www.ehr.nsf.gov/EHR/DUE/start.htm >

(1) CCLI NSF's Course, Curriculum, and Laboratory Improvement
< http://www.ehr.nsf.gov/EHR/DUE/programs/ccli/ccli.htm >

(2). Web Sites of DUE-Supported Projects: Advanced Technological Education (ATE)
< http://www.ehr.nsf.gov/EHR/DUE/web/ate/atelist.htm#biot >

(3) Web Sites of DUE-Supported Projects: Course and Curric. Develop. (CCD)
< http://www.ehr.nsf.gov/EHR/DUE/web/ccd/ccdlist.htm#biot >

U.S. OSTP - Office of Science and Technology Policy
< http://www.whitehouse.gov/WH/EOP/OSTP/html/OSTP_Info.html >

a. Science Division
< http://www.whitehouse.gov/WH/EOP/OSTP/Science/html/Science.html >

b. President's Committee of Advisors on Science and Technology (PCAST)
< http://www.whitehouse.gov/WH/EOP/OSTP/NSTC/PCAST/pcast.html >

c. *Science in the National Interest*, W.J. Clinton and A. Gore, Jr., 1994
< http://www.whitehouse.gov/WH/EOP/OSTP/Science/html/Sitni_Home.html >

d. National Science and Technology Council
< http://www.whitehouse.gov/WH/EOP/OSTP/NSTC/html/NSTC_Home.html >

U.S. Dept. of Education

< http://www.ed.gov/ >

a. Office of Postsecondary Education

< http://www.ed.gov/offices/OPE/ >

b. Higher Education Programs

< http://www.ed.gov/offices/OPE/OHEP/ >

c. "Moving American Education into the 21st Century"- Remarks of 2/16/99 by Secretary Richard Riley

< http://www.ed.gov/Speeches/02-1999/990216.html >

U.S. Geological Survey

a. USGS Science for A Changing World- Biology - registry of Earth and Environmental Science Internet Resources

< http://www.usgs.gov/network/science/biology/ >

b. Learning Web

< http://www.usgs.gov/education/ >

c. Biological Resources

< http://www.nbs.gov/features/education.html >

F. SEARCHES AND DIRECTORIES

Colleges and Universities

a. American Universities
< http://www.clas.ufl.edu/CLAS/american-universities.html >

b. International Universities
< http://wsdo.sao.uwf.edu/~geo/ >

c. Canadian Universities
< http://www.uwaterloo.ca/canu/ >

d. Community Colleges
< http://www.mcli.dist.maricopa.edu/cc/ >

ERIC - Educational Information Resources Center (U.S. Dept. of Education). An invaluable resource despite ERICs failure to include crucial articles in non-pedagogic discipline-specific journals (see, S. Bowen, "ERIC databases do not contain Physics Education Research References over the last many years," *APS Forum on Education Newsletter*, Summer 1999, p. 6.

a. Introduction < http://www.accesseric.org:81/ >
b. Site Map < http://www.accesseric.org:81/sitemap/sitemap.html >
c. Digests < http://www.ed.gov/databases/ERIC_Digests/index/ >
d. List of Sites < http://www.accesseric.org:81/sites/barak.html >
e. Links to various ERIC Searches
< http://www.accesseric.org:81/searchdb/searchdb.html >
f. Clearing House for Higher Education < http://www.eriche.org/ >
g. Clearing House for Science, Mathematics, and Environmental Education
< http://www.ericse.org/ >
h. Clearing House for Assessment and Evaluation < http://ericae.net/ >
(1) Search ERIC from ERIC/AE (articles back to 1990, the "more references like this" or "find similar" search is especially valuable)
< http://www.ericae.net/aesearch.htm >
i. Clearing House for Information and Technology < http://ericir.syr.edu/ithome/ >
(1) Search ERIC from ERIC/IT - called "AskEric" (articles from 1966 to 10/98)
< http://ericir.syr.edu/Eric/ >

Excite E-mail Look Up
< http://www.excite.com/reference/email_lookup >

Hot Bot e-mail Look Up
< http://www.hotbot.com/partners/email.asp >

Indiana University Cognitive Science Department - Guide to the Web
< http://www.psych.indiana.edu/www.html >

Inter-Links - Internet navigator, resource locator, and tutorial (10^8 hits since 1/1/94)
< http://alabanza.com/kabacoff/Inter-Links/ >

Liszt - $90x10^3$ mailing lists
< http://www.liszt.com/ >
a. Liszt - Biology [Note: the list is incomplete and inadequate. R. Hake]
< http://www.liszt.com/select/Science/Biology/ >
b. Liszt - Science Education [Note: the list is incomplete and inadequate. R. Hake]
< http://www.liszt.com/select/Education/Science/ >

LISTSERV® lists at the official catalog CataList. Click on "Search" in "Search for a mailing list of interest." A search for "biology" in lists whose name (XYZ-L), host name (LISTSERV.XYZ.EDU) and/or title ("Central America Discussion List") contains "biology" yielded (on 4/16/99) 68 hits.
< http://www.lsoft.com/catalist.html >

Metacrawler < http://www.go2net.com/search.html >

New Jour (J.J. O'Donnell - Univ of Pennsylvania) - Journals and Newsletters Available on the Web
< http://ccat.sas.upenn.edu/jod/jod.html >

NLM - National Library of Medicine Search Engine - access 9 million citations in MEDLINE and Pre-MEDLINE (with links to participating on-line journals, and other related databases; 692 hits on the phrase "Problem Based Learning," 579 hits on the phrase "Active Learning," 30 hits on "Socratic").
< http://www.ncbi.nlm.nih.gov/PubMed/ >

SciCentral - Multidiciplinary Meta-Web Site (Biological Sciences, Physical & Chemical Sciences, Health Sciences, Earth & Space Sciences, Engineering Sciences, Women & Minorities in Science, Government Agencies) A gateway to more than 50,000 science and engineering Web sites, conceived and created by professional scientists.
< http://www.scicentral.com/ >

Web Sites for Educators - good discussion of copyright law and the Web
< http://etc.iupui.edu/teachers.html >

Who-Where Search (Lycos)
< http://query1.whowhere.com/jwz/name.wsrch >

WWW Search Engines < http://cuiwww.unige.ch/meta-index.html >

Yahoo's List of Search Engines
< http://search.yahoo.com/bin/search?p=Search+Engines >

IV. SOME GENERAL REFERENCES RELEVANT TO UNDERGRADUATE SCIENCE EDUCATION REFORM (American Institute of Physics format; in reverse chronological order; only references not listed previously in Sec. II; a few of these are repeated in Sec. V)

1. J.D. Bransford, A.L. Brown, R.R. Cocking, ,eds. *How People Learn: Brain, Mind, Experience, and School* (Nat. Acad. Press, 1999); on the web at < http://www.nap.edu/readingroom/enter2.cgi?0309065577.html >; see also the listing in Sec. VA.

2. *Transforming Undergraduate Education in Science, Mathematics, Engineering, and Technology* (Nat. Acad. Press, 1999) see listing in Sec. VA. (Forward is "A Call to Action" by Bruce Alberts, President of the National Academy of Sciences.)

3. *Beyond 2000 - science education for the future* (Nuffield Foundation, UK, 1999) - produced by a group of prominent UK science educators, makes 10 major recommendations for the future direction of science education, at < http://www.kcl.ac.uk/depsta/education/be2000/index.html >.

4. 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 >.

5. J. Roschelle and R. Pea, "Trajectories from Today's WWW to a Powerful Educational Infrastructure," *Educational Researcher*, June-July 1999, 22-25,43; see especially "Vector 3: Towards Tools That Foster Self-Improving Communities": "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."

6. H. Gardner, *The Disciplined Mind* (Simon & Schuster, 1999). A generally thoughtful analysis from a standpoint opposite to that of Hirsch's *The Schools We Need* (see below).

7. A.A. Bartlett, "Reflections on Sustainability, Population Growth, and the Environment," *Population and Environment* **16**(1), 5-34 (1994); updated versions in *Renewable Resources Journal* **15**(4), 6-23 (1998) and *Focus* **9**, 49-68 (1999).

8. D. Goodstein, (a) "Now Boarding: The Flight from Physics," *Am. J. Phys.* **67**(3), 183-186 (1999) also on line at < http://ojps.aip.org/ >: "The most important role of the college physics course today seems to be to weed out a few poor souls who might otherwise make it into 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." (b) "Scientific Elites and Scientific Illiterates," Sigma Xi, *Proceedings of a Forum on Ethics, Values, and the Promise of Science* (New Haven, CT: Sigma XI, February 25-26, 1993); (c) "The Big Crunch" under "David Goodstein" at < http://www.caltech.edu/subpages/pmares.html >.

9. *Nature and Human Society: The Quest for a Sustainable World* (D), P. Raven and T. Williams, eds., (Nat. Acad. Press, 1999) see listing in Sec. VB.

10. A. Hobson, *Physics: Concepts and Connections* (Prentice Hall, 1999). Good treatment of societal topics, see esp. the chapters "Are We Alone? : The Search for Extraterrestrial Intelligence" and "The Energy Future."

11. A. Sokal and J. Bricmont, *Fashionable Nonsense: Postmodern Intellectuals' Abuse of Science* (St. Martin's Press, 1998). [See the exchange between these authors and N.D. Mermin in "Letters," *Phys. Today* **52** (8, pt.1), 15, 82-83 (1999).

12. T. R. Sizer and N. F. Sizer, *The Students Are Watching : Schools and the Moral Contract* (Beacon Press, 1999).

13. *Developing a Digital National Library for Undergraduate Science, Mathematics, Engineering, and Technology Education*, Report of a Workshop (Nat. Press, 1998), also at < http://www.nap.edu/readingroom/books/dlibrary/ > (see the listing in Sec. VA), in which a prestigious NRC committee (a) considered a recommendation on p. 72 of the "George Report" *Shaping the Future (*ref. 59 of this section) that the NSF sponsor the development of a "national electronic library...(NL) ... for validating and disseminating successful educational practices," and (b) concluded, in part, that ".... the establishment of an NL could potentially be a useful tool for improving undergraduate SME&T education...(but)...participants believed that the workshop discussions had not made a convincing case that an NL was an essential component of SME&T education reform."

14. *Reinventing Schools: The Technology is Now*, D.A. Elmore, S.E. Olsen, and P.M. Smith, (Nat. Acad. Press, 1998. Available *only* on the web at < http://www.nap.edu/readingroom/books/techgap/pdf.html >. See also the listing in Sec. VA.

15. *Teaching About Evolution and the Nature of Science* (Nat. Acad. Press, 1998), also at < http://www.nap.edu/readingroom/books/evolution98/ > and the listing in Sec. VA. See also the "Science and Creationism" web site at < http://www4.nas.edu/opus/evolve.nsf >.

16. *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 >.

17. *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 (e.g., ref. 18) 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. 19.

18. L.B. Resnick and M.W. Hall, "Learning Organizations for Sustainable Education Reform," *Daedalus* **127**(4), 89-118 (1998).

19. 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/ >.

20. *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. 19). See also Sec. IIIF under “HCS - House Committee on Science.”

21. I. Halloun and D. Hestenes, "Interpreting VASS dimensions and profiles," *Science & Education*, **7**(6), 553-577 (1998). (VASS _ Views About Sciences Survey) Biology, physics, chemistry, and math versions are available at < http://modeling.la.asu.edu/modeling/R&E/Research.html >. E-mail a request to Larry Dukerich <Dukerich@asu.edu> to obtain a password. A description of VASS is available at < http://modeling.la.asu.edu/halloun/hallounDP.html >.

22. J.R. Anderson, L.M. Reder, and H. A. Simon, "Radical Constructivism and Cognitive Psychology" in *Brookings Papers on Education Policy - 1998*, Diane Ravitch, ed. (Brookings Institution Press, 1998), p. 227-278. (Includes supporting comments by K. Andres Ericsson and Robert Glaser.) Anderson *et al.* write: "The time has come to abandon philosophies of education and turn to a science of education.....If progress is to be made to a more scientific approach, traditional philosophies will be found to be like the doctrines of folk medicine. They contain some elements of truth and some elements of misinformation. This is true of the radical constructivist approach. Only when a science of education develops that sorts truth from fancy - as it is beginning to develop now will dramatic improvements in educational practice be seen."

23. S. Bowen, "Cognitive Psychology and Learning Theory: A Web Tour," American Physical Society *Forum on Education Newsletter*, Summer, 1998, p. 13-14, see also at < http://www.csu.edu/ChemistryAndPhysics/assessmt.htm >.

24. Electronic Classroom Communication Systems (ECCS's) may allow a cost-effective semi-Socratic approach to instruction in large-enrollment "lecture" sections: (a) Nelson Cue, "A Universal Learning Tool for Classrooms?" in *Proceedings of the First Quality in Teaching and Learning Conference*, 1998, Hong Kong, to be published; (b) R.A. Burnstein and L.M. Lederman, "Report on progress in using a wireless keypad response system," in *The Changing Role of Physics Departments in Modern Universities: Proceedings of the ICUPE*, ed. by E.F. Redish and J.S. Rigden, (AIP, Woodbury, NY, 1997). p. 531-537; (c) R.J. Dufresne, W.J. Gerace, W.J. Leonard, J.P. Mestre, and L. Wenk, "*Classtalk*: A classroom communication system for active learning," *J. Computing in Higher Ed.* **7**(2), 3-47 (1996), also at < http://www-perg.phast.umass.edu/research/Classtalk/default.html >; (d) R.J. Dufresne and W.J. Gerace "Using 'Extended Scenario' to Enhance Learning During Interactive Lectures," at < http://www-perg.phast.umass.edu/research/Classtalk/ExtendedScenario/default.html >. See listings under ECCS in Sec. IIIC, Web Addresses.

25. H.A. Simon, "What We Know About Learning," *Journal of Engineering Education* **87**(4), 343-348 (1998).

26. A.R. Liboff, "Magnet Therapy," *Physics and Society* **27**(4), 5-7 (1998): "Medical educators in this country continue to ignore the additional second year of physics that should be required of anyone seeking to enter medical school.... (as argued in) ..... A.R. Liboff and M. Chopp, "Should the pre-med requirements in physics be changed?" *Am. J. Phys.* **47**, 331-336 (1979). "

27. Ted Marchese, "Not-So-Distant Competitors: How New Providers Are Remaking the Postsecondary Marketplace,"*AAHE Bulletin*, May 1998, also at < http://www.aahe.org/bulletin/bull_1may98.htm >: "Quite suddenly, in just two or three years, American higher education has come face-to-face with an explosive array of new competitors..... What would the postsecondary marketplace look like if (say) Microsoft, Deutsche Telekom, International Thomson, and the University of California combined to offer UC courses and degrees worldwide? In time, its only competitor could be a combine of like standing and deep pockets: an IBM-Elsevier-NEC-Oxford combine, for example. We shall see."

28. L. Springer, M.E. Stanne, and S. Donovan, "Effects of small-group learning on undergraduates in science, mathematics, engineering, and technology: A meta-analysis," accepted for publication in the *Review of Educational Research* (University of Wisconsin - Madison, National Institute for Science Education, 1998); on the web at < http://www.wcer.wisc.edu/nise/CL1/resource/R2.htm >.

29. *Daedalus* **127**(1), 1998, "Science in Culture," for a description see < http://daedalus.amacad.org/inprint.html >.

30. *Daedalus* **127**(2), 1998, " The Brain," for a description see < http://daedalus.amacad.org/inprint.html >.

31. M.R. Matthews, ed. *Constructivism in Science Education - A Philosophical Examination* (Kluwer, 1998).

32. N. Koertge, ed., *A House Built on Sand: Exposing Postmodernist Myths about Science* (Oxford, 1998)

33. *Daedalus* **126**(4), 1997 "The American Academic Profession," for a description see < http://daedalus.amacad.org/inprint.html >.

34. A. Etzioni and O. Etzioni, "Communities: Virtual vs. Real," editorial, *Science* **277**, 29 (1997) and (as befits the theme) on-line at < http://www.gwu.edu/~ccps/E30.html >: "Virtual" on-line communities complement and reinforce "real" off-line communities and have several advantages over the latter, e.g., (a) easy communication over national borders and time zones; (b) inclusion of homebound (aged, ill, or handicapped) people; (c) accommodation of more individuals than off-line meeting rooms; (d) strong memories; (e) high safety; (f) allowance for exploration of new relationships and identities - as documented by MIT's Sherry Turkle (see, ref. 73 below); and (g) indifference to physical appearance and off-line identity.
(A famous cartoon by Peter Steiner (see at < http://www.cartoonbank.com/index.asp > shows a dog turning his head from a computer screen and saying to another dog "On the internet nobody knows you're a dog.") Indeed, the compilation of this cross-disciplinary survey would have been virtually impossible without the internet - who would have taken a bloodhound seriously? For more information on A. Etzioni's work see his web page at < http://gwis2.circ.gwu.edu/~comnet/ >.

35. *Preparing for the 21st Century: The Education Imperative* (National Research Council, 1997), also available at < http://www2.nas.edu/21st >. See also the listing in Sec. VA. Also in this series at < http://www2.nas.edu/21st > in HTML and Adobe Acrobat Portable Document File (PDF) formats are: (a) *Science and Engineering Research in a Changing World*, (b) *Technology and the Nation's Future*, (c) *Challenges Facing a Changing Society*, (d) *The Environment and the Human Future*, (e) *Focussing on Quality in a Changing Health Care System.*

36. *Science Teaching Reconsidered: A Handbook* (Nat. Acad. Press, 1997), information at < http://www.nap.edu/readingroom/books/str/ >, see also the listing in Sec. VA.

37. Eric Mazur, *Peer Instruction: A User's Manual* (Prentice Hall, 1997). Discussion of an interactive method for large classes which is applicable in nearly all disciplines. For a review see M.D. Somers in the *Am. . J. Phys.* **67**(4), 359-360 (1999). "Professionals" may obtain free copies of the book (a) from Prentice Hall campus representatives, or (b) by downloading the Adobe Acrobat portable document file at < http://galileo.harvard.edu/ >.

38. T. Marchese, "The New Conversations About Learning: Insights from Neuroscience and Anthropology, Cognitive Science and Work-Place Studies" in *Assessing Impact: Evidence and Action*," (AAHE, 1997), p. 79-95, also at < http://www.newhorizons.org/lrnbus_marchese.html >.

39. 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."

40. J.M. Wilson, "How Computing and Communications are Changing Physics Education," in *The Changing Role of Physics Departments in Modern Universities: Proceedings of the ICUPE*, ed. by E.F. Redish and J.S. Rigden, (AIP, Woodbury, NY, 1997), p. 357-373: "The image of 'distance learning' is often linked to self-study 'correspondence courses' or passive viewing of television. The innovative use of emerging technologies and learning innovations can make that image of distance learning simply a distant memory. We will show how the studio courses are evolving into *interactive* learning distance courses." (Our *italics*.)

41. J.M. Wilson, "Distance Learning for Continuous Education," *Educom Review* **32**(2), 1997. < http://www.educause.edu/pub/er/review/reviewArticles/32212.html >.

42. T. Oppenheimer, "The Computer Delusion," *Atlantic Monthly*, July 1997, pp. 45-62; on the web at < http://www.theatlantic.com/issues/97jul/computer.htm >. Oppenheimer takes a dim view of value of computers in education, contrary to the outlook of refs. 14, 40, 41, 87. 88, 111, and 112.

43. E.J. Langer, *The Power of Mindful Learning* (Addison Wesley, 1997).

44. J.R. Anderson,, L.M. Reder, and H.A. Simon, "Situated learning and education," *Educational Researcher* **25**(4), 5-11 (1996); "Rejoinder: Situative versus cognitive perspectives: Form versus substance," *ibid*. **26**(1), 18-21 (1997).

45. J.C. Greeno, "On Claims that Answer the Wrong Question," *Educational Researcher* **26**(1), 5-17 (1997).

46. M. Hunt, *How Science Takes Stock: The Story of Meta-Analysis* (Russel Sage Foundation, 1997).

47. R.K. Hobbie, *Intermediate Physics for Medicine and Biology* (Springer, 3rd edition, 1997).

48. 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, see listing in Sec. IIIC).

49. A. Cromer, *Connected Knowledge: Science, Philosophy, and Education* (Oxford, 1997).

50. R.G. Newton, *The Truth of Science* (Harvard, 1997).

51. R.N. Giere, *Understanding Scientific Reasoning.* (Holt, Rinehart, and Winston, 1997).

52. D.C. Phillips, (a) "Coming to Grips with Radical Social Constructivism," *Science & Education* **6**, 85-104 (1997); (b)"The Good, the Bad, and the Ugly: The Many Faces of Constructivism," *Educational Researcher* **24** (2), 5 (1995).

53. D.R. Geelan, "Epitemological Anarchy and the Many Forms of Constructivism," *Science & Education* **6**, 15-28 (1997). Arrives at a position similar to that of Solomon (ref. 75): "If, rather than defending and supporting their own perspectives, constructivists were to actively seek out and apply competing ways of understanding, holding these in a dialectical tension, I believe that significant advances and developments in contructivist theory and practice would ensue."

54. M.H. Bickhard, "Constructivisms and Relativisms: A Shopper's Guide" *Science & Education* **6**, 29-42 (1997).

55. R. Nola, "Constructivism in Science and Science Education: A Philosophical Critique," *Science & Education* **6**, 55-83 (1997).

56. M.R. Matthews, "Introductory Comments on Philosophy and Constructivism in Science Education," *Science & Education* **6**, 5-14 (1997).

57. A.W. Chickering and S.C. Ehrmann, "Implementing The Seven Principles: Technology as Lever" (*AAHE Bulletin*, October, 1996, p. 3-6, also < http://www.tltgroup.org/ehrmann.htm >.

58. *National Science Education Standards* (Natl. Acad. Press, 1996), < http://www.nap.edu/readingroom/books/nses/ >, see also the listing in Sec. VA.

59. *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), at < http://www.nsf.gov/cgi-bin/getpub?nsf96139 >; *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).

60. *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/ > (see also the listing in Sec. VC). A good set of references is appended.

61. Karl Pister (former Chancellor of UC - Santa Cruz, on the Convocation Program Steering Committee of ref. 40 above), "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." < http://www.ucsc.edu/news_events/review/text_only/Winter-96/Win_96-Pister-Renewing_.html >

62. H.E. Daly, *Beyond Growth: The Economics of Sustainable Development* (Beacon Press, 1996).

63. E.D. Hirsch, Jr., *The Schools We Need: Why We Don't Have Them* (Doubleday, 1996) - A generally thoughtful (if not always consistent) analysis from a standpoint opposite to that Gardner's *The Disciplined Mind* (ref. 6).

64. L. Laudan, *Beyond Positivism and Relativism: Theory, Method, and Evidence* (Westview, 1996).

65. J. F Osborne, "Beyond Constructivism," *Science Education* **80** (1), 53-82 (1996).

66. S.C. Ehrmann, "Asking the Right Question: What Does Research Tell Us About Technology and Higher Learning?" in *Change: The Magazine of Higher Learning*, **27**(2), 20-27 (1995), also at < http://www.learner.org/edtech/rscheval/rightquestion.html >. See also the response by R.R. Hake at < http://www.aahe.org/hake.htm > to S.C. Ehrmann's AAHESGIT Post #146 of 1997 on "Research on Impact of Educational Users of Information Technology."

67. S.C. Ehrmann, "The Bad Option And The Good Option," *Educom Review* **30**(5), 1995. < http://www.educause.edu/pub/er/review/reviewArticles/30541.html >:
"Bad Option: we will have chosen this avenue if we continue to teach over computer and video networks just as we have in traditional classrooms-'unquestioningly.' Some administrators even encourage this ("You'll love this new technology; you can just teach the way you always have!") If institutions do broadcast their instruction out into the void beyond the campus, outcomes are likely to deteriorate still further. If today's best graduates are symbolized by those Harvard graduates....[n 'A Private Universe'-videotape of graduating seniors asked "What causes the seasons?" They explain that the seasons are caused by yearly changes in the distance between the Sun and the Earth! See < http://cfa-www.harvard.edu/cfa/sed/privateuniv.html >)....., what will the average graduate of tomorrow be like?
Good Option: we will have chosen the Good Option if most faculty members begin to reexamine their teaching and their courses: These faculty members could ask more probing questions in class (whether the students are in the same room or a hundred miles away)."

68. *Joining Forces: Spreading Successful Strategies* - NSF Conference of February 23-25, 1995 (National Science Foundation, 1995, Report NSF 95-126-New).

69. *Restructuring Engineering Education: A focus on change* - Report of an NSF Workshop on Engineering Education - April 1995 (National Science Foundation, 1995, Report NSF 95-65 - new).

70. Educom Review Staff, "Roger Schank: End Run to the Goal Line," *Educom Review* **30**(1), 1995. < http://www.educause.edu/pub/er/review/reviewArticles/30114.html >

71. Elaine Seymour and Nancy Hewitt, "Talking About Leaving: Factors Contributing to High Attrition Rates Among Science, Mathematics, and Engineering Undergraduate Majors" (Bureau of Sociological Research, University of Colorado, 1994); Elaine Seymour, "Guest Comment: Why undergraduates leave the sciences," *American Journal of Physics* **63**(3), 203-211 (1995).

72. *Daedalus* **124**(4), 1995, "American Education: Still Separate, Still Unequal," for a description see < http://daedalus.amacad.org/inprint.html >.

73. R. Sylwester, *A Celebration of Neurons: An educator's guide to the Human Brain* (Association for Supervision and Curriculum Development, 1995). Compare Bruer, ref. 48.

73. S. Turkle, *Life on the Screen: Identity in the Age of the Internet* (Simon & Shuster, 1995). For more on Turkle's work see her web page at < http://web.mit.edu/sturkle/www/ >.

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

75. Joan Solomon, "The Rise and Fall of Constructivism," *Studies in Science Education* **23**, 1-19 (1994). A good review of the history of pedagogical constructivism.

76. E.F. Redish, "Implications of cognitive studies for teaching physics," *Am. J. Phys.* **62**, 796-803 (1994), also at < http://www.physics.umd.edu/rgroups/ripe/papers/cogsci.html >.

77. K.A. Ericsson, R.T. Krampe, and C. Tesch-Romer, "The Role of Deliberate Practice in the Acquisition of Expert Performance," *Psychological Rev.* **100**(3), 363-406, 1993; K.A. Ericsson and N. Charness, "Expert performance, its structure and acquisition, *Am. Psychologist* **49**, 725-747 (1994); K.A. Ericsson and J. Smith, eds., *Toward a General Theory of Expertise: Prospects and Limits* (Cambridge Univ. Press, 1991); KA. Ericsson, ed. *The Road to Excellence: The Acquisition of Expert Performance in the Arts and Sciences, Sports, and Games* (Erlbaum, 1996).

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

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

80. J.T. Bruer, *Schools for Thought: A Science of Learning in the Classroom* (MIT Press, 1994).

81. M.R. Matthews, *Science Teaching : The Role of History and Philosophy of Science* (Philosophy of Education Research Library, 1994).

82. Howard Gardner, *Multiple Intelligences: The Theory in Practice* (Basic Books, 1993).

83. J.R. Anderson, *Rules of the Mind* (Lawrence Erlbaum, 1993).

84. S.B. Sarason, (a) *The Case for Change: Rethinking the Preparation of Educators* (Jossey-Bass, 1993), (b) *The Predictable Failure of Educational Reform : Can We Change Course Before It's Too Late?* (Jossey-Bass, 1990).

85. M.R. Matthews, "Constructivism and Science Education: Some Epistemological Problems," *J. Sci. Ed. and Tech.* **2**(1), 359 (1993).

86. S. Tobias, *Revitalizing Undergraduate Science: Why Some Things Work and Most Don't* (Research Corporation, Tucson, AZ, 1992). For more recent commentary see S. Tobias, "From Innovation to Change: Forging A Physics Education Reform Agenda for the 21st Century," *APS Forum on Education Newsletter*, Summer 1999, p. 3 - 4; on the web at < http://webs.csu.edu/~bisb2/FEdnl/Tobias.htm >.

87. J.J. Kaput, "Technology and Mathematics Education" in *Handbook of Research on Mathematics Teaching and Learning*, D.A. Grouws, ed. (Macmillan, 1992)

88. 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).

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

90. H.W. Stevenson and J.W. Stigler, *The learning gap: Why our schools are failing and what we can learn from Japanese and Chinese education* (Summit Books, 1992).

91. J.A. Paulos, *Beyond Numeracy: Ruminations of a Numbers Man* (Vintage Books, 1992).

92. T.M. Duffy and D.H. Jonassen, *Constructivism and the Technology of Instruction: A Conversation* (Lawrence Erlbaum, 1992).

93. R.M. Hazen and J. Trefil, *Science Matters: Achieving Scientific Literacy* (Doubleday, 1991).

94. J. Lave and E. Wenger, *Situated learning: Legitimate peripheral participation* (Cambridge University Press, 1991).

95. S. Tobias, *They're Not Dumb, They're Different: Stalking the Second Tier* (Research Corporation, Tucson, AZ, 1990).

96. *The Liberal Art of Science: Agenda for Action* (American Association for the Advancement of Science, 1990).

97. *The Freshman Year in Science and Engineering: Old Problems, New Perspectives for Research Universities* (Alliance for Undergraduate Education, 1990); see esp. Sec. V "The Importance of Collaboration Among the Disciplines": "the walls...(between disciplines)... must come down....Students are typically interested in problems of modern society, and these problems often have multifacited 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."

98. 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*." (Our *italics*.)

99. G.A. Goldin, "Epistemology, Constructivism, and Discovery Learning in Mathematics," in *Journal for Research in Mathematics Education, Monograph #4: Constructivists' Views of the Teaching of Mathematics* (National Council of Teachers of Mathematics, 1990). Argues that there is some virtue in constructivist pedagogy but little virtue in constructivist philosophy.

100. M. Csikszentmihalyi, "Literacy and Intrinsic Motivation," *Daedalus* **119**(2), 115-140 (1990).

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

102. P. Smith, *Killing the Spirit: Higher Education in America* (Viking, 1990).

103. L.A. Steen, ed. *On the Shoulders of Giants: New Approaches to Numeracy* (National Academy Press, 1990).

104. D. Bok, *Universities and the Future of America* (Duke University Press, 1990).

105. *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 in the natural sciences merits the highest priority on the national agenda."

106. *Science for All Americans: A Project 2061 Report on the Literacy Goals in Science, Mathematics, and Technology* (American Association for the Advancement of Science, 1989).

107. J.S. Brown, A. Collins, and P. Duguid, "Situated cognition and the culture of learning," *Educational Researcher* **18**(1), 34-41 (1989).

108. A. Collins, J.S. Brown, and S. Newman, "Cognitive apprenticeship: Teaching students the craft of reading, writing, and mathematics," in *Knowing, learning, and instruction: Essays in honor of Robert Glaser*, L.B. Resnick, ed., (Erlbaum, 1989), p. 453-494.

109. N.L. Gage, "The Paradigm Wars and Their Aftermath: A 'Historical' Sketch of Research on Teaching Since 1989," *Educational Researcher* **18**(7), 4-10 (1989; a history as recorded by a hypothetical observer in the year 2009. For a forecast of paradigms in the year 2009 for physics-education research see R.R. Hake, "Towards Paradigm Peace in Physics-Education Research," submitted to the AERA-D annual meeting 4/2000; on the web at < http://www.physics.indiana.edu/~hake >.

110. E. Von Glasersfeld, *The Construction of Knowledge: Contribution to Conceptual Sematics* (Intersystems, 1988). For more information on Glasersfeld and other "radical constructivists" see the web page "Radical Constructivism" by Alex Reigler of the Brussels Free University at < http://www.univie.ac.at/cognition/constructivism/ >. Glasersfeld's homepage < http://www.umass.edu/srri/vonGlasersfeld/ > contains 8 of his articles in pdf form.

111. G. Forman and P.B. Pufall, eds., *Constructivism in the Computer Age* (Lawrence Erlbaum, 1988).

112. A. A. diSessa, "The Third Revolution in Computers and Education," *J. Res. in Sci. Teach.* **24**, 343-367 (1987).

113. H. Gardner, *The Mind's New Science: A History of the Cognitive Revolution* (Basic Books, New York, 1987).

114. 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."

115. *Undergraduate Science, Mathematics, and Engineering Education* (National Science Board Task Committee on Undergraduate Science and Engineering Education - Homer A. Neal, Chairman, 1986).

116. H. Gardner, *Frames of Mind: The Theory of Multiple Intelligences* (Basic Books, 1985).

117. A.H. Schoenfeld, *Mathematical Problem Solving* (Academic Press, 1985).

118. G. Holton (with S. Brush), *Introduction to Concepts and Theories in Physical Science* (Princeton Univ. Press, 2nd edition, 1985).

119. L.H.T. West and A.L. Pines, eds., *Cognitive Structure and Conceptual Change* (Academic Press, 1985).

120. D.A. Kolb, *Experiental Learning: Experience as the Source of Learning and Development* (Prentice Hall, 1984).

121. *A Nation At Risk: The Imperative for Educational Reform* (National Commission on Excellence in Education, U.S. Government Printing Office, Washington, D.C., 1983).

122. D. Gentner and A.L. Stevens, eds., *Mental Models* (Lawrence Erlbaum, 1983).

123. J.M. Ziman, *Reliable Knowledge: An Exploration of the Grounds for Belief in Science* Cambridge University Press, 1978).

124. W. G. Perry, *Forms of Intellectual and Ethical Development in the College Years: A Scheme* (Holt, Rinehart, and Winston, 1970).

124. A. N. Whitehead, *The Aims of Education*, (Free Press, 1967, originally published in 1929).

V. SOME RELEVANT ON-LINE BOOKS AND REPORTS FROM THE NATIONAL RESEARCH COUNCIL'S NATIONAL ACADEMY PRESS

[D = description only; or entire contents can be read on-line from: I = scanned Image (fuzzy and painfully slow)*, H = HTML document, P = Adobe Acrobat Portable Document File (PDF)].

A. Education < http://www.nap.edu/readingroom/enter2.cgi?ED.html >

How People Learn: Brain, Mind, Experience, and School (I), J.B. Bransford, A.L. Brown, and R.R. Cocking, eds., 1999.

Next Steps for TIMMS: Directions for Secondary Analysis (I), A. Beatty, L.W. Paine, and F.O. Ramirez, eds., 1999.

Transforming Undergraduate Education in Science, Mathematics, Engineering, and Technology, Committee on Undergraduate Science Education (I, H), 1999.

Reinventing Schools: The Technology is Now (H, P), D.A. Elmore, S.E. Olsen, and P.M. Smith, 1998). This book is available *only* electronically.

Teaching About Evolution and the Nature of Science (H), Working Group on Teaching Evolution, 1998. See also the "Science and Creationism" web site at < http://www4.nas.edu/opus/evolve.nsf >.

Uncommon Measures: Equivalence and Linkage Among Educational Tests (I, H), M.J. Feuer, P.W. Holland, B.F. Green, M.W. Bertenthal, and F. C. Hemphill, eds., 1998

Learning About Assessment, Learning Through Assessment (I), M. Driscoll and D. Bryant, 1998.

Developing a Digital National Library for Undergraduate Science, Mathematics, Engineering, and Technology Education, Report of a Workshop (I, H), Steering Committee for Developing Such a Library, 1998.

Learning from TIMMS: Results of the Third International Mathematics and Science Study: Summary of a Symposium (I), A. Beatty, ed., 1997.

Science Teaching Reconsidered: A Handbook (I, H, P), Committee on Undergraduate Science Teaching, 1997.

*Preparing for the 21st Century: The Education Imperative (*H, P), National Research Council, 1997), also available at < http://www2.nas.edu/21st >.

Science for All Children: A Guide to Improving Elementary Science Education in Your School District (I), National Science Resources Center, 1997.

The Role of Scientists in the Professional Development of Science Teachers (I, H) Committee on Biology Teacher Inservice Programs, 1996.

National Science Education Standards (I, H, P), National Research Council, 1995.

Learning, Remembering, Believing: Enhancing Human Performance (I, H), D. Druckman and R.A. Bjork, eds., 1994)

Everybody Counts: A Report to the Nation on the Future of Mathematics Education (I), Mathematical Sciences Education Board and the Board on Mathematical Sciences (sic), 1989.

Climbing the Ladder: An Update on the Status of Doctoral Women Scientists and Engineers (I), Committee on the Education and Employment of Women in Science and Engineering, 1983.

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*Caution: If you wish to access Image "I" versions and use *Navigator 4.0,* turn off "Warn me before accepting a cookie" in Edit/Preferences in order to avoid an interminable series of cookie permission signs and possible crashes. Other browsers may require similar treatments. Whether the bug causing this problem is in the browser, the Academy Press system, or both is not presently clear.

B. Biology < http://www.nap.edu/readingroom/enter2.cgi?BI.html >

Nature and Human Society: The Quest for a Sustainable World (D), P. Raven and T. Williams, eds., 1999 (in press).

Serving Science and Society into the New Millennium (I), U.S. Department of Energy, 1998.

Biotechnology Unzipped: Promises and Realities (I), E.S. Grace, 1997.

Biodiversity II: Understanding and Protecting Our Biological Resources (I), M.L. Reaka-Kudla, D.E. Wilson, and E.O. Wilson, eds., 1996.

Calculating the Secrets of Life: Applications of the Mathematical Sciences in Molecular Biology (I), E.S. Lander and M.S. Waterman, eds.,1995.

Discovering the Brain (D), S. Ackerman for the Institute of Medicine, 1992.

Fulfilling the Promise: Biology Education in the Nation's Schools (D), Committee on High-School Biology Education, 1990.

Biodiversity (D) E.O. Wilson, ed., 1988.

A Biological Survey for the Nation (I, H), Committee on the Formation of a National Biological Survey, 1993.

Shaping the Future: Bilology and Human Values (D), S. Olsen for the Board on Biology, 1989.

C. Engineering < http://www.nap.edu/readingroom/enter2.cgi?EG.html >

Frontiers of Engineering: Reports on Leading Edge Engineering from the 1998 NAE Symposium on Frontiers of Engineering (I), National Academy of Engineering, 1999.

From Analysis to Action: Undergraduate Education in Science, Mathematics, Engineering, and Technology Report of a Convocation (I,P) 1996.

Engineering Within Ecological Constraints (I), P. Schulze, ed., 1996.

Prospectus for National Knowledge Assessment (I,H? it's blank), Committee on Knowledge Assessment, 1996: "Knowledge assessment is a tool for assisting countries to analyze their capabilities for participating in the knowledge revolution."

D. Behavioral Science < http://www.nap.edu/readingroom/enter2.cgi?BS.html >

Summarizing Population Health: Directions for the Development and Application of Population Metrics (P), Committee on Summary Measures of Population Health, , M.J. Field and M.R.Gold, eds., Institute of Medicine, 1998

Enhancing Human Performance: Issues, Theories, and Techniques (I), D. Druckman and J.A. Swets, eds., 1988.

Enhancing Human Performance: Issues, Theories, and Techniques: Background Papers (I), Committee on Techniques for the Enhancement of Human Performance, 1988.

VI. BIBLIOGRAPHY OF ACTIVE LEARNING IN BIOLOGY (1986-1993 only, American Psychological Association format) Abstracted from the University of South Florida's "Bibliography of Active Learning in Science" at < http://www.cte.usf.edu/resources/res_def.html >.

A. Broad Overviews of the Field

1. Danieley, H. (1990). Exploring mitosis through the learning cycle. American Biology Teacher, 52(5), 295-296, 1990.

2. Salay, J. (1992, February). Biology as collage. American Biology Teacher, 54(2), 102.

B. Using Audio-Visual Materials to Promote Active Learning

1. Hale, E. M. (1993, April). Overhead transparencies for viewing molecular structure in three dimensions. American Biology Teacher, 55(4), 227.

2. Huang, S. D., & Aloi, J. (1991, May). The impact of using interactive video in teaching general biology. American Biology Teacher, 53(5), 281-284.

3. Igelsrud, D. (1987). Laserdiscs. American Biology Teacher, 49(2), 115-119.

4. Mattson, P. (1991, January). Human biology, health education, and the "video generation". American Biology Teacher, 53(1), 25-28.

5. Rode, G. A. (1992, April). Rap music as a method of review. American Biology Teacher, 54(4), 242-243.

6. Rogers, F. A. (1987). Videotapes as a learning tool in biology. Journal of College Science Teaching, 16(5), 458-461.

7. Igelsrud, D. (1987). Laserdiscs. American Biology Teacher, 49(2), 115-119.

C. Using Case Studies or Case Method Teaching to Promote Active Learning

none

D. Using Collaborative/Cooperative Methods or Group Work to Promote Active Learning

1. Danieley, H. (1990). Exploring mitosis through the learning cycle. American Biology Teacher, 52(5), 295-296.

2. Okebukola, P. A. (1992, April). Concept mapping with a cooperative learning flavor. American Biology Teacher, 54(4), 218-221.

3. Watson, S. B. (1992, February). The essential elements of cooperative learning. American Biology Teacher, 54(2), 84-86.

E. Using Computer Aided Instruction to Promote Active Learning

1. Buttles, S. (1992, November/December). A model for incorporating and evaluating use of a computer laboratory simulation in the nonmajors biology course. American Biology Teacher, 54(8), 491 494.

2. Duhrkopf, R., & Kramer, W. (1990). Using your computer for videodisc applications. American Biology Teacher, 52(8), 511-513.

3. Huang, S. D., & Aloi, J. (1991, May). The impact of using interactive video in teaching general biology. American Biology Teacher, 53(5), 281-284.

4. Miller, B. (1993, February). Some applications of hypercard-based media in the secondary biology classroom. American Biology Teacher, 55(2), 110-114.

5. Sigisimondi, L. A. & Calise, C. (1990). Integrating basic computer skills into science classes: Analysis of ecological data. American Biology Teacher, 52(5), 297-301.

6. Silvius, J. E. (1993, April). Using a computer data base in the biology laboratory with specific application to the herbarium collection. American Biology Teacher, 55(4), 245-246.

7. Thompson, S. R., Seligmann, P. F., & Cava, F. J. (1993, January). A pH and computer approach to measuring respiration rate. American Biology Teacher, 55(1), 46-48.

F. Using Demonstrations or Lab Activities to Promote Active Learning

1. Anderson, R. P. (1993, January). A quick, easy, investigative laboratory for studying the control of gene expression. American Biology Teacher, 55(1), 38-41.

2. Beiswenger, J. M., & Brewer, C. A. (1993, April). Predicting biological response to global warming: A laboratory activity to promote discussion. American Biology Teacher, 55(4), 222-226.

3. Brewer, C. A., & Beiswenger, J. M. (1993, April). Carbon dioxide and the greenhouse effect: A problem evaluation activity. American Biology Teacher, 55(4), 238-240.

4. Doe, F. J., & Leslie, J. F. (1993, October). A laboratory exercise for isolating and characterizing microbial mutants with metabolic defects. American Biology Teacher, 55(7), 430-433.

5. Gillen, A. L., Brown, W. E., & Williams, R.P. (1989). Developing a dynamic demonstration. American Biology Teacher, 51(5), 306-310.

6. Kangas, P. C. (1990, January). A demonstration of the role of animals in ecosystems: Why aren't there any good children's books about ecosystems? American Biology Teacher, 52(1), 50-51.

7. Lumpe, A. T., & Oliver, J. S. (1991, September). Dimensions of hands-on science. American Biology Teacher, 53(6), 345-348.

8. Mickle, J. E. (1990, November/December). A model for teaching mitosis and meiosis. American Biology Teacher, 52(8), 500-503.

9. Porter, J. R., Thomulka, K. W., & Smith, R. A. (1992, February). Demonstrating bacterial flagella. American Biology Teacher, 54(2), 108-111.

10. Quackenbush, R. E. (1992, January). Genetics of the domestic cat. American Biology Teacher, 54(1), 29-32.

11. Rindos, D., & Atkinson, J. W. (1990, May). Pizza chromosomes. American Biology Teacher, 52(5), 281-287.

12. Rosenberg, H. I. (1992, March). How to improve the quality of the environment in the undergraduate dissection laboratory. American Biology Teacher, 54(3), 171-172.

13. Smith, M. (1991, February). Plant growth-responses to touch--literally a "hands-on" exercise. American Biology Teacher, 53(2), 111-114.

14. Vestal, B. M., & Estes, J. R. (1992, January). A classroom exercise in empirical analysis: Gender differences in book-carrying behavior. American Biology Teacher, 54(1), 33-36.

15. Yurkiewicz, W. J. (1993, October). Immunology labs made easy with insects. American Biology Teacher, 55(7), 434-436.

G. Using Discussion, Debate, or Student Presentations to Promote Active Learning

1. A. S. (1983, February). Determinism or probability--or teaching students how to ask questions. American Biology Teacher, 45(2), 102-104.

2. Armstrong, K., & Weber, K. (1991, May). Genetic engineering--a lesson on bioethics for the classroom. American Biology Teacher, 53(5), 294-297.

3. Barman, C. R., & Hendrix, J. R. (1983, January). Exploring bioethical issues: An instructional model. American Biology Teacher, 45(1), 23-31.

4. Costenson, K., & Lawson, A. E. (1986). Why isn't inquiry used in more classrooms? American Biology Teacher, 48, 150-155.

5. Danieley, H. (1990, May). Exploring mitosis through the learning cycle. American Biology Teacher, 52(5), 295-296.

6. Fail, J. L., Jr. (1991, March). The value of student-originated and student-run ecology projects. American Biology Teacher, 53(3), 170-171.

7. Lawson, A. E. (1991, February). Exploring growth (and mitosis) through a learning cycle. American Biology Teacher, 53(2), 107-110.

8. Morishita, F. (1991, February). Teaching about controversial issues: Resolving conflict between creationism and evolution through law-related education. American Biology Teacher, 53(2), 91-93.

9. Salay, J. (1992, February). Biology as collage. American Biology Teacher, 54(2), 102.

10. Wyatt, H. V. (1984, Fall). Writing, tables, and graphs: Experience with group discussions in microbiology practical work. Journal of Biological Education, 18(3), 239-245.

11. Zipko, S. J. (1991, March). The pros and cons of environmental debates. American Biology Teacher, 53(3), 172-175.

H. Using Field Trips or Field Work to Promote Active Learning

1. Klepper, N. H. (1990). Lifetime legacy: The successful field trip. American Biology Teacher, 52(2), 245-248.

2. Leonard, W. H., Eddy, D., Towle, R., & Wong, D. (1983, September). A biomes field trip. American Biology Teacher, 45(5), 273-275.

I. Using Games or Simulations to Promote Active Learning

1. Fifield, S., & Fall, B. (1992, April). A hands-on simulation of natural selection in an imaginary organism, Platysomaapoda. American Biology Teacher, 54(4), 230-235.

2. Hammersmith, R. L., & Mertens, T. R. (1990, November/December). Teaching the concept of genetic drift using a simulation. American Biology Teacher, 52(8), 497-499.

3. Sheridan, P. (1992, January). Dating fossil pollen: A simulation. American Biology Teacher, 54(1), 41-45.

J. Using Guided Designs to Promote Active Learning

none

K. Using Library Assignments to Promote Active Learning

1. Jacobson, T. E., & Wilson, L. D. (1991, May). A bibliographic instruction program for college biology students. American Biology Teacher, 53(5), 298-300.

2. Laferriere, J. E. (1987). Introducing biology students to library reference resources. American Biology Teacher, 49(6), 368-369.

3. Nussbaum, F. E., Jr. (1991, May). Introduce successful library assignments to students in biological sciences. American Biology Teacher, 53(5), 301-304.

L. Using Projects to Promote Active Learning

1. Hollingshead, B., & McDowell, G. (1992, May). Building a botanical outdoor learning center. American Biology Teacher, 54(5), 291-294.

M. Using Role Play or Performance to Promote Active Learning

1. Biermann, C. A. (1988, March). How-to-do-it: The protein a cell built (and the house Jack built). American Biology Teacher, 50(3), 162-163.

2. Stencel, J., & Barkoff, A. (1993, February). Protein synthesis: Role playing in the classroom. American Biology Teacher, 55(2), 102-103.

N. Using Writing Activities to Promote Active Learning

1. Ambron, J. (1987). Writing to improve learning in biology. Journal of College Science Teaching, 16(4), 263-266.

2. Cannon, R. E. (1990, March). Experiments with writing to teach microbiology. American Biology Teacher, 52(3), 156-158.

3. Hotchkiss, S. K., & Nellis, M. K. (1988, September/October). Writing across the curriculum: Team teaching the review article in biology. Journal of College Science Teaching, 18(1), 45-47.

4. House, K. (1983, September). Improving student writing in biology. American Biology Teacher, 45(5), 267-270.

5. Middleton, A. L. A. (1990, April). Science writing in the mass media as a useful teaching tool. American Biology Teacher, 52(4), 209-212.

6. Nekvasil, N. P. (1991, March/April). Adding writing proficiency to undergraduate biology research -a formula for success at Saint Mary's. Journal of College Science Teaching, 20(5), 292-293.

7. Reynolds, F. E., & Pickett, L. (1989). Read! think! write!: The reading response journal in the biology classroom. American Biology Teacher, 51(7), 435-437.

8. Schlenker, R. M. (1990, November/December). Student research report writing. American Biology Teacher, 52(8), 491-492.

9. TePaske, E. R. (1982). Writing in biology: One way to improve analytical thinking. American Biology Teacher, 44(2), 98-99.

10. Trombulak, S., & Sheldon, S. (1989, May). The real value of writing to learning in biology. Journal of College Science Teaching, 18(6), 384-386.

VII. EPILOGUE

The NRC report *Developing a Digital National Library for Undergraduate Science, Mathematics, Engineering, and Technology Education*, Report of a Workshop (Nat. Acad. Press, 1998), ref. 13 of Sec. IV "General References" (see also the listing in Sec. VA) summarizes some serious concerns regarding undergraduate Science, Mathematics, Engineering, and Technology (SME&T) reform:

(1) "Despite efforts by individuals and calls for improvement from prestigious national organizations (e.g., Clinton and Gore... (see OSTP listing in Sec. IIIF, Web Listings) ..., National Research Council, National Science Foundation, Project Kaleidoscope), *progress in the reform and improvement of undergraduate SME&T education often has been agonizingly slow*..... During the past three decades, the NSF and other public and private sources have provided hundreds of millions of dollars to support the development of classroom and laboratory programs and materials that could, if widely disseminated and adopted, help change how undergraduates in the United States learn about SME&T. However, many college and university faculty are either unaware of these resources, have difficulty accessing them, or resist their use. As a result, too many faculty continue to spend considerable time and effort 'reinventing' courses, course materials, and laboratory programs that are already available to them and could be adapted to their own teaching situations." (Our *italics*.)

(2) "Several of the greatest problems in transforming collegiate science curricula relate directly to people's knowledge of the resources. If there is no 'library' that focuses upon collecting, classifying, indexing, querying, sharing, and making accessible technological curricular resources and reviews of those materials, then there are enormous costs in the initiation, instantiation, maintenance, and extension of curricular reform: ..... (b) because there is no equivalent to the *Science Citation Index* for the many curricular initiatives that are funded, or are local to one campus, or even those ..... (described in published) .... articles .... there is an enormous wastage due to the 'not-invented-here' syndrome. In particular, NSF does not get the full benefit of its critical investment. Many marvelous innovations of the post-Sputnik era have simply been lost because few others than the innovators themselves have any knowledge at all about these NSF-funded innovations....." J.R. Jungck in a paper commissioned by the study (ref. 62, Sec. II of this survey).

(3) "The most crucial task now facing the NSF and other funders is the conversion of innovation to broad and sweeping change. We know a good deal about what works well for SME&T students. It will require deep commitment to integrate the best of these innovations into the ongoing life of undergraduate SME&T education, thereby effecting the comprehensive educational change that is needed," Joan Girgus (Pew Charitable Trusts - see listing in Sec. IIIC) on p. 43 of *Shaping the Future*, ref. 59 of Sec. IV "General References."

(4) "Innovations and successes in education need to spread with the speed and efficiency of new research results," on p. 6 of *From Analysis to Action: Undergraduate Education in Science, Mathematics, Engineering, and Technology*, ref. 60 of Sec. IV "General References." The more complete and meaningful quote is: "Undergraduate education will not change in a permanent way through the efforts of 'Lone Rangers.' *Change requires ongoing interaction among communities of people and institutions that will reinforce and drive reform.* And replication is essential: innovations and successes in education need to spread with the speed and efficiency of new research results. *With the support of institutions, foundations, and federal agencies, educators need to form 'invisible colleges' resembling the national and international research communities*." (Our *italics*.)

The above concerns suggest the need for greater cooperation among the disciplines in order to speed the glacial pace of undergraduate SME&T reform. As suggested in the "Introduction" to this survey, investigators in each discipline, in order to make their work more visible to workers in other disciplines, might consider the production of counterparts of the physicists' (A) "Physical Sciences Resource Center," (B) "Resource Letter on Physics Education Research," and (C) "Physics Education Research Papers on the Web," together with reviews by disciplinary experts in education research (e.g, A. Van Heuvelen "Learning to think like a physicist: A review of research-based instructional strategies," *Am. J. Phys.* **59**, 891-897 (1991). Lacking such resources, guides such as the present "Research, Development, and Change in Undergraduate X Education: A Web Guide for Non-X's" may be of some transitory value.