June 15, 2004

To: Dean Bare
College of Forest Resources

From: Ad Hoc Forest Resources Library Space Work Group
Carol Green, Forest Resources Librarian
Robert Edmonds, Professor, Associate Dean
James Fridley, Professor
David Briggs, Professor, Faculty Vice-Chair
Michelle Trudeau, Student & Academic Services Director
Greg Brazil, Facilities Manager
Francis Greulich, Professor, Committee Chair

Re: Proposed Future Disposition of Forest Resources Library Space

The Work Group, appointed by your memorandum of 26 April 2004, has concluded its activities and arrived at a consensus best use of the space. In arriving at this recommendation we widely and openly solicited and discussed input from the faculty, staff, and students of the College. As a result three groups from within the College broached exploratory proposals. One of these groups, upon continued reflection, decided to withdraw its proposal. The other two groups discovered a commonality of interests and merged their two separate proposals into a unified and mutually supportive suggestion for use of the space. It is essentially this latter proposal, with some minor modifications, that the Work Group now brings forward for your consideration.

The attached proposal has garnered additional support from faculty, staff, and students who were not directly involved in its development. Several supporting letters have been received by the Work Group and are included here. It is undeniably clear to our Work Group that proponents of the selected proposal have captured and skillfully articulated what is widely felt to be the best College use of the space.

Members of the Work Group would like to strongly recommend that you put this proposal before the Provost at the earliest possible moment. We esteem current opportunities for University level concurrence and funding to be excellent. We have heard that Dean George Bridges would be favorably inclined toward providing some funds for this undertaking. We also feel that there is now an excellent prospect of gathering substantial support for these innovative educational ideas from outside the University. The possibility of developing outside matching funds, especially through the good offices of the Provost, should not be overlooked. It is also not entirely unlikely that the new University president, in casting about for new ideas to mark his tenure of office, may look with favor upon this trail breaking opportunity in education.

The educational concept behind this proposal is not incremental, but rather, it represents a major departure from the traditional teaching methods of higher education. Likewise, the supporting physical facilities will represent a dramatic departure from those found in the typical university environment. The motivating concepts behind the designs and some examples of their physical expression can be observed at:

http://www.physics.ncsu.edu:8380/physics_ed/Room_Design_files/frame.htm

The Work Group recommends however that actual physical layout of the space be determined by a professional design team in an exercise of the type that defined the new Merrill Hall. The Committee recommends that monies for developing these preliminary concepts for the physical facilities be requested of the Provost as soon as possible so that work can move forward in a timely manner.

It is our final recommendation that this proposal be presented, in person, to the Provost, and that key faculty and staff, including Professor Tom Hinckley and Marc Morrison who were instrumental in its development, be invited to play a role in the development and presentation of oral arguments.

Attachments

A Proposal for the Bloedel Hall Former Library Space

Environmental Learning Forum: Transforming Instruction & Technology & Meeting the Needs of the 21st Century

An Integrated Facility for Teaching and Learning in Environmental Science and Resource Management

Summary Statement: To meet the learning needs of students involved in the new instructional initiatives within the College of Forest Resources (e.g., the new ESRM curriculum, the Urban Ecology IGERT, etc.), we see the coordinated development of the space formerly allocated to the Forest Resources Library serving two integrated, complimentary functions: (1) innovative instructional space meeting the student needs of the core courses and (2) technologically advanced support for the core courses as well as other student teaching and research functions. The melding of these two activities into one functional space will address major deficiencies in College instructional space and technology support. An innovative design that captures the synergism between active learning and diverse educational and computer technologies will allow us to best capitalize on current opportunities and simultaneously maximize efficient use of resources to meet multiple needs.

For our college to succeed in its implementation of the newly approved ESRM curriculum, the College's flagship teaching and learning endeavor, the curriculum's core courses must facilitate class and studio sizes of 20-to-70 students in a highly collaborative, technologically enhanced setting that allows presentation (including live video), full class discussion (not just dialog with the instructor), and highly focused small group (4-6 student) discussions and data analyses. The architectural setting must be exciting, professional, and 'theatre like' in its feel. A teaching and learning facility with these characteristics will provide the College a cornerstone to become a truly world-class educational leader and the University with an observable unit that embraces an active learning pedagogy.

Background: Our new curriculum, adopted by College faculty in 2003, is founded on teaching and learning innovations that —properly supported—will place the College as a national leader of environmental and resource science education. The core courses are the centerpiece of this educational transformation and embody the essence of the 1989 report, 'Science for All Americans,' by the

American Association for the Advancement of Science. This report emphasized that the teaching of science should be ”approached with the same rigor as science at its best,“ and that such teaching ”involves active learning, strategies to engage students in the process of science and (the use of) teaching methods demonstrated to reach diverse students.” In an April 23, 2004 article in Science, Handelsman and others noted the surprising lack of progress, especially by Research 1 universities, in embracing these recommendations. This article emphasizes that there is a rich body of peer reviewed literature and case studies on the effectiveness of active learning (vs. traditional “transmission-of-information” lectures and “cookbook” laboratory exercises). The space formerly occupied by the Forest Resources Library provides us with a unique opportunity to establish this type of education. An innovative design that captures the synergism between active, collaborative learning and diverse educational and information technologies will allow us to capitalize on this unusual opportunity.

We will have, by mid-June, taught each of the four core courses, ESRM 301, 302, 303 and 304, at least once. Throughout the development of these courses our faculty, TAs and CIDR colleagues have worked closely to design, evaluate and re-design courses in progress as well as to implement improvements to future courses. We have developed partnerships with a diverse group of University-wide staff, Seattle community and agency personnel, extension and research faculty at Washington State University and stakeholders throughout the region. Through this endeavor, instructors and students all agree in their observations that the emphasis on active learning and discovery in these classes is working effectively and should enhance the College’s ability to attract more undergraduate majors. All, however, also note how our current and woefully inadequate facilities are a barrier to achieving complete success. Instructional spaces within the College are limited and archaic. For example, it is not unusual to have almost 40 students in room 105 Winkenwerder working on small group projects, giving presentations and receiving instruction through pre-1990 equipment. The facilities are not simply inadequate; they are highly distractive to effective learning.

Similarly, the College’s technology services are spread throughout Bloedel Hall and, as a result, provide inefficient service. This is particularly acute in Bloedel 311, the main student computer facility, where space and hours are limited. Integrating the College’s technology services together with the proposed instructional facility would truly enhance learning in the College. The resultant space would be effective, efficient and flexible.

Proposal: Our proposal has both spatial and technological components. In addition, this proposal addresses and integrates two currently separate, but highly critical needs. First, an instructional facility and second, computing resources and technologies to best serve this facility as well as existing and expanding student needs.

Spatially, we envision a complex that includes a large meeting place where, during an instructional period with facilitation by instructors, a class of 70 students can all see and converse with each other while clearly viewing material being discussed or presented. At the same time these students would be sitting in clusters of 4-6 so that they could, as smaller discussion units, critically explore the concepts being introduced – often for eventual contribution to the class as a whole – methods known and demonstrated to enhance learning. The seating would invite individual or group use of notebook computers and other materials. Larger video displays would allow sharing of information and ideas with the entire class. This large meeting facility would be configured so that it could be reduced in size (virtually or actually) when smaller sized classes were convened. Possible realizations of the facility could have similarities with theater in the round and oval or horseshoe-shaped board rooms.

Such a design will also be appreciated by industry, government and other stakeholder speakers asked to give presentations or to lead discussions. We contend that innovative instruction and classroom design will be a major element in the College's leadership in education. As a consequence, this space must be designed so that external observation by researchers and other onlookers is possible. It is appropriate that the effectiveness of science education methods be evaluated scientifically and that our experiences be transferable.

The complex would also include separate, perhaps surrounding, facilities where small groups could work simultaneously and independently of users in the "auditorium" facility. These facilities will likely include a mix of enclosed (sound isolated) and open spaces with, for example, work tables, white boards, smart boards, tack-able wall space, and notebook computer enabling technologies such as video display screens and network access.

We are proposing that the College adopt a "notebook-computer enabling" approach to instruction within this new teaching space. This would include network access via both WiFi and ethernet cables at all seats designated for teaching, learning and studying. "Installed" computers for handling computations requiring more power and speed would be located nearby or on mobile platforms. Some potential innovative and creative uses of this technology include:

transmission and reception of field data, laboratory and clinical images for analysis of disease and insect problems, video-conferencing, multiple location instruction, and the downloading and displaying of real time data. For example, students could place sensors on an early field trip and find out what happens during the remainder of the term, or some students in the field could send data back to other students in the classroom. There should also be the ability to have video teleconferencing with agency, practitioners or stakeholders. Courses and workshops conducted in this contemplated learning space could be offered via such video links to students or professionals physically located at other sites, expanding outreach by the College and potentially increasing tuition and/or fee revenue.

The Forest Resources librarian would have an office within the facility and would be available as a resource during class periods and through regular office hours and appointments. In addition, virtual reference thorough such UW Library services such as Q&A Live and direct access to the UW Libraries Catalog, databases and other services would offer students real-time access to library resources as well as other internet services.

Design and Allocation: We feel that the specifics of space and its best utilization and the nature and extent of technology will emerge during the pre-design phase of the project. Also during this phase, renderings will be developed and these can serve specific fund raising roles.

Faculty, Staff and Students Associated with this Proposal

Faculty: Brubaker, Ewing, Fridley, Hinckley, Manuwal, Marzluff, Paun, and Turnblom

Staff: Costen, Krause, Morrison.

Graduate Students: Mitchell Almaguer-Bay, Jon Honea, Virginia Travers

Undergraduate Students: Brenda Anderson, Jennifer Leach, Angela Steel

References:

Handelsman, J., D. Ebert-May, R. Beichner, P. Bruns, A. Chang, R. DeHaan, J. Gentile, S. Lauffer, J. Stewart, S.M. Tilghman, and W.B. Wood. 2004. Scientific Teaching. Science 304:521-522.

Web References

- Harvard:
  - http://www.sciencemag.org/cgi/content/full/304/5672/810b and
  - http://mazur-www.harvard.edu/education/educationmenu.php
- Ecological Soc of America: http://tiee.ecoed.net/
- University of Delaware: http://www.udel.edu/pbl/
- University of Oregon: http://yucca.uoregon.edu/wb/index.html
- Community Colleges: http://www.bioquest.org/lifelines/

From: Daniel Vogt <dvogt@u.washington.edu>
To: Frank Greulich <greulich@u.washington.edu>
Subject: Support for Environmental Learning Forum Proposal

Hi Frank

I would like to offer my support for the proposal that you and others have submitted for use of the College of Forest Resources' Library space.

"Environmental Learning Forum: Transforming Instruction & Technology & Meeting the Needs of the 21st Century - An Integrated Facility for Teaching and Learning in Environmental Science and Resource Management"

I think the recent addition of core curricula and new pathways offered in the College have been a great and necessary step for the College. Times have changed and we need to not only change with the times but should lead these changes when we can. However success of presenting the components of these changes to the students will be limited by the presentation methods which are, in turn, highly limited by the facilities and technology available for instruction. Some CFR faculty have attempted using some of the new instructional methods within their capabilities and seem to be very satisfied. But most of these new instructional methods do require a different physical setting and instructional technologies that aren't currently available at the College or, in some cases, not even within the University. If the proposal you have presented could be implemented, the College could teach more effectively and the students could learn more efficiently.

Let me know if I can be of any help in supporting your proposal.

Daniel Vogt
Associate Professor
Forest Resources

From: Larry Mason [mailto:larrym@u.washington.edu]
To: Greg Brazil; 'Luke Rogers'; moshea@u.washington.edu
Subject: Re: Document Update - Library Space Committee

Greg,

This proposal sounds terrific! One addition that would be very useful as we develop distance learning technologies would be to designate a small space (approx the size of AND 114) off to one corner to be equipped as a sound proof room for recording video instructional materials. The large room could be very valuable for meetings as well as instructional activities. Centralized office facilities for the college IT team could be located here and would seem an important benefit as well. Break out rooms could complete utilization of the perimeter.

Thanks,

Larry Mason
Project Coordinator
Rural Technology Initiative
College of Forest Resources
University of Washington, Box 352100
Seattle, WA 98195-2100

Office: 206-543-0827
Home: 206-366-0953
www.ruraltech.org

From: Luke Rogers [mailto:lwrogers@u.washington.edu]
To: Greg Brazil; moshea@u.washington.edu; larrym@u.washington.edu
Subject: Re: Document Update - Library Space Committee

Post-Library Space Committee,

I think your vision of the Library is very well thought out. I agree that the College is in need of a modern teaching space that allows for student collaboration and access to technologies like WiFi and video conferencing. I also agree that integrating some of the Colleges existing IT infrastructure into one area would be beneficial for both the IT staff and their clients. It would seem logical to put staff like Morrison, Krause and Coston in 062, 064 and the surrounding area so that they could take advantage of the existing service counter and service elevator (for deliveries).

Another opportunity in the teaching/collaboration space is to make it dual purpose so that it can be used for both teaching and for meetings. While the College does have Anderson 23 and space at CUH, Pack, and ONRC, it would be nice to have the capability to host 50+ person meetings here on campus.

Larry Mason's suggestion to use a small room in the Library as a studio is excellent. With the current use of video technology in the College and the expected proliferation of video products it makes a lot of sense to dedicate an area specifically for the purpose. An appropriately constructed studio and adjoining teaching facility will help to pave the way for CFR distance learning.

Luke Rogers
Senior Geographic Information Research Scientist
Forest Resources

From: "Jon M. Honea" <jhonea@u.washington.edu
To: "Michelle Trudeau" <michtru@u.washington.edu; "Mabay@U. Washington.
Subject: Re: Document Update - Library Space Committee

Just got back from a week-long conference, so haven't been able to reply until now. I wholeheartedly endorse this proposal for the use of the newly opened library space! CFR needs to continue to respond to improvements in teaching technology and methodology demonstrated in peer-reviewed studies to enhance the student learning experience. I believe that any student reading this proposal would be as excited as I am about the prospect of working in such a facility developed to realize a learner's full potential.

Thank you,
Jon Honea
Ph. D. Candidate, Ecosystem Analysis
College of Forest Resources
University of Washington

From: "Edie Sonne" <edie@u.washington.edu
To: "Michelle Trudeau" <michtru@u.washington.edu
Subject: Re: Document Update - Library Space Committee

Michelle

Thanks for forwarding on. I took a quick look at the proposal and have a few comments. First of all, having a classroom that supports the kind of innovative and collaborative teaching of the ESRM core courses is absolutely essential. A curriculum is only as good as the atmosphere in which it is taught.

I'm really excited about this proposal.

I don't know how detailed the proposal is supposed to be, but I was left with a couple questions. From the proposal I interpret that the space will accommodate a classroom, a computer facility (to replace Bloedel 311?), and breakout rooms. Is there really enough space for all of this? The computer facilities need to be accessible during all school hours- not just when there's not a class.

Will the IT group also be moving down there?

I think it is a good idea to know exactly what can and cannot fit BEFORE it goes to the provost. Otherwise it seems like we didn't do our homework.

Just a few cents.

Edie

Edie Sonne Hall, PhD Candidate
College of Forest Resources
University of Washington

From: "Jessica M Coburn" <waterbug@u.washington.edu
To: "Michelle Trudeau" <michtru@u.washington.edu
Subject: Re: Document Update - Library Space Committee

I think that this is a great plan. It is exactly what I would have wanted and I wish it was going to arrive in time for my education!

My only comment is that if during the planning phase you can't fit it all in and some has to be scrapped then here are the least important parts as I see it:

-Video conferencing

-A combination of ethernet and WiFi at every student desk. Perhaps just Ethernet around in certain places, especially teaching stations because they need fast connections. But then WiFi can take care of most needs and be available anywhere in the space.

The most important component as I see it that should not be cut out are the student group rooms. All year with every group assignment we have felt the need for rooms where you can be at a computer and discuss while not distracting/interrupting/annoying other people in the comp lab. We have felt the need to have places where we can practice our presentations with a computer so we know how the powerpoint will work and with privacy so that we again don't disturb others and so that we are comfortable to practice and get the speech right before presenting to others. These little group rooms are by far the most important element and if the college is able to put them in soon (before I graduate) it would be most beneficial to all students.

Thanks,

Jessica Coburn, Undergraduate
Environmental Science and Resource Mgmt
College of Forest Resources, U of W

EDUCATION

Scientific Teaching

Jo Handelsman,[1]* Diane Ebert-May,[2] Robert Beichner,[3] Peter Bruns,[4] Amy Chang,[5] Robert DeHaan,[6,†] Jim Gentile,[7] Sarah Lauffer,[1] James Stewart,[8] Shirley M. Tilghman,[9] William B. Wood[10]

Since publication of the AAAS 1989 report "Science for all Americans" (*1*), commissions, panels, and working groups have agreed that reform in science education should be founded on "scientific teaching," in which teaching is approached with the same rigor as science at its best (*2*). Scientific teaching involves active learning strategies to engage students in the process of science and teaching methods that have been systematically tested and shown to reach diverse students (*3*).

Given the widespread agreement, it may seem surprising that change has not progressed rapidly nor been driven by the research universities as a collective force. Instead, reform has been initiated by a few pioneers, while many other scientists have actively resisted changing their teaching. So why do outstanding scientists who demand rigorous proof for scientific assertions in their research continue to use and, indeed, defend on the basis of the intuition alone, teaching methods that are not the most effective? Many scientists are still unaware of the data and analyses that demonstrate the effectiveness of active learning techniques. Others may distrust the data because they see scientists who have flourished in the current educational system. Still others feel intimidated by the challenge of learning new teaching methods or may fear that identification as teachers will reduce their credibility as researchers (*3*).

This Policy Forum is needed because most scientists don't read reports but they do read *Science*. In addition, reports generally do not offer a guide to learning how to do scientific teaching, as we do with supporting online material (SOM) (*3*) and table (see page 522). We also present recommendations for moving the revolution forward.

Implementing Change in Lectures

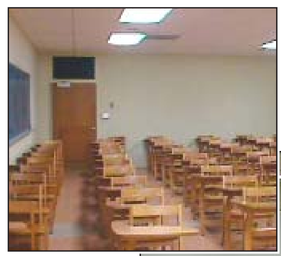
Active participation in lectures and discovery-based laboratories helps students develop the habits of mind that drive science. However, most introductory courses rely on "transmission-of-information" lectures and "cookbook" laboratory exercises—techniques that are not highly effective in fostering conceptual understanding or scientific reasoning. There is mounting evidence that supplementing or replacing lectures with active learning strategies and engaging students in discovery and scientific process improves learning and knowledge retention (*3*).

Introductory classes often have high enrollments, frequently approaching 1000 students in biology courses. This need not be an impediment to scientific teaching. Many exercises that depart from traditional methods are now readily accessible on the Web, which makes it unnecessary for teachers to develop and test their own (*3*). Quantitative assessment indicates that these interactive approaches to lecturing significantly enhance learning, and although time allocated to inquiry-based activities reduces coverage of specific content, it does not reduce knowledge acquisition as measured by standardized exams (*4*).

Faculty are also using computer systems to engage students, assess learning, and shape teaching. Students can be asked to read and solve problems on a Web site, and their answers can be analyzed before class to guide the design of lectures (*3*).

Some scientists have replaced lectures almost entirely. Laws's course "Calculus-Based Physics Without Lectures" at Dickinson University (*5*) and Beichner's program, SCALE-UP, at North Carolina State University (see figure, this page) rely on a problem-based format in which students work collaboratively to make observations and to analyze experimental results. Students who learned physics in the SCALE-UP format at a wide range of institutions demonstrated better problem-solving ability, conceptual understanding, and success in subsequent courses compared with students who had learned in traditional, passive formats (*3*).

These results are neither isolated nor discipline-specific. At the University of Oregon, Udovic showed dramatic differences between students taught biology in a traditional lecture and those taught "Workshop Biology," a series of active, inquiry-based learning modules (*6*). Similarly impressive results were achieved by Wright in a comparison of active and passive learning strategies in chemistry (*7*). Others have taught cross-disciplinary problem-based courses that integrate across scientific disciplines, such as Trempy's, "The World According to Microbes," at Oregon State University, which integrates science, math, and engineering. The course serves science majors and nonmajors, and outcome assessments indicate high content retention and student satisfaction (*8*).



A physics classroom at North Carolina State University arranged for traditional lectures (inset) and redesigned for group problem-solving in the SCALE-UP program.

Students as Scientists

Scientists of all disciplines have developed inquiry-based labs that require students to develop hypotheses, design and conduct experiments, collect and interpret data, and write about their results (*9*). Many of these involve simple, inexpensive materials configured so that they invite students to ask their own questions. In addition to labs that have already been tested in the classroom, resources are available to help teachers convert cookbook labs into open-ended, inquiry-based labs (*3*). Some schools provide introductory-level students with the opportunity to conduct original research in a professor's research lab rather than take a tradition-

[1]Howard Hughes Medical Institute Professor, Department of Plant Pathology, University of Wisconsin–Madison; [2]Department of Plant Biology, Michigan State University; [3]Department of Physics, North Carolina State University; [4]Howard Hughes Medical Institute; [5]American Society for Microbiology; [6]National Research Council; [7]Dean of Natural Sciences, Hope College; [8]Department of Curriculum and Instruction, University of Wisconsin–Madison; [9]President, Princeton University; [10]Department of Molecular Cellular, and Developmental Biology, University of Colorado at Boulder. For complete addresses, see SOM.

*To whom correspondence should be addressed. E-mail: joh@plantpath.wisc.edu.

†Present address: Division of Educational Studies, Emory University, Atlanta, GA, 30322, USA.

al classroom lab course (*3*). These opportunities are challenging for instructors, but teach students the essence of investigation.

How Universities Can Promote Change

Research universities should provide leadership in the reform movement. Faculty and administrators should collaborate to overcome the barriers and to create an educational ethos that enables change. We need to inform scientists about education research and the instructional resources available to them so that they can make informed choices. We must admit that citing our most successful students as evidence that our teaching methods are effective is simply not scientific. Instead, we need to apply innovative metrics to assess the outcomes of teaching. Controlled experiments and meta-analyses that compare student achievement with various teaching strategies provide a compelling basis for pedagogical choices (*10*), but the need for assessment extends into every classroom. Many tools to assess learning are available (*3*). Assessments of long-term retention of knowledge, entrance into graduate school, and employment and professional success should be included as well.

Research universities should overhaul introductory science courses for both science majors and nonmajors using the principles of scientific teaching. The vision should originate from departments and be supported by deans and other academic administrators. Science departments should incorporate education about teaching and learning into graduate training programs and should integrate these initiatives into the educational environment and degree requirements. This could include, for example, development of peer-reviewed instructional materials based on the student's thesis research. Funding agencies have a responsibility to promote this strategy. National Institutes of Health and the National Science Foundation should, for example, require that graduate students supported on training grants acquire training in teaching methods, just as the NIH has required training in ethics.

Universities need to provide venues for experienced instructors to share best practices and effective teaching strategies. This will be facilitated, in part, by forming educational research groups within science departments. These groups might be nucleated by hiring tenure-track faculty who specialize in education, as 47 physics departments have done in the past 6 years. Other strategies include incorporating sessions about teaching into their seminar series, developing parallel series about teaching, or establishing instructional material "incubators" where researchers incorporate research results into teaching materials with guidance from experts in pedagogy. The incubators would provide an innovative mechanism to satisfy the "broader impact" mandate in research projects funded by the NSF.

Universities should place greater emphasis on awareness of new teaching methods, perhaps ear-marking a portion of research start-up packages to support attendance of incoming instructors at education workshops and meetings. Deans and department chairs at Michigan State University and University of Michigan have found that this strategy sends a message to all recruits that teaching is valued and it helps with recruiting faculty who are committed to teaching.

Distinguished researchers engaged in education reforms should exhort faculty, staff, and administrators to unite in education reform and should dispel the notion that excellence in teaching is incompatible with first-rate research. Federal and private funding agencies have contributed to this goal with programs such as the NSF's Distinguished Teaching Scholar Award and the Howard Hughes Medical Institute Professors Program, which demonstrate that esteemed researchers can also be innovative educators and bring prestige to teaching.

Universities and professional societies need to create more vehicles for educating faculty in effective teaching methods. For example, the National Academies Summer Institutes on Undergraduate Education, the Council of Graduate Schools' Preparing Future Faculty program, the American Society for Microbiology Conference for Undergraduate Educators, and Workshops for New Physics and Astronomy Faculty are steps toward this goal (*3*).

Finally, the reward system must be aligned with the need for reform. Tenure, sabbaticals, awards, teaching responsibilities, and administrative support should be used to reinforce those who are teaching with tested and successful methods, learning new methods, or introducing and analyzing new assessment tools. This approach has succeeded at the University of Wisconsin–Madison, which has rewritten tenure guidelines to emphasize teaching, granted sabbaticals based on teaching goals, and required departments to distribute at least 20% of merit-based salary raises based on teaching contributions (*3*).

If research universities marshal their collective will to reform science education, the impact could be far-reaching. We will send nonscience majors into society knowing how to ask and answer scientific questions and be capable of confronting issues that require analytical and scientific thinking. Our introductory courses will encourage more students to become scientists. Our science majors will engage in the process of science throughout their college years and will retain and apply the facts and concepts needed to be practicing scientists. Our faculty will be experimentalists in their teaching, bringing the rigor of the research lab to their classrooms and developing as teachers throughout their careers. Classrooms will be redesigned to encourage dialogue among students, and they will be filled with collaborating students and teachers. Students will see the allure of science and feel the thrill of discovery, and a greater diversity of intellects will be attracted to careers in science. The benefits will be an invigorated research enterprise fueled by a scientifically literate society.

SCIENTIFIC TEACHING EXAMPLES

Group problem-solving in lecture

www.ibscore.org/courses.htm

http://yucca.uoregon.edu/wb/index.html

http://mazur-www.harvard.edu/education/educationmenu.php

Problem-based learning

www.udel.edu/pbl/

www.microbelibrary.org

www.ncsu.edu/per/scaleup.html

http://webphysics.iupui.edu/jitt/jitt.html

Case studies

www.bioquest.org/lifelines/

http://ublib.buffalo.edu/libraries/projects/cases.case.html

http://brighamrad.harvard.edu/education/online/tcd/tcd.html

Inquiry-based labs

www.plantpath.wisc.edu/fac/joh/bbtl.htm

www.bioquest.org/

http://biology.dbs.umt.edu/biol101/default.htm

http://campus.murraystate.edu/academic/faculty/terry.derting/ccli/cclihomepage.html

Interactive computer learning

www.bioquest.org/

www.dnai.org

http://evangelion.mit.edu/802TEAL3D/

http://ctools.msu.edu/

References and Notes

1. AAAS, "Science for all Americans: A Project 2061 report on literacy goals in science, mathematics, and technology" (AAAS, Washington, DC, 1989).
2. AAAS, "The Liberal Art of Science" (AAAS, Washington, DC, 1990).
3. Supporting online material provides further references on this point.
4. D. Ebert-May *et al.*, *Bioscience* **47**, 601 (1997).
5. P. Laws, *Phys. Today* **44**, 24 (1991).
6. D. Udovic *et al.*, *Bioscience* **52**, 272 (2002).
7. J. C. Wright *et al.*, *J. Chem. Educ.* **75**,986 (1998).
8. J. Trempy *et al. Microbiol. Educ.* **3**, 26 (2002).
9. J. Handelsman *et al.*, *Biology Brought to Life: A Guide to Teaching Students How to Think Like Scientists* (McGraw-Hill, New York, 1997).
10. L. Springer *et al.*, *Rev. Educ. Res.* **69**, 21 (1999).

11. We thank C. Matta, C. Pfund, C. Pribbenow, A. Fagen, and J. Labov for comments and A. Wolf for contributions to the supplemental materials. Supported in part by the Howard Hughes Medical Institute.

Supporting Online Material

www.sciencemag.org/cgi/content/full/304/5670/521/DC1

Syllabus Magazine

Fri., June 4, 2004

Designing the Space: A Conversation with William J. Mitchell

Syllabus interviews William J. Mitchell, Dean of MIT's School of Architecture and Planning, about the design of technology-enhanced learning spaces. Active on both academic and research frontiers, Mitchell is also head of the Media Arts and Sciences Program at the MIT Media Lab

SYLLABUS: I'd like to explore your ideas about learning spaces for higher education—particularly any design changes that we'll see as we move forward with digital technology and new forms of communication that change the way we work and interact.
WILLIAM: I think there's a fundamental change going on right now. Over the last couple of decades there have been a lot of attempts to create high-tech educational spaces that have all sorts of technology built into them, like computers and video projectors—very complex, specialized facilities to support education in various ways. With the emergence of portable wireless technology, that's becoming less and less necessary. What we're starting to see is the emergence of spaces that are designed around human rather than technological needs. The spaces are pleasant and have a nice ambience to them, and you can just use your wireless laptop there or whatever you may need to use; but the space is not built around that because it doesn't have to be. That's a very interesting and exciting development.

S: Do you see collaboration being important to this change?
WJM: Certainly. Two types of collaboration, both synchronous and asynchronous. We're going to see, particularly as greater bandwidth becomes available, more and more use of video conferencing and other collaboration technologies, just as a matter of course, to integrate remote participants into discussions. Incidentally, I see that as much more of an import technology rather than an export technology. There was a lot of interest for quite a while in using video techniques to beam out lectures to wide audiences. I never found that very interesting. What's much more interesting is to bring a remote guest into a seminar, to bring resources into a classroom, to bring collaborators into a process in ways that hadn't been possible in the past. So that's one important part of it. Another important part is just being able to quickly access accumulated online material in context. One of the exciting things I find in seminars now is that students all come in with their wireless laptops, and in the course of the seminar they source in and pull into the conversation material that's relevant to the discussion at hand; and that can be very exciting.

S: And that's something that they could perhaps act on and change dynamically with the media that's available?
WJM: Exactly. All of this comes down to the point that the high-quality education, high-quality learning, face-to-face situations remain enormously important. The architectural settings to structure face-to-face interactions are very, very important indeed, and we can enrich those settings by overlaying them with digital technology.

S: You mentioned collaboration as an import technology with the idea of importing guest lecturers or experts to add to the experience that the students are having. Do you see this also as a way of democratizing education for students in general?
WJM: Yes, very much so. There are all kinds of complicated resource constraints that exist in the educational world that are not educationally beneficial. For example, I frequently teach design studios, and an important component of the design studio is to be able to have eminent architects to act as critics in the studio. The problem with that is that eminent architects have demanding practices that take them to the far corners of the world, and it's very difficult to get them physically in the studio at a particular moment. But if you can establish a remote connection, then it becomes possible to access a whole lot of people and make use of them in ways that simply have been infeasible in the past; so it absolutely expands the availability of human resources. Now I don't mean that as a substitute for the face-to-face; I mean that as an augmentation and a way of expanding the community.

S: How do you assess, when you have designed a space, the degree to which it will be strong or weak in supporting a particular educational process?
WJM: Really the only way you can do it is by observing it over time. It's something that is actually relatively rarely done just because of the way spaces get made. I think you tend to build them and put them into use and go on to the next thing, and there is not as much systematic evaluation as there should be. But I think one of the really important things is going to be, as new technologies keep moving into learning spaces, to do systematic evaluative work to figure out how they work—not just immediately, but over the long term, because architecture is a long-term thing.

S: Based on your experience, are there some case studies or other sorts of models or information that would suggest that particular kinds of spaces that are good and effective in supporting specific kinds of teaching? Could you point to some outstanding examples at various institutions?
WJM: Let me go back to the point that I began with. I think the spaces that work well over the long term are spaces that are built around very fundamental human needs like comfort, natural light, operable windows, good social ambience, nice sort of quality, views out the window. All these sorts of things are immensely important, and because people don't change very much, those things remain important. If you build space around specific technology, it very rapidly becomes obsolete because technology changes very quickly, and it's also the wrong priority. You really want to build space around the people rather than technology. We've seen it with computer technology. It's very interesting if you look back over several decades. It used to be that spaces for engagement with computers were very much dominated by the needs of the computers—specialized computer rooms and computer labs that had lighting conditions and air conditioning and so on—really those spaces were aimed towards the care and feeding of the computer, and people in the space just had to tolerate that. Then with personal computers, machines became more robust and more distributed into everyday working environments, but they were still at fixed locations and so you got stuck in your cubicle like Dilbert because you had to work with your machine. Now what's happening is, as technology becomes more portable and robust, and much less demanding in its environmental requirements, you don't build a space around a laptop; you just take a laptop to a space where you like to be.

S: Does that make the design of the spaces less challenging then?
WJM: No, it makes it actually more challenging, because the hardest thing is to make good humane spaces that people are excited to be in and stimulated by and that really support their work. It's fairly easy actually to design a space that meets very specific technical requirements and take that as a kind of excuse for not addressing other architectural issues. It's actually much tougher to focus on the fundamentals of architecture.

You really can't separate the issues of technology and the space that accommodates it at this point—you have to think of the two of them together.

S: If you were designing a teaching space today, would there be any design strategies that you would be especially enthusiastic about or any that you would be careful to avoid?
WJM: I've said the rigidity of building space around particularly technologies is certainly to be avoided. Then design strategies of as much flexibility as possible, as much accommodation of unexpected interactions and learning strategies as possible is really what you want to go for.

S: Is there an example of some of that flexibility that you could give me?
WJM: Let me give you an example from the design studios of MIT, which is pretty close to home, and I've been observing them very closely as they've evolved over the last few years. A few years back when we did some big renovations, we of course wired up the studio and provided networking at every student desk and power supply at every student desk, and that turned out to be an effective thing for its time. We put a lot of desktop computers into the studio. That worked pretty well, but it did have the disadvantage that if you wanted to look at student work you had to go to their computer. At the same time we also put in a little café right in the heart of the studio space with lots of café tables. What we see these days is a huge amount of the real learning action is actually taking place at the café tables rather than what's formally designated as workspace. Students sit there, have discussions; they have their portable technology with them so they're not disconnected when they go to those locations. So there's really been a very powerful shift from these kinds of highly specialized, fairly rigidly organized spaces to ad hoc grouping and much more flexible space use in spaces that you would not even have thought of as workspace before.

S: You say that the students seem to sort of gravitate towards that café space. Do you suppose that's because of the novelty or because that particular architect hit on something that works?
WJM: Well, it's a nice space to be, and people do tend to vote with their feet and gravitate to nice spaces if they don't have something constraining them to somewhere else. There's always the possibility of novelty effect, but that's why you have to look at spaces to see what happens over the long term.

S: In the facilities planning process at higher education institutions, who would ideally be included in the input? And in reality, who would normally be included? In other words, is there adequate and appropriate outreach to the ultimate users of these spaces?
WJM: It varies enormously from project to project and from institution to institution, but I think in general there's probably not enough direct engagement of the end users, particularly the student end users, in the process. It's challenging to structure a process that really accomplishes that. Also, you have to keep in mind that students are a relatively transient population and administrators and faculty members have to be able to deal with the situation over the long term. Nonetheless, I think real effort at much more serious engagement of the end users is always a good thing to do and something that is often neglected. The other thing I'd say is that at this point you really have to put architects and technology people together at the very beginning of the process. They have to really interact with each other so that each group understands what the other has to say. You really can't separate the issues of technology and the space that accommodates it at this point—you have to think of the two of them together.

S: Are academic institutions as a rule really all that much ahead of the curve in terms of anticipating future needs for instructional spaces?
WJM: No, I'd say they often tend to be very conservative and relatively unimaginative about these things.

S: What could they do better? What kind of advice could they take from you in terms of planning a little better?
WJM: I think you have to do experiments. We're in a period of extremely rapid change. It's easy enough to speculate about what might work, but there's a difference between speculation and evidence. I think is extremely important for academic institutions to do, wherever they can, lots of small-scale, adventurous experiments and really monitor the results and try to build up a reliable experience base rather than depend on preconceptions and prejudices.

Technology is going to become simultaneously more sophisticated, less obtrusive, and less visible...

S: Do you think campuses are in fact likely settings for these kinds of experiments? You'd think that the environment of education would be just absolutely the prime kind of place to experiment. Do you think that's the reality of it, or do you think campuses are going to continue to be conservative?
WJM: I must say, there has been a lot of experimentation at MIT in the last few years, and I think that's the right direction. We have learned a lot from the experimentation, and I think we're not alone in that. So yes, some campuses are beginning to experiment. But there's a factor that works against it—buildings are expensive. People want to minimize risk in construction projects and so may get organized in a very bureaucratic way. It's risk minimization rather than experimentation. That's in fact very shortsighted, and it really is important to be more adventurous and experimental.

S: Do you think wireless technologies are going to lessen the risk because you may not have to lay wired connections?
WJM: We're always going to have a combination of wired and wireless infrastructure. As you know, what wireless really does is to connect you to the nearest point of fixed infrastructure, and the fixed infrastructure usually takes it from there, so the wired infrastructure in fact doesn't go away. And wired infrastructure is always going to be more reliable. I think the need to accommodate wired infrastructure and to invest in it and to provide things like wiring closets and conduits and network drops and all of those sorts of things, that's not going to go away. Wireless is not a substitute for that. What it does is provide flexibility in space use on top of that, to remove some of the rigidities in space use, but I don't think it really reduces very much the need to invest in a basic wired infrastructure.

S: In general, are campus learning spaces now being designed more for multiple uses, and do you see an effort to serve a range of instructional formats, especially in the light of technology-enabled classrooms?
WJM: It's hard to generalize but yes, I think there's a growing realization that flexibility is important, that the new technologies allow much more flexibility, and yes, one ought to try to take advantage of that.

S: What changes will we see in learning spaces on campuses in the future? How will new forms of digital communication, interaction, and information delivery impact choices about the design of physical spaces?
WJM: Technology is going to become simultaneously more sophisticated, less obtrusive, and less visible. It's going to kind of disappear into the woodwork and into very unobtrusive portable devices. Actually I think what we're going to see is not a kind of scenario of very fancy specialized high-tech instructional spaces. Quite the opposite, we'll see spaces becoming more and more simple in a way, human-oriented. We'll see things like outdoor space, in the right climates anyway, much more utilized. If you can get wireless reception outside under a tree on a nice day, there isn't any great reason to be in the classroom anymore. I think it'll be the amazing disappearing technology basically, so it'll be omnipresent and supporting learning activities in a very flexible kind of way, but it won't be dominant and it won't be highly visible.

S: Do you see any particular technologies being really key? I know you're talking about technologies being so integrated into what we do that they tend to be invisible, but are there any that will in fact stand out that will be important to everyone?
WJM: I think it'll be a mix of things. Obviously Web-based, asynchronous, ubiquitous provision of learning materials is going to be one important thing, along with telecommunications for very flexibly establishing synchronous links. I think things like remotely operated sharable laboratories are going to be extremely interesting and a new way of thinking about resources. I think we'll see increasingly sophisticated audiovisual capabilities being used. I don't think that there are any great surprises in any of that, but I think we'll really see all of those things developing and merging and defining a pretty seamless broad-based electronic learning environment.

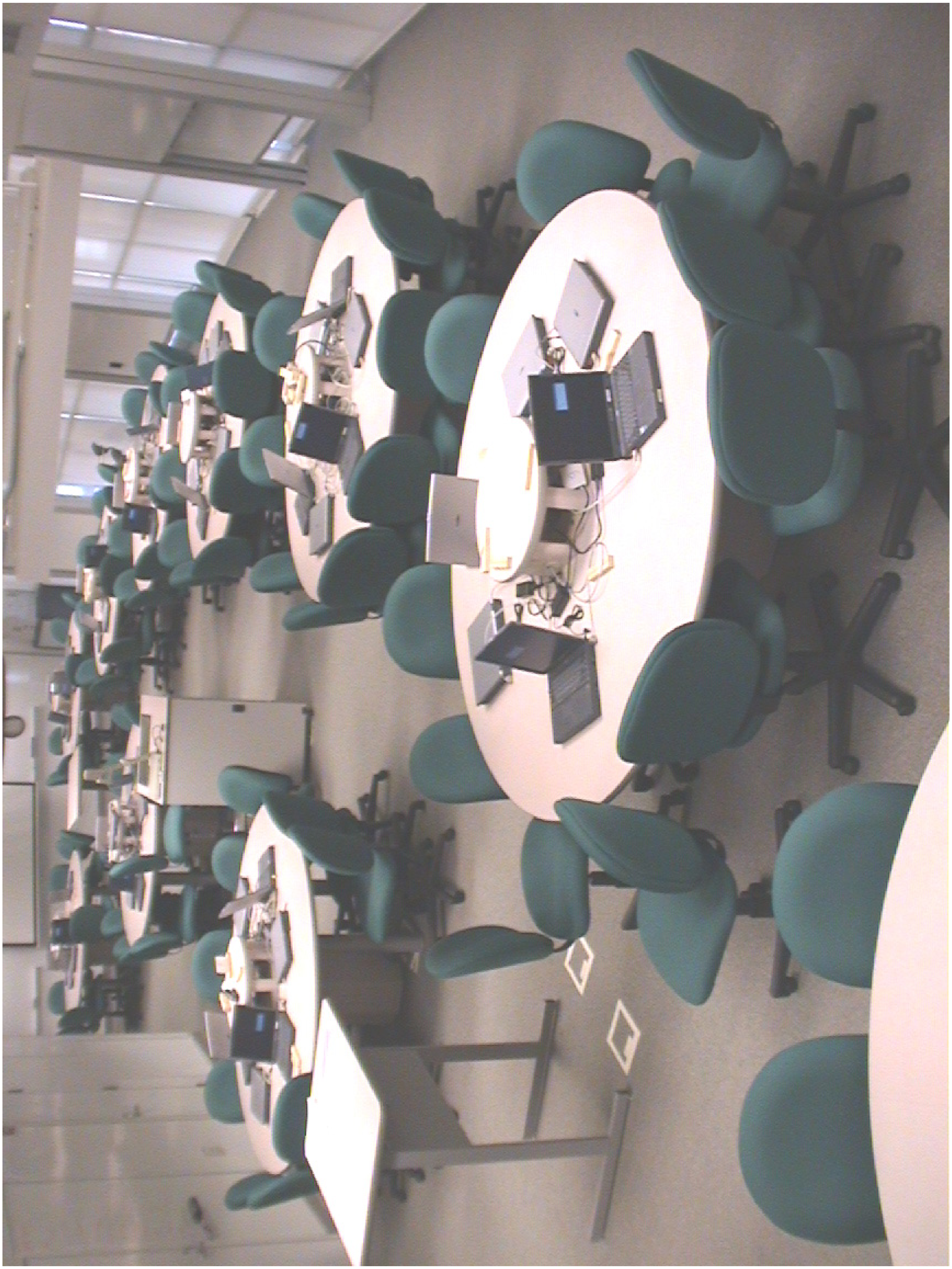
S: What would you say is the main thing to consider about the design of future instructional spaces?
WJM: The fundamental point is that learning technology shouldn't dominate. It should be unobtrusively and ubiquitously supportive and it should enable us to re-humanize learning spaces rather than make technologically oriented spaces. And one should allow an enormous amount of flexibility.

S: And is there a particular bit of wisdom about designing learning spaces that you always keep in mind?
WJM: The incredible unpredictability of the engagement of technology with culture is the lesson that comes out over and over again, which means you've got to be incredibly sensitive to the way technology and culture come together and ready to rethink assumptions and develop new experiments and transform the way you do things. You've got to be able to turn on a dime.

[Editor's note: William Mitchell will be the opening keynote at the Syllabus fall2003 conference in Cambridge, Mass., December 9, 2003.]

Selected classroom views from the powerpoint presentation at:

http://www.physics.ncsu.edu:8380/physics_ed/Room_Design_files/frame.htm




SCALE-UP

Science Supporting Online Material
POLICY FORUM: **Scientific Teaching**

Jo Handelsman,[1*] Diane Ebert-May,[3] Robert Beichner,[4] Peter Bruns,[5] Amy Chang,[6] Robert DeHaan,[7†] Jim Gentile,[8] Sarah Lauffer,[1] James Stewart,[2] Shirley M. Tilghman,[9] William B. Wood[10]

Contents

[1]Howard Hughes Medical Institute Professor, Department of Plant Pathology, [2]Department of Curriculum and Instruction, University of Wisconsin-Madison, Madison, WI 53706, USA. [3]Department of Plant Biology, Michigan State University, East Lansing, MI 48824, USA. [4]Department of Physics, North Carolina State University, Raleigh, NC, 27695, USA. [5]Howard Hughes Medical Institute, Chevy Chase, MD 20815, USA. [6]American Society for Microbiology, Washington, DC 20036, USA. [7]National Research Council, Washington, DC 20001, USA. [8]Dean of Natural Sciences, Hope College, Holland, MI 49423, USA. [9]President, Princeton University, Princeton, NJ 08544, USA. [10]Department of Molecular, Cellular, and Developmental (MCD) Biology, University of Colorado at Boulder, Boulder, CO 80309, USA.

*To whom correspondence should be addressed. E-mail: joh@plantpath.wisc.edu

†Present address: Division of Educational Studies, Emory University, Atlanta, GA 30322, USA.

REFERENCES DIRECTLY RELATED TO THE TEXT

Reports Calling For Education Reform

National Research Council, *Transforming Undergraduate Education in Science, Mathematics, Engineering, and Technology* (National Research Council, Committee on Undergraduate Science Education, National Academy Press, 1999).

National Research Council, National Science Foundation/National Research Council Convocation, National Academy of Sciences, Washington, DC, 9-11 April 1995.

J. D. Bransford, A. L. Brown, R. R. Cocking, Eds., *How People Learn: Brain, Mind, Experience, and School: Expanded edition* (National Academy Press, Washington, DC, 2000).

E. Boyer, "Scholarship reconsidered: Priorities of the professorate" (The Carnegie Foundation for the Advancement of Teaching, Stanford, CA, 1990).

Effective Teaching Methods to Reach Diverse Students

The Reinvention Center at Stony Brook, "Reinventing undergraduate education: Three years after the Boyer Report" [State University of New York (SUNY) Stony Brook, NY, 2003].

M. A. Fox, N. Hackerman, *Evaluating and Improving Undergraduate Teaching in Science and Technology, Engineering, and Mathematics* (Committee on Undergraduate Science Education, National Research Council, National Academy Press, 2003).

R. A. McCray, R. L. DeHaan, J. A. Schuck, Eds., *Improving Undergraduate Instruction in Science, Technology, Engineering, and Mathematics: Report of a Workshop Committee on Undergraduate STEM Instruction* (National Research Council, National Academy Press, 2003).

National Research Council, *BIO2010: Transforming Undergraduate Education for Future Research Biologists* (Committee on Undergraduate Biology Education to Prepare Research

Scientists for the 21st Century, Board on Life Sciences, National Research Council, National Academy Press, 2003).

A. F. Cabrera *et al.*, *Journal of College Student Development* **43**, 20-34 (2002).

A. F. Cabrera, A. Nora, E. M. Bernal, P. T. Terenzini, E. T. Pascarella, paper presented at the Annual Meeting of the Association for the Study of Higher Education, Miami, FL, 5-8 November 1998.

B. B. Alexander *et al.*, *Journal of Women and Minorities in Science and Engineering* **3**, 145 (1997).

R. E. Fullilove, P. U. Treisman, *Journal of Negro Education* **59**, 463-478 (1990).

L. S. Shulman, *The Wisdom of Practice: Essays on Teaching, Learning, and Learning to Teach.* (Jossey-Bass, San Francisco, 2004).

Why Faculty Resist Change

E. Boyer, *Scholarship Reconsidered: Priorities of the Professorate* (The Carnegie Foundation for the Advancement of Teaching, Stanford, CA,1990).

L. S. Shulman, *Teaching as Community Property: Essays on Higher Education* (Jossey-Bass, San Francisco, 2004).

T. R. Cech, *Science* **299**, 165 (2003).

Quantitative Evaluation of Active Learning

D. Ebert-May, C. Brewer, S. Allred, *Bioscience* **47**, 601-608 (1997).

R. R. Hake, *American Journal of Physics* **66**, 64 (1998).

D. Udovic, D. Morris, A. Dickman, J. Postlethwait, P. Wetherwax, *Bioscience* **52**, 272–281 (2002).

J. C. Wright *et al.*, *Journal of Chemical Education* **75**, 986 (1998).

Supplements to Traditional Lectures

D. Ebert-May, C. Brewer, S. Allred, Innovation in large lectures—Teaching for active learning. *Bioscience* **47**, 601-607 (1997).

Wilbert J. McKeachie, *McKeachie's Teaching Tips: Strategies, Research, and Theory for College and University Teachers*. (Houghton Mifflin, Boston, 11th ed., 2002).

P. J. Pukkila, Introducing student inquiry in large introductory genetics classes. *Genetics* **166**:11-18 (2004).

http://webphysics.iupui.edu/jitt/jitt.html ("Just in time teaching" computer-based course management)

Replacing Lectures

K. Powell, *Nature* **425**, 234-236 (2003).

www.ncsu.edu/per/TestInfo.html

www.nscu.edu/per/SCALEUP/Classrooms.html

P. Laws, *Physics Today* **44**,24-31 (1991)

Inquiry-Based Labs

J. Handelsman, B. J. Houser, H. Kriegel, *Biology Brought to Life: A Guide to Teaching Students How to Think Like Scientists.* (McGraw-Hill, New York, 1997).

www.wisc.edu/cbe/wibc/index.html.

Experiments and Data about Teaching Methods

R. R. Hake, *Conservation Ecology* 5, 28 (2002).

D. Ebert-May, J. Batzli, H. Lim, *Bioscience* 53, 1221-1228 (2003).

Assessment Tools

M. E. Huba, J. E. Freed, *Learner-Centered Assessment on College Campuses: Shifting the Focus from Teaching to Learning* (Allyn & Bacon, New York, 1999).

T. A. Angelo, K. P. Cross, Eds., *Classroom Assessment Techniques: A Handbook for College Teachers* (Jossey-Bass, San Francisco, 1994).

National Science Foundation "Broader Impact"

www.nsf.gov/pubs/2002/od127/imptnot.pdf

www.plantpath.wisc.edu/fac/joh/incub.htm

Workshops on Teaching for Science Educators

W. Wood, J. Gentile, *Cell Biology Education* 2, 207-209 (2003).

www.preparing-faculty.org

http://www.academiessummerinstitute.org/

Changes in Reward System to Reinforce Teaching

http://wiscinfo.doit.wisc.edu/secfac/divcomm/biological/TenureGuidelines.pdf

www.ohr.wisc.edu/grants/facsabb99-2000.html

Table S1. Examples of Scientific Teaching Methods.

Method	References and Websites
Group brainstorming or problem solving in lecture	(*S1*,*S2*, *S3*) ConcepTests http://mazur-www.harvard.edu/education/educationmenu.php Integrated Biological Science Courses Organized around Research Experience (IBSCORE) www.ibscore.org/courses.htm Workshop Biology http://yucca.uoregon.edu/wb/index.html
Problem-based learning	(*S4*, *S5*, *S6*) Problem-Based Learning www.udel.edu/pbl/ Case Studies in Problem-Based Learning www.microbelibrary.org/newsletter/nltrs00.pdf Student-Centered Activities for Large Enrollment Undergraduate Program www.ncsu.edu/per/scaleup.html Just-in-time Teaching http://webphysics.iupui.edu/jitt/jitt.html
Case studies	National Center for Case Study Teaching in Science http://ublib.buffalo.edu/libraries/projects/cases/case.html LifeLines Online www.bioquest.org/lifelines/ Harvard Medical School Case Studies http://brighamrad.harvard.edu/education/online/tcd/tcd.html
Inquiry-based labs	(*S1*, *S2*, *S7*) Biology Brought to Life: A Guide to Teaching Students to Think Like Scientists www.plantpath.wisc.edu/fac/joh/bbtl.htm The BioQUEST Curriculum Consortium www.bioquest.org/ Introduction to Biological Inquiry and Analysis http://campus.murraystate.edu/academic/faculty/terry.derting/ccli/cclihomepage.html Project IBSCORE, University of Montana http://biology.dbs.umt.edu/biol101/default.htm
Interactive computer learning	The BioQUEST Curriculum Consortium www.bioquest.org/ DNA Interactive www.dnai.org Technology Enabled Active Learning (TEAL) Studio Project http://evangelion.mit.edu/802TEAL3D/ http://ctools.msu.edu/

Table References

S1. D. Ebert-May, C. Brewer, S. Allred, *Bioscience* **47**, 601-608 (October 1997).

S2. J. Handelsman, B. J. Houser, H. Kriegel, *Biology Brought to Life: A Guide to Teaching Students How to Think Like Scientists* (McGraw-Hill, 1997).

S3. C. Dreifus, "A conversation with Shirley Tilghman; Career that grew from an embryo," *New York Times*, 8 July 2003, F2.

S4. J. Trempy, M. Skinner, W. Siebold, *Microbiology Education* **3**, 26-36 (2002).

S5. W. Wood, J. Gentile, *Cell Biology Education* **2**, 207-209 (2003).

S6. www.preparing-faculty.org.

S7. D. Udovic, D. Morris, A. Dickman, J. Postlethwait, P. Wetherwax, *Bioscience* **52**, 272–281.

Table S2. Teaching Materials and Online Resources.

Teaching Materials and Online Resources by Subject Area	URL	Type of Material or Resource	Description
Biology			
Biology Brought to Life: A Guide to Teaching Students to Think Like Scientists	**www.plantpath.wisc.edu/fac/joh/bbtl.htm**	Classroom activities, inquiry-based labs	These online book chapters offer ideas for cooperative exercises and inquiry-based labs that can be integrated into biology courses. Chapters include how-to instructions, rationale, and full-length labs with teacher guides.
BioQUEST Curriculum Consortium	http://bioquest.org	Multimedia	This collection of computer tools allows students to *pose* their own problems, solve these *problems* through investigations of their own design, and *persuade* their peers that their conclusions are correct: the BioQUEST "3 P's."
Concept mapping tool (CTOOLS)	www.ctools.msu.edu	Multimedia (assessment)	This Web-based concept mapping tool provides students and faculty with a visual representation of principles and relationships among concepts. It includes computer-based scoring capabilities.
DNA from the Beginning	www.dnaftb.org	Multimedia	This technology-rich Web site includes concept lists, graphics, animations, and more for teaching about DNA.
DNA Interactive	www.dnai.org	Multimedia	This interactive Web site teaches students about the structure, function, and history of DNA through fascinating animations and problem-solving scenarios.
Frog Deformities	www.first2.org/resources/inquiry_activities/frog_activity.htm	Online activity	In this activity, students engage in experimental design and data analysis to understand complex interactions between environmental variables and frog populations.
Genetics Education Center	www.kumc.edu/gec/	Online resources	This Web site is designed for educators who are interested in human genetics and the human genome project. It includes links to lesson plans, the human genome project, networks, and programs.
Genome Consortium for Active Teaching (GCAT)	www.bio.davidson.edu/Biology/GCAT/GCAT.html	Online activities	This online resource brings functional genomic methods into undergraduate curricula through student research and is a collection of information and data for teaching genomics.
Guppy Simulation	www.first2.org/resources/inquiry_activities/guppy_activity.htm	Online activity	In this computer-based activity, students build understanding of natural selection, sexual selection, and fitness.
Integrated Biological Science Courses Organized around Research Experience (IBSCORE)	www.ibscore.org/courses.htm	Course materials	This course uses a teamwork approach that involves all students in a classroom, promotes critical thinking, and teaches communication skills in science.

Introduction to Biological Inquiry and Analysis	http://campus.murraystate.edu/academic/faculty/terry.derting/ccli/cclihomepage.html	Course materials	In this course, students learn basic concepts in biology and engage in science as a process of active inquiry that serves as a framework for further study. The Web site includes 10 in-class assignments and an introduction to basic statistics.
LifeLines	http://bioquest.org/lifelines	Online activities (case-based learning)	This collection of online cases is designed by community college teachers and is based on real-life scenarios.
Microbes Count!	http://bioquest.org/microbescount	Multimedia	This collection of multimedia resources, simulations, and tools is an interactive, open-ended forum for learning about microbiology.
MicrobeLibrary	www.microbelibrary.org	Online activities	This searchable portal provides a peer-reviewed, Web-based collection of resources about the microbial world, including visual images and animations, curriculum activities for both classroom and laboratory, and articles. The collection is linked directly to a recommended core curriculum for introductory microbiology education.
Problem-based Learning	www.udel.edu/pbl/	Online activities (problem-based learning)	This collection of problem-based learning (PBL) activities challenges students to work cooperatively in groups to solve real-world problems.
Teaching Case Database	http://brighamrad.harvard.edu/education/online/tcd/tcd.html	Online activities (case-based learning)	This collection of online cases is designed for medical students at Harvard Medical School.
Teams and Streams	http://surf.to/teamstreams/	Inquiry-based labs	These labs provide a framework for teachers to move from traditional, confirmatory approaches to student-driven inquiry. Students post results on Web sites of their own design.
Workshop Biology	http://yucca.uoregon.edu/wb/index.html	Course materials, resources	This program is designed to improve biology teaching for non-biology majors. The Web site includes many resources, including a downloadable, 230-page curriculum development handbook, and more.
Chemistry			
ChemLinks	http://chemlinks.beloit.edu/	Multimedia	This collection of modules is designed to enhance the appreciation and learning of chemistry.
Peer-led Team Learning	www.sci.ccny.cuny.edu/~chemwksp/	Classroom activities	This Web site outlines strategies for teaching in a “workshop format” where teams of students are guided by a peer leader. This model provides an active learning experience for students, creates a leadership role for undergraduates, and engages faculty in a creative new dimension of instruction.

General Science			
Calibrated Peer Review	http://cpr.molsci.ucla.edu/	Online activities	This Web-based program provides resources for implementing frequent writing assignments in large classes with limited instructional resources.
Just-in-time Teaching (JITT)	http://webphysics.iupui.edu/jitt/jitt.html	Multimedia	This program provides teacher resources and computer-based activities that use technology and problem-solving skills to improve learning. Students complete Web-based assignments prior to class so the instructor can revise teaching "just in time."
National Center for Case Study Teaching in Science	http://ublib.buffalo.edu/libraries/projects/cases/case.html	Online activities	This Web site offers instructions and rationale for case-based learning, and includes a collection of online cases for many science disciplines.
National Institute for Science Education	www.wcer.wisc.edu/nise/	Online activities and assessment resources	This institute provides literature about teaching and learning, strategies for improving science education, and assessment guides for teachers and students.
Student-Centered Activities for Large Enrollment Undergraduate Programs (SCALE-UP)	http://scaleup.ncsu.edu/	Multimedia	This program offers pedagogical methods and classroom management techniques that include hands-on activities, simulations, questions, problem-solving scenarios, and hypothesis-driven labs.
Physics			
Activity-based Physics	http://physics.dickinson.edu/~abp_web/abp_homepage.html	Multimedia	This suite of textbooks, computer software, and other materials is based on physics education research. The activity-based materials help students learn difficult physics concepts.
Cooperative Group Problem Solving in Physics	http://groups.physics.umn.edu/physed/Research/CGPS/CGPSintro.htm	Teaching strategies and inquiry-based labs	This Web site contains information about how to implement cooperative group problem-solving into physics classrooms, as well as a downloadable lab manual.
Peer Instruction	http://mazur-www.harvard.edu/education/educationmenu.php	Classroom activities	This article suggests strategies that can be used to embellish lectures with activities where students teach each other, as well as rationale for these activities, and ConcepTest examples.
Physlets	http://webphysics.davidson.edu/Applets/Applets.html	Multimedia	This Web site and companion book contain physics problems with animated physics applets.
Technology Enabled Active Learning (TEAL) Studio Project	http://evangelion.mit.edu/802TEAL3D/	Multimedia	These computer simulations are designed to help freshmen develop intuition about and conceptual models of physical phenomena. The tools are based on an active-learning approach that merges lecture, lab, and discussion sections. Course notes, graphics, and animations are available.

General Teaching			
The Active Learning Site	www.active-learning-site.com/bib1.htm	Bibliography	This comprehensive bibliography lists articles about active learning.
Center for Science and Math Teaching	http://ase.tufts.edu/csmt/	Teaching strategies and resources	This Web site provides references and software (microcomputer-based laboratory tools) that enable students to learn physical concepts.
Center for Teaching Effectiveness	www.utexas.edu/academic/cte/resources/teach.html	Teaching strategies and resources	This online, how-to guide offers advice for all aspects of developing a university course, including teaching strategies, references, media aids, advice about diversity, and more.
HHMI New Generation Program	http://newgenerationprogram.wisc.edu	Teaching strategies and resources	This program provides strategies for teaching graduate students and postdocs to teach and mentor, including syllabi, evaluation tools, and peer-review information.
KnowledgeRoom Networks	www.knowledgeroom.com/	Multimedia tool	This innovative Web site enhances classroom education by providing user-friendly, virtual space where students can research, explore, collaborate, and communicate.
Online Databases			
Biology Education Online (BEoN)	www.accessexcellence.org/LC/BEoN/		This is an online, peer-reviewed journal for K-16 educators in the life sciences.
BioScienceEdNetwork (BEN)	www.biosciednet.org		This digital, searchable database of biology instructional materials and resources is designed to help undergraduate educators to improve their teaching through resources, collaboration, and network building.
The Learning Matrix	http://thelearningmatrix.enc.org/		This site provides access to peer-reviewed digital resources that promote inquiry- and problem-based learning in college mathematics, science, and technology classes. Instructions are included for posting new instructional materials.
Multimedia Educational Resource for Learning and Online Teaching (MERLOT)	www.merlot.org		This electronic database is a “free and open resource” of instructional materials, including peer reviews and comments. Instructions are included for posting new instructional materials.
National Science Digital Library	http://nsdl.org/		This digital library contains resource collections and services for science, technology, engineering and mathematics education.
Science, Math, Engineering, and Technology Education	www.smete.org/		This digital library offers access to online teaching and learning materials for students and teachers.
Professional Society Web sites and other Publications			
American Association for the Advancement of Science	www.aaas.org/education/		Education homepage

American Association of Physics Teachers	www.aapt.org		Journals: *Physics Teacher* and *American Journal of Physics*
American Chemical Society	www.chemistry.org/portal/a/c/s/1/educatorsandstudents.html http://jchemed.chem.wisc.edu/		Education homepage Journal: *Journal of Chemistry Education*
American Physical Society	www.aps.org/educ/		Education homepage
American Physiological Society	www.the-aps.org/education/edu_ugrad.html		Education homepage
American Society for Cell Biology	www.ascb.org www.cellbioed.org		Online Journal: *Cell Biology Education*
American Society for Microbiology	www.asm.org/education		Journals: *Microbiology Education* and *ASM News*
Association of College and University Biology Educators	www.acube.org		Journal: *Bioscene: Journal of College Biology Teaching*
Ecological Society of America	www.esa.org/education/		Education homepage
National Association of Biology Teachers	www.nabt.org		Journal: *American Biology Teacher*
National Association for Research in Science Teaching	www2.educ.sfu.ca/narstsite/		Journal: *Journal of Research in Science Teaching*
National Science Teachers Association	www.nsta.org		Journal: *Journal of College Science Teaching*
Teaching Professor	www.teachingprofessor.com		Newsletter about teaching methods and research

FURTHER READING ABOUT SCIENTIFIC TEACHING

Philosophy & Paradigm Shift

Boyer, E. L. 1990. *Scholarship Reconsidered: Priorities of the Professoriate*. (The Carnegie Foundation for the Advancement of Teaching, Princeton, NJ).

Gaff, J. G., and L. M. Lambert. 1996. Socializing future faculty to the values of undergraduate education. *Change* (July/August): 38-45.

Johnson, D. W., Johnson, R. T., Roger, T., and Smith, K. A. 1991. "Cooperative learning: Increasing college faculty instructional productivity. ASHE-ERIC Higher Education Report No.4." (The George Washington University, School of Education and Human Development, Washington, DC).

McCauley, R. N. 1984. Knowledge, mind, and facts, in *Rejuvenating Introductory Courses*, K. I. Spear, Ed. (Jossey-Bass, San Francisco), pp. 53-62.

Palmer, P. J. 1998. *The Courage to Teach: Exploring the Inner Landscape of a Teacher's Life*. (Jossey-Bass, San Francisco).

Shulman, L. S. 1993. Teaching as a community property. *Change* (November/December): 6-7.

Shulman, L. S. 1995. Faculty hiring: A pivotal opportunity to foster a culture of teaching. *American Association for Higher Education Bulletin* (May): 6-10.

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

Theories

Johnson, D. W., and R. T. Johnson. 1991. *Learning Together and Alone*. (Prentice Hall, Englewood Cliffs, NJ).

King, P. M., and K. S. Kitchener. 1994. *Developing Reflective Judgment: Understanding and Promoting Intellectual Growth and Critical Thinking in Adolescents and Adults*. (Jossey-Bass, San Francisco).

Mintzes, J. J., and J. H. Wandersee. 1998. Reform and innovation in science teaching: A human constructivist view, in *Teaching Science for Understanding: A Human Constructivist View*. (Academic Press, San Diego), pp. 29-58.

Ramsden, P. 1992. *Learning to Teach in Higher Education*. (Routledge, London).

Shulman, L. S. 1987. Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review* **57**: 1-22.

Strike, K. A., and G. J. Posner. 1992. A revisionist theory of conceptual change, in *Philosophy of Science, Cognitive Psychology, and Educational Theory and Practice*, R. A. Duschl and R. J. Hamilton, Eds.. (SUNY Press, Albany, NY), pp. 147-176.

Tobin, K., and D. Tippins. 1993. Constructivism as a reference for teaching and learning, in *The Practice of Constructivism in Science Education*, K. Tobin, Ed. (AAAS Press, Washington, DC), pp. 3-21.

Principles & Methods

Allen, D. and K. Tanner. 2003. Learning content in context—Problem-based learning. *Cell Biology Education* **2**: 73-81.

Allen, D. and K. Tanner. 2003. Mapping the journey—Concept maps as signposts of developing knowledge structures. *Cell Biology Education* **2**, 133-136.

Angelo, T. A. 1993. A “teacher's dozen”: Fourteen general, research-based principles for improving higher learning in our classrooms. *AAHE Bulletin* (April): 3-13.

Angelo, T. A., and K. P. Cross. 1993. *Classroom Assessment Techniques: A Handbook for College Teachers*. (Jossey-Bass, San Francisco).

Barr, R. B., and J. Tagg. 1995. From teaching to learning: A new paradigm for undergraduate education. *Change* **27**(6): 12-25.

Beichner, R. 1996. Impact of video motion analysis on kinematics graph interpretation skills. *American Journal of Physics* **64**(10): 1272-1278.

Bonwell, C. C., and J. A. Eison. 1991. *Active Learning: Creating Excitement in the Classroom*. (The George Washington University, School of Education and Human Development, Washington, DC).

Brookfield, S. D. 1990. *The Skillful Teacher*. (Jossey-Bass, San Francisco).

Brookfield, S. D. 1995. *Becoming a Critically Reflective Teacher*. (Jossey-Bass, San Francisco).

Cerbin, W. 1995. Connecting assessment of learning to improvement of teaching through the course portfolio. *Assessment Update* **7**(1): 4-6.

Committee on Undergraduate Science Education 1997. *Science Teaching Reconsidered: A Handbook*. (National Academy Press, Washington, DC.

Ebert-May, D., C. Brewer, and S. Allred. 1997. Innovation in large lectures—Teaching for active learning. *Bioscience* **47**: 601-607.

Finkel, D. L., and G. S. Monk. 1983. Teachers and learning groups: Dissolution of the Atlas complex, in *Learning in Groups*, C. Bouton, Y. Russell, and Y. Garth, Eds. (Jossey-Bass, San Francisco), pp. 83-97.

Gmelch, W. H. 1996. It's about time. *Academe* (September/October): 22-26.

Handelsman, J., B. Houser, and H. Kriegel. 1996. *Biology brought to life: A Guide to Teaching Students to Think Like Scientists.* (McGraw-Hill, New York, NY).

Heller, P., and M. Hollabaugh. 1992. Teaching problem solving through cooperative grouping. Part 2: Designing problems and structuring groups. *American Journal of Physics* **60**: 637-644.

Hill, W. F. 1969. *Learning Through Discussion*. (Sage Publication, Beverly Hills, CA).

Jacobs, L. C., and C. L. Chase. 1992. in *Developing and Using Tests Effectively: A Guide for Faculty*. (Jossey-Bass, San Francisco), pp. 18-19.

King, A. 1994. Inquiry as a tool in critical thinking, in *Changing College Classrooms*, D. F. Halpern, Ed. (Jossey-Bass, San Francisco), pp. 13-38.

Matejka, K., and L. B. Kurke. 1994. Designing a great syllabus. *College Teaching* **42**: 115-117.

McDermott, L. C. and E. F. Redish. 1999. Resource Letter: PER-1: Physics education research. *American Journal of Physics* **67**(9): 755-767.

McKeachie, W. J., N. Chism, R. Menges, M. Svinicki, and C. E. Weinstein. 1994. *Teaching Tips: Strategies, Research, and Theory for College and University Teachers*. (Heath, Lexington, MA).

Redish, E. F., J. M. Saul, and R. N. Steinberg. 1997. On the effectiveness of active-engagement microcomputer-based laboratories. *American Journal of Physics* **65**(1): 45-54.

Reed, C. G. 1989. What makes a good teacher? *Bioscience* **39**: 555-557.

Shodell, M. 1995. The question-driven classroom. *The American Biology Teacher* **57**: 278-281.

Sternberg, R. J., L. Okagaki, and A. S. Jackson. 1990. Practical intelligence for success in school. *Educational Leadership* **48**: 35-39.

Sundberg, M. D., and G. J. Moncada. 1994. Creating effective investigative laboratories for undergraduates. *Bioscience* **44**: 698-704.

Sundberg, M. D., M. L. Dini, and E. Li. 1994. Decreasing course content improves student comprehension of science and attitudes towards science in freshman biology. *Journal of Research in Science Teaching* **31**: 679-693.

Tobias, S., and J. Raphael. 1997a. *The Hidden Curriculum—Faculty-Made Test in Science*, Part 1: *Lower-Division Courses*. (Plenum, New York).

Tobias, S., and J. Raphael. 1997b. *The Hidden Curriculum—Faculty-Made Test in Science*, Part 2: *Upper-Division Courses*. (Plenum, New York).

Trombulak, S. C. 1995. Merging inquiry-based learning with near-peer teaching. *Bioscience* **45**: 412-416.

Tyser, R. W., and W. J. Cerbin. 1991. Critical thinking exercises for introductory biology courses. *Bioscience* **41**: 41-46.

Van Rooyen, H. G. 1994. The quest for optimum clarity of presentation: Context creation as teaching skill. *The American Biology Teacher* **56**: 146-150.

Wood, W. B., J. H. Wilson, R. M. Benbow, and L. E. Hood. 1981. *Biochemistry: A Problems Approach*. (Benjamin/Cummings, Menlo Park, CA).

Textbooks

Ellis, A. B., M. J. Geselbracht., B. J. Johnson, G. C. Lisensky, and W. R. Robinson. 1993. *Teaching General Chemistry: A Materials Science Companion*. (American Chemical Society, Washington, DC).

Enger, E. D., and F. C. Ross. 2000. *Concepts in Biology*. (McGraw-Hill, Boston, MA).

Minkoff, E. C., and P. J. Baker. 2001. *Biology Today: An Issues Approach*. (Garland, New York, NY).

Postlethwait, J. H., and J. L. Hopson. 2003. *Explore Life*. (Brooks/Cole-Thomson Learning, Pacific Grove, CA).

Schwartz, A. T., D. M. Bunce, R. G. Silberman, C. L. Stanitski, W. J. Stratton, and A. P. Zipp. 1997. *Chemistry in Context: Applying Chemistry to Society*. (Brown, Dubuque, IA).

Other Compilations of Active Learning References

www.active-learning-site.com/bib1.htm

www.ncsu.edu/felder-public/