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Vision and Change in Undergraduate Biology Education: A Call to Action Presentation to Faculty for Undergraduate Neuroscience, July 2011

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The biology of the 21st century requires a revolution in teaching that corresponds to the revolution that the discipline experienced in the last decades of the 20th century. Consensus is not a tradition in the many disparate subdisciplines that constitute modern biology, but the demands of effective instruction prompted an unprecedented series of conversations among all the stakeholders of undergraduate biology education. A culminating conference resulted in consensus on both the form and substance of modern biology courses: They should emphasize repeatedly five core concepts and six core competencies in a student-centered, inquiry-driven pedagogy modeled on a number of "best practices." The conference report can serve as a guide to individual faculty members, departments, and institutions seeking to reform their teaching practices.

Key words: undergraduate education; curriculum reform; scientific teaching; assessment; student-centered learning; professional development; backwards design; professional societies

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Vision and Change in Undergraduate Biology Education: A Call to Action is a publication available in print or on the web that represents the culmination of an extended process of conversation among all the stakeholders who seek excellence in the educational experience of undergraduates. The process was marked by a remarkable degree of agreement despite the various cultural differences that characterize faculty, students, and administrators; biochemists, anatomists, ecologists, and botanists; those at community colleges, research-intensive universities, comprehensive state universities, and liberal arts colleges; and representatives of funding agencies and of professional societies. In what follows I set the stage for the conversations leading to this document. Then I take the reader through the meat of the document. Finally, I sum up with some ideas for how the National Science Foundation (NSF) can foster the transformation of undergraduate education in biology that the document demands.

Curricular reform in biology shares many features with other disciplines in science, mathematics, and engineering: it must examine the current system, identify problems, develop and test strategies to solve them, and then persuade others to adopt the improved strategies. Biology is unique among the scientific disciplines, however. Where the American Chemical Society speaks for all of chemistry, the American Physics Association for all of physics, and the American Mathematical Society for all of mathematics, biologists identify most closely with their subdiscipline, be it cell biology, ecology, botany, physiology, or neuroscience. Likewise professional societies in biology are multiple and diverse. No single venue serves as a forum for curricular innovations with emerging, authoritative consensus. No single voice speaks on subjects such as quality of curricula, recommended instructional strategies, or standards for preparation of students.

All the more remarkable, then, is the recent development of a consensus among all biologists that at the undergraduate level new instructional practices need to be widely implemented. At their heart these practices focus not so much on disconnected facts but rather the process by which they come to be accepted, the work of the scientist in coming to understand a problem. The biology of the 21st century should not be taught by methods of the 20th century (which in many cases have not changed since the days of the medieval European university, where limited access to information made lecturing the desirable method for sharing knowledge and understanding). With the advent of new means of communication and ever enlarging bodies of information, it no longer makes sense to try to “cover” all available information, even in specialty courses. Rather, we serve our students best if we show them how to use the tools of the trade, including but not limited to textbooks. Interestingly enough, such a strategy also serves many students best: even students who memorize easily are found not to retain knowledge gained passively. The scholarship of teaching and learning, not well understood by most practitioners of science instruction, has demonstrated that learning is improved if students play an active role in its construction, whether in discussion or in laboratory or field observation and experimentation.

A thread can be built that connects writings on science education from as early as the publication in 1961 of Bruner’s "The Act of Discovery." Key landmarks since then are Novak and Gowin, *Learning How to Learn* in 1984, Rutherford and Ahlgren's *Science for All Americans,* a part of AAAS's Project 2061 in 1989, the series from Project Kaleidoscope beginning with “What Works: Building Natural Science Communities” in 1991, and since 1996 a series of influential reports from the National Research Council. Each in turn was widely praised for the problems the reports identified and suggestions for solutions they provided. But aside from a few pioneering faculty who took seriously the need to change their instructional practice, very little reform has been accomplished, particularly in the large research universities. Even in small liberal arts colleges, where a point of pride is the close mentoring of students by faculty, much of science instruction remains lecture-based with evaluation targeted at learned facts, and a relatively low degree of cognitive mastery.

It is in this context that the movement that has come to be called “Vision and Change” emerged. It began in 2006 with conversations at the NSF between staff in two directorates: Biology (BIO) and Education and Human Resources (EHR), particularly the Division of Undergraduate Education. They realized that systemic change would be greatly facilitated if biologists could identify a shared “vision” of the goal for undergraduate biology education. It is important to point out that even within NSF it is less common than it might be for different directorates to collaborate as intensely as the Vision and Change process demanded. Still more remarkable is that NSF reached out to the National Institutes of Health and the Howard Hughes Medical Institute, major funders of research in the biological sciences and also interested in biology education, to contribute to the process. With these resources and organizational assistance from the American Association for the Advancement of Science, a steering group planned a series of regional conversations held in 2007. In groups of about 20, representatives of all the stakeholders in undergraduate biology education came together in regional meetings across the country to discuss the goals and the resolutions that it would take to reach them. All kinds of colleges and universities were represented, all the sub-disciplines of biology, faculty at all levels and with varying expertise, administrators, funding agencies, and professional societies. Importantly, students also participated, and their voice was unusually influential.

From these conversations, focus areas were identified to develop further. This occurred at a major national conference held in Washington, DC in 2009. Remarkably, the work of the breakout sessions during this conference resulted in unusual consensus both as to the nature of the problem and directions to take towards its solution. This result, capturing both the substance and the tone of the conference, appeared in print in February, 2011, and already we are seeing evidence of its widespread influence. Demand for the print version exceeded the first print run, and a total of 8000 hard copies have been distributed, not to mention the many visitors to the web site, www.visionandchange.org, from which the file can be downloaded.

What follows is a summary of my discussion of the report, as presented at the Faculty for Undergraduate Neuroscience (FUN) meeting in Claremont, California, July, 2011. The report is organized as a series of Chapters. The first identifies a key goal as "Undergraduate Biology Education for All Students." Using the mantra that "the biology we teach should reflect the biology we practice," faculty are urged to offer introductory students of all majors access to the new ways of handling information, the situation of scientific questions at interdisciplinary boundaries, and the many real-world applications that make the science come to life. Only in this way will students be prepared to play their part in societal decisions that involve scientific ideas and processes.

The second chapter, "Cultivating Biological Literacy," offers a framework for biology education that identifies five core concepts and six core competencies that should permeate all biology instruction. Whether encountered in the one course that a student of humanities takes or repeatedly in the many courses of the biology major, these concepts and competencies form the foundation of modern biological sciences.

The third chapter, "Student-Centered Undergraduate Biology Education," identifies evidence-based innovations in pedagogy that improve student learning. The implementation of those innovations requires what is known as "scientific teaching" (Handelsman et al., 2004), that is, to hold our teaching to the same standards of evidence of success that we routinely apply in our scientific research. Clearly, such an approach requires new ways to assess progress toward learning goals, an area unfamiliar to most practicing biologists. Fortunately, the chapter includes a table summarizing 16 examples of instructional methods and assessment instruments, together with references to the published literature. Another table identifies seven strategies for student-centered learning, likewise linked to the published literature. These would be an excellent place for both novices and experienced classroom teachers to begin, especially those who had not yet tried strategies other than lecture-style delivery of information.

Chapter 4 identifies "Challenges Ahead." The changes called for are neither incremental nor trivial; they will require a major reorientation of many faculty members' teaching style. Such change can be assisted with targeted professional development, through workshops, the activities of professional societies, hiring of educational specialists as regular faculty in science departments (a practice already widespread in chemistry and physics), and participation in such organizations as FUN, Project Kaleidoscope and the Council on Undergraduate Research. Training programs for future faculty, whether at the graduate student or postdoctoral level, are even more likely to influence the culture, since the students will not have to "un-learn" traditional strategies in order to make room for newer ones. Even pre-service teacher training can be reoriented to engage secondary school students to continue in the study of science. It is in the area of faculty development that like-minded administrators can be particularly influential.

Chapter 5, "Unity of Purpose," is the call to action. We now have a road map for the concerted and sustained efforts of all stakeholders to ensure the needed biological literacy on the part of our students. This, however, raises practical questions: Where to begin? How to spread the word? How to modify the reward structure of academe so that efforts toward improving teaching are valued? A good place to start is the report itself, where each chapter identifies "next steps," "action items," sidebars with student voices, and examples of effective practices in a wide variety of institutional settings. The list of references is particularly helpful in focusing practicing scientists on the most influential published sources.

Let me now return to the discussion of core concepts and competencies. The former are the Big Ideas that underlie all of biology (and other sciences, too, in some cases). The latter are skills that can be developed as means of practicing science, and eventually developing a scientific way of looking at the world. The assertion is that with these concepts and competencies permeating a course, <u>no matter the choice of content</u>, the course will serve the students and influence them to remain interested and curious about the natural world. So, what are these touchstones?

- Evolution --- the diversity of life evolved over time by processes of mutation, selection, and genetic change.
- Structure and Function --- how the basic units of structure (at all levels of organization) define the function of all living things.
- Information flow, exchange, and storage --- how the growth and behavior of organisms are activated through the expression of genetic information in a specific context.
- Pathways and transformations of energy and matter --- how biological systems grow and change by processes based upon pathways of chemical transformation, physical processes, and the laws of thermodynamics.
- Systems --- the interconnections and interactions of living things at all levels, requiring a combination of reductionist analysis and holistic considerations of how the parts make the whole.

At one level these may seem unexceptional, but taken as inclusive of all that is important about biology, they are remarkably apt and effective in framing the conversation that we have with our students.

Now to the competencies. These are all abilities, skills, talents that require development through practice. Again they may seem fairly obvious, but as a whole they transcend applications merely to biology or even to science, and prepare students well for informed citizenship. Our goal should be to help students develop the following skills:

- Apply the process of science --- Recognize that each fact emerges from a series of questions and systematic attempts to reach answers to the questions.
- Use quantitative reasoning --- Recognize that qualitative statements, powerful in their own way, are strengthened by measurement: not "it is growing" but "its mass is increasing by x%/hour." This skill also demands that students develop facility with abstract representation.
- Use modeling and simulation --- Recognize both the power and limitations of a model taken as representing the actual organism or process. Learn to read graphs and understand tabular data.
- Tap into the interdisciplinary nature of science --- Appreciate that division of biological content among a series of courses is more an administrative convenience than inherent to that content and be able to follow common threads through various courses, whether biological, other scientific, or indeed, in any subject.
- Communicate and collaborate with other disciplines --- Recognize that no one individual can master the deep knowledge in all the areas necessary to address complex questions, but that it is essential to collaborate. Further understand that collaboration requires interpersonal skills, particularly in oral and written communication.
- Understand the relationship between science and society --- Recognize that, though abstract in many ways, science is embedded in society and relies on society for its continued support. To the extent that scientists recognize that interaction, they will take it as an obligation to nurture the connections, to interpret their work for the general public and to invite the non-specialist to join the conversation at whatever level is appropriate.

These competencies are readily fostered in laboratory or field work, particularly in a research setting, but can be implemented creatively even in the format of a non-laboratory course.

So, how do we proceed? Let's start with the student-centered classroom, as discussed in Chapter 3. Instead of a list of topics to be "covered" and tested after the lecture, such a classroom is managed by questions like these: "What should a student know and be able to do by the end of the course?" "How will I be able to recognize proficiency and mastery?" "What would it take to persuade me that a student has achieved proficiency and mastery (and what evidence would convince my colleagues)?" These questions are best addressed by the practice of "backwards design": first, identify your goals; then the level of performance that would indicate achievement of the goals; and finally, what needs to be done to elicit that level of performance. If the problem is approached this way, you will likely find that typical "assessment" may not be as useful as you had previously thought. Usually the goal is not to be able to recite the Krebs Cycle or identify the spinal nerves, but rather to integrate specifics into a much deeper and more nuanced understanding. And, incidentally perhaps, to retain the understanding beyond the end of the examination!

Here we are confronted by the inverse relationship between the ease of an assessment strategy and the likelihood that it will say something important about learning (see p. 24 of the report). The standard multiple choice or true/false test will measure only the least engaging level of learning, the ability to recall information without context. As assessments become more thoughtful, they elicit more thoughtful responses requiring analysis, synthesis, and other higher-order cognitive tasks. Thus making models of a process, solving quantitative problems, or making concept maps are better than machine-gradable multiple-choice exams; short-answer essay questions are even better; and still better are not exams at all but open-ended essays, reports, or research papers, and prepared or extemporaneous oral discussion. Though difficult to evaluate, the value of using these types of assessment has led a number of people to develop rubrics or other strategies to guide both the student and the faculty member in gauging the quality of the response and hence the degree of learning.

This is the vision. What is needed for the change? This is the material of Chapter 4, already alluded to above. Future faculty must be nurtured through formal programs and enrichment opportunities that make them aware of the newer instructional strategies. Current faculty must be provided with development opportunities and incentives. Both groups must be empowered to change not only individual courses but to encourage entire departments to adopt best practices, within each department's specific context. To bring student-centered practice campus wide, to make it a hallmark of the institution's identity, is the ultimate goal.

We thus come to the call to action. If not now, then when? If not we, then who? We can start from the ground up: inform yourselves using the resources of the Vision and Change document. Use the ones that fit your work the best and persuade your colleagues that these issues are of paramount importance. Together persuade your administration that resources spent on this effort yield important and necessary learning gains and ultimately benefit the entire institution. And work to offer recognition not only to high quality research but also effective teaching, and better yet, the integration of the two. We can also work from the top down: put a copy of this report on your chair's or dean's desk and invite him or her to read it. (It is actually quite a quick read; in fact a number of the hard copies have been put to precisely that use!) Use evidence from your own classes to convince your administration that not only do students learn better and retain their knowledge better, but a wider range of students can be engaged in the study of science, benefitting both them and the scientific enterprise.

As FUN, you have your triennial meetings. Most of you are also members of the Society for Neuroscience. Make sure that you offer awards to exemplary teachers among you (as I know you do). Remain visible on the national scene with workshops disseminating effective practices (as I know you do). Provide venues for publication of good teaching ideas (as I know you do). And identify and convene the community of educators in your discipline, so that they can continue to interact even between national conferences.

Professional societies play key roles by providing a forum for discussion about education in meetings and journals whose major purpose is to share research findings. They can manage and "vet" suggestions for improved educational practice in the discipline. They can take a leadership role in promoting institutional change by identifying exemplary role models. In some disciplines they can recommend standard curricula and offer accreditation for exemplary programs.

The NSF can also play an important role. In the Division of Undergraduate Education we offer a variety of grant programs. Among these, the largest and most varied is our flagship program, Transforming Undergraduate Education in the STEM disciplines (TUES). Proposals range from relatively small projects ($200,000 for 2 to 3 years) up to several million dollars for widespread national dissemination of proven strategies. These projects can involve faculty development, course improvement, laboratory improvement (through development of new instructional modules or application of new instrumentation), research on teaching and learning itself, or adapting and adopting a well studied procedure to a new audience. Not only is TUES the most wide-ranging program in DUE, it also attracts the most proposals. Every summer we take over a hotel in Arlington and convene 40 or 50 panels of peer scientist-educators to accomplish proposal review, a critical function that informs the program officer as to the strengths and weaknesses of the proposed activity. Our recommendation for or against funding takes that peer review very seriously. If you would like to learn more about the TUES program or any other NSF program you can read the solicitation that describes the program and check out the abstracts of recent awards on the NSF web site (www.nsf.gov). That site also gives the names and contact information for the Program Directors assigned to each program. You are welcome, even encouraged, to check with a program officer before submitting a proposal, to be sure it is appropriate to the program in question. One of the best ways to see what kinds of proposals are favorably regarded is to volunteer to serve on a panel. Send me an e-mail expressing your interest and include a two-page *curriculum vitae*. I will add your information to a spreadsheet and it will be considered the next time we are assembling panels.

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