VISION AND CHANGE IN UNDERGRADUATE BIOLOGY EDUCATION:
A VIEW FOR THE 21ST CENTURY
2007–2008 Faculty Conversations
Preliminary Report

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Introduction

Both the disciplines of biology and of science education have undergone a revolution. The major focus of the biological sciences—understanding life—remains unchanged; but breakthrough discoveries of the second half of the 20th century have changed the basic nature of the questions asked, while new and emerging technologies are changing the ways key questions are addressed. In undergraduate STEM education new approaches and new technologies are also emerging based on evolving theories of learning. New developments in the nature of institutions of higher education have changed the manner in which people pursue higher education, and there is a growing appreciation of the need to broaden participation within the sciences by advancing the education of all students including those from underrepresented groups and those who will enter careers other than those related to science. There is also a growing realization of the necessity to fully inform and educate all students about the wealth of professions available to those who study the sciences and about the way science is done (Vision and Change briefing document, 2007).

To determine how undergraduate biology education can best reflect the exciting recent advances in the biological sciences and the knowledge gained about teaching and learning, the American Association for the Advancement of Science (AAAS) organized "Vision and Change in Undergraduate Biology Education: A View for the 21st Century," a set of informal conversations designed to enable a wide segment of the biological sciences community to explore the changes that need to take place and how best to effect those changes. A key outcome of the project is the development and expansion of effective networking and coordination among the stakeholders in this change process, as well as raising the overall visibility of the change process among stakeholders, policy makers, and the general public.

This report summarizes ideas collected in 2007-2008 through a series of seven "conversations" on undergraduate biology education conducted at locations throughout the United States. The conversations engaged 180 participants, a majority of them biology faculty, administrators, and others actively engaged in the discipline and in teaching biology. Participants represented almost all the sub-disciplines within biology, a wide variety of academic institutions and a variety of experiences ranging from post-docs to those well established in their field. In addition to the conversations, 80 representatives from professional societies were invited to a meeting organized by the American Institute of Biological Sciences (AIBS) and AAAS to discuss their perspectives on undergraduate education in the biological sciences. The conversations included, as observers and in other roles as appropriate, representatives of AAAS and NSF. In addition, some conversations included representatives from the Howard Hughes Medical Institute (HHMI) and the National Institutes of Health's National Institute of

General Medical Sciences (NIGMS), Division of Minority Opportunities in Research (MORE).

Each conversation was informed by a paper summarizing the issues prompting the need for the discussions and a series of background questions to help frame the discussions. Participants were first asked to frame a question of importance to them and indicate why it was important to consider this issue. The participants then regrouped to agree on key points for discussion in the afternoon, which centered on resolving issues raised in the morning. Summaries of comments from across the conversations are provided below.

Curriculum

A. Focus on Two Major Goals

The curriculum should focus on two major goals: 1) Engage students in the process of science; and 2) Present science as a vibrant and active field. To engage students in the scientific process, they should have:

- Hands-on laboratory/field experiences within courses;
- Research opportunities in laboratories/field;
- Inquiry-based activities allowing active exploration of a broad theme or model system; and
- Manipulation of large and small data sets, with use of spreadsheets and data analysis to develop quantitative skills.

Students should perceive biology as an evidence-based science with testable theories and data to support them and should clearly understand "…how scientists know what they know."

Students should see biology as a growing and dynamic field that applies the scientific method to global problems. Toward this end, the curriculum should link the content knowledge students learn to policy and advocacy issues and opportunities. Students should also see biology as a human endeavor, engaging real people in important investigations. Undergraduate biology clubs could be launched to offer students opportunities to participate in biology activities outside the classroom and to network with biologists in informal settings. Finally, students should understand that biologists form a worldwide community, collaborating on research and teaching. There should be expanded opportunities for biology students to do international studies during their undergraduate years.

B. Build an Active-Learning Curriculum

The 21st century biology curriculum should be rich with active-learning opportunities. Content coverage must be carefully selected to provide time for students to engage in active-learning activities. A balance must be created between content knowledge and process skills development. This is important for both biology majors and students in general education courses, including pre-service elementary teachers who will introduce students to their first science lessons.

Research experiences should be incorporated for all students via research laboratories or inquiry-rich laboratory courses. Institutions should create tools to help students locate research opportunities; these could include lab-matching services, seminars on finding a research lab, or undergraduate biology clubs. Institutions or professional societies could publish student research, for example, on their websites to further hone and reinforce the importance of writing and research skills.

Integrate skills development throughout the curriculum. Quantitative skills and writing skills development should be embedded within the biology curriculum as well as taught in mathematics and/or English/writing courses. Students should be able to identify problems, develop hypotheses, structure explorations, carry out data collection and data analysis, and draw appropriate conclusions from the data. Students should develop written and oral communications skills to allow them to develop constructive arguments based on evidence, collaborate with partners, work as teams, and share their findings. Finally, students should be able to determine the accuracy and validity of information and its sources, distinguish between real science and unsupported claims in print and web-based sources, and assess the real level of controversy on a subject.

Finally, the curriculum should utilize technologies that engage student interest and interaction. Examples include on-demand audiovisual content (Webcasts/podcasts) and social networking websites (e.g., Facebook, MySpace, etc.).

C. Keep Content Current

Textbooks, by their nature, cannot reflect the most current content in science. They tend to reinforce students' perception of biology as a compendium of facts rather than a dynamic and ever-changing body of knowledge. Therefore, curriculum should not rely on textbooks as the sole source of information for students. Course content should link curricular activities to real-world problems and science-in-the-news stories that are socially relevant to the target audience of students. It should also link the curriculum to the primary literature, wherever possible, and integrate research seminars as course activities.

D. Structure Curriculum to Address Student Needs

It is critical to recognize that the diversity of biology students and their needs are greater than ever. Several groups are still profoundly underrepresented among life scientists, and departments must seek and implement effective methods to recruit, retain, and promote achievement among students of color. Some students come underprepared for the rigors of quantitative study in biology. Those students need more than the standard coursework and may need study skills training to succeed. And an increasing number of students will come to biology education while working full-time to support themselves and their families. These students need additional flexibility in terms of timelines and course structure (e.g., online courses). In addition, an increasing number of students will begin their biology studies as a second career. All of these students, as well as the more traditional students, bring a background of existing knowledge and life experiences. Biology educators must find ways to build connections between students' existing knowledge and experiences and the science curriculum. Finally, many students will begin their undergraduate training at community colleges and seek to transfer to four-year colleges and universities. Connections between and alignment with these institutions must be strengthened to facilitate these transfers.

Student Assessment and Pedagogy Evaluation

A. Assess Both Content and Process Objectives

Assessments must match the course objectives and overall learning goals for biology majors as well as for students majoring in other subjects. Therefore, assessments must measure process skills and student perceptions, as well as content knowledge. They should tap into a variety of learning styles and preferences and, where possible, should facilitate further learning rather than simply serving as a final measurement.

By going beyond traditional methods, faculty will have a richer set of data by which they can assess student achievement. Student perceptions such as attitudes, perceived learning, levels of engagement, and perceived usefulness can be of great assistance not only in assessing student development but in evaluating course activities. Case studies not only tap content knowledge but process, writing, and teamwork skills. Class activities and assignments such as laboratory reports, electronic homework, clicker questions, and "two-step" tests provide a broader view of a student's engagement and development. Even student discussions on social networking sites can provide insights into student understanding.

Finally, departments should consider having students maintain a portfolio of their work across their undergraduate years. This portfolio provides a venue for student reflections and a powerful set of data for discussions with the student's advisor.

B. Evaluate New Teaching Methods for Effectiveness

Both traditional and new teaching methods have advocates, yet there may or may not be evidence to document their effectiveness. As new methods are incorporated into the curriculum, it will be important to determine which methods have evidence of success and which need evaluation. This should apply to both traditional and new methods. However, this may require assistance from biology teaching scholars, educational researchers, and/or statisticians, particularly when developing an evaluation or testing plan for new materials or methods.

Recommendations for Faculty, Departmental, and Institutional Development

A. Build a Culture for Teaching and Learning

Departments and institutions must actively build a culture that supports the scholarship of teaching and learning. Evaluation and assessment data can be used to demonstrate to both faculty and administration that improved teaching and learning using active-learning strategies contribute to achievement of departmental and institutional goals. Biology teaching scholarship must be valued by the institution in order to succeed; therefore, indicators of teaching scholarship should be included as criteria for hiring, tenure and promotion. New faculty should receive start-up funds and release time for teaching as well as research activities. To provide additional expertise for departmental change, institutions should consider hiring science education specialists; these specialists should be well-supported in tenure-track positions in biology departments (or jointly with education departments).

B. Leverage Resources

Departments with similar goals for building a culture for teaching and learning should create partnerships across the institution. By planning together, departments can expedite evaluation planning and, through hiring and training, can develop a "critical mass" of science teaching scholars within and across departments. Finally, successes should be shared; departments should publicize their teaching successes, giving credit to the institution as well as funding agencies.

C. Develop Graduate/Postdoctoral Students as Biology Teaching Scholars

Graduate programs should establish the expectation that their program graduates will have expertise in teaching and teaching scholarship as well as in research. Programs should provide both formal training and ongoing mentoring to develop teaching expertise for both content and process objectives. Where possible, departments should explore opportunities to link research activities and teaching activities. Partnerships should be established or expanded to build cooperative programs between community colleges and research institutions to share teaching mentoring and research opportunities. Finally, these program changes should be evaluated to determine their impacts on graduates' successes in their first professional positions.

D. Develop Faculty as Biology Teaching Scholars

Departments must adopt a clear definition of the scholarship of biology teaching so that faculty members understand their target goal. This definition should be incorporated in the development of criteria for new faculty hires. Departments should provide both structured training and ongoing mentoring to develop teaching skills for both content and process skills. Where possible, existing programs of demonstrated effectiveness should be replicated rather than creating new programs. Finally, departments should recognize the importance of adjunct faculty and include them in faculty development initiatives.

E. Provide Institutional Recognition and Rewards

Teaching scholarship must be recognized as an important contribution to the department and institution, not a "dead-end" career choice. Release time should be provided for faculty development and development of teaching materials and methods. Finally, biology teaching scholarship must count positively in tenure and promotion decisions.

Recommendations to Develop National Resources

A. Work toward Developing a Consensus on a "Common Core," and Explore Life Sciences Accreditation and National Assessments

Participants voiced support for the development of an overarching set of core concepts and competencies and hoped that a set of standardized assessment instruments could be developed to aid in determining student attainment of learning goals. The

possibility of an informal accreditation process for life sciences programs was also discussed. Efforts should be undertaken to develop agreement on a common core of topics that should be part of life sciences undergraduate education. This "core" could serve to help guide institutional program revision and development of tools for assessing overall impact. However, there was concern about using such a core and assessments as rigid accreditation benchmarks.

B. Establish a National Center for Undergraduate Education

A centralized center should be created to promote the development of undergraduate education by providing models, training, and support for individuals and departments working to improve their biology/life sciences programs and courses. It would also serve as a center for disseminating programs of demonstrated effectiveness.

C. Establish a National Clearinghouse for Undergraduate Education Materials and Pedagogy

There was strong support for creating an online national clearinghouse for life sciences/biology teaching materials and strategies. This could be done by an expansion or revision of BioSciEd Net (BEN), the National Science Digital Library's Pathway Portal to the Life Sciences, or through another portal such as Merlot or Nature Education. A registry of "best practices" and "best materials" should be a part of the national clearinghouse, as well as links to data sets for teaching quantitative skills and summaries of research on teaching and learning.

Recommendations for Professional Societies

The conversations resulted in a recurring call for professional scientific societies to play a greater role in improving undergraduate life sciences education. Recommendations ranged from providing materials and training for educators to promoting the importance of scholarship in teaching and learning. Major recommendations are summarized below.

A. Set a New Standard

Professional societies should set a new standard for how their members view the scholarship of teaching and learning. This should occur through their normal activities (meetings, publications, awards). Peer-reviewed science education journals and/or articles indicate that the society values educational scholarship and can help faculty seeking tenure based on biology teaching scholarship. Professional meetings should be rich with opportunities to attend sessions on teaching and learning as well as "safe places" to talk about educational issues. Society awards for teaching excellence and teaching scholarship raise the status of these activities for all members.

B. Hold Education Conferences

Professional science societies should hold conferences on education, either jointly with education societies or on their own. These meetings would allow sharing of research findings and project evaluations, facilitate network-building, promote collaboration, and offer professional development in teaching. A biannual Gordon

conference was suggested to bring together key education representatives from each society to set an agenda for meetings and projects.

C. Serve as Stewards of the Discipline

A number of groups recommended that professional societies serve as the repository of content knowledge, develop and steward educational materials, and develop and provide professional development activities for their discipline. They should also play a lead role in establishing core content/content inventories for their disciplines. These inventories could ultimately lead to certification of teachers and/or courses as meeting current standards in a subdiscipline. As major publishers of research papers, societies should take the lead in re-purposing this content for use by undergraduate students and faculty (e.g., research summaries, PowerPoint slides associated with research articles, etc.). The societies should establish networks of biology educators and provide professional development for both faculty and graduate students.

D. Provide Memberships for Educators

Many biology teachers no longer belong to their professional science society and need mechanisms that would encourage them to use society resources. Special rates on meeting registration and membership and free access to general content would encourage educators to remain connected to their disciplinary society and utilize its resources in their courses.

E. Collaborate with Other Societies

Scientific societies should work together to implement many of these crosscutting strategies. Especially important is the need for collaboration related to developing a consensus regarding a common core of "big ideas in biology" that should be included in undergraduate biology.

About the Authors

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Marsha L. Matyas serves as the Director of Education Programs for the American Physiological Society (APS). Her research fields include factors affecting science and engineering interests and participation rates among women and minorities at the precollege, undergraduate, and graduate levels and curriculum development for biology education and professional development. She earned her master's degree in cell biology and her doctorate in science education at Purdue University. For eight years, she directed the Projects on Women in Science at the American Association for the Advancement of Science (AAAS) and served as a program officer at the National Science Foundation.

At the APS, she directs a variety of programs, including: professional development programs for graduate and postdoctoral students and science educators, minority recruitment and retention programs at the precollege, undergraduate, and graduate levels;

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George conducts evaluations, project and program reviews, and evaluation workshops for both the National Institutes of Health and National Science Foundation, as well as reviews SMT proposals for private foundation and public agencies, including Carnegie Corporation of New York, the Ford Foundation, and the European Commission. She works with UNIFEM, UNESCO, and non-governmental organizations on gender, science, and technology initiatives related to college and university recruitment and retention and women leadership in SMT.

George currently serves as principal investigator (PI) or co-PI on several National Science Foundation (NSF) grants, including the Vision and Change in Undergraduate Biology Education: A View to the 21st Century Initiative; the Alliance for Graduate Education and the Professoriate (AGEP); National Science Education Digital Library (NSDL) Biological Sciences Pathways for biological sciences educators in undergraduate, graduate and professional schools; Women's International Scientific Cooperation Program (WISC); Historically Black Colleges and Universities-Undergraduate Programs (HBCU-UP); and Course, Curriculum, and Laboratory Improvement (CCLI) conferences.

George serves on the board of the International Women in Science and Engineering Network (INWES); American Institute of Biological Sciences (AIBS) Education Committee; Maria Mitchell Women in Science Awards Committee; McNeill/Lehrer Productions Online Science Reports Advisory Committee: Great Science for Girls: Extension Services for Gender Equity in Science Advisory Committee, Academy for Educational Development; and the South Dakota Biomedical Research Network Advisory Committee.

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In addition, Malcom serves as a Regent of Morgan State University and as a trustee of Caltech. In addition, she has chaired a number of national committees addressing education reform and access to scientific and technical education, careers and literacy. Malcom is a former trustee of the Carnegie Corporation of New York. She is a fellow of the AAAS and the American Academy of Arts and Sciences. She served on the National Science Board, the policymaking body of the National Science Foundation from 1994 to 1998; and from 1994-2001 she served on the President's Committee of Advisors on Science and Technology.

Malcom received her doctorate in ecology from The Pennsylvania State University; master's degree in zoology from the University of California, Los Angeles; and bachelor's degree with distinction in zoology from the University of Washington. She also holds 15 honorary degrees. In 2003 Malcom received the Public Welfare Medal of the National Academy of Sciences, the highest award given by the Academy.