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Feature

Points of View: Content versus Process: Is This a Fair Choice?

Note from the Editors
Cell Biology Education (CBE) *is pleased to present "Points of View," a series designed to address issues faced by many people within the life sciences educational realm. We present several differing points of view back-to-back on a given topic to promote discussion of the topic. Readers are encouraged to participate in the online discussion forum hosted by* CBE *at http://www.cellbioed.org/discussion/public/main.cfm. We hope op-ed pieces on "Points of View" will stimulate thought and dialogue on significant educational issues.*

In this issue, we address the question "What should a biology student know?" Can biologists agree on a core set of content that all biology students should know? What about biology majors versus nonmajors? Can we create a list of facts or skills that every biology student should master? Or should our goals de-emphasize content and concentrate on ability to think, reason, analyze, and communicate? Are the details unimportant as long as students can ask good questions and figure out ways to answer their questions? We present two different "Points of View" that differ in their preferred educational outcomes.

The "Points of View" we present in this issue provide two perspectives that may be familiar ones argued in your department. We invite you to share your ideas, experiences, and insights on the discussion board.

Undergraduate Biology Courses for Nonscientists: Toward a Lived Curriculum

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Effective power in action is the true end of education, rather than the storing up of information.
Charles Eliot, president of Harvard, 1898

In spite of centuries of teaching biology, we biologists continue to be ensnared in attempts to define what parts of biology are essential for a literate nonscientist to know. Such discussions gain deeper urgency with the nearly annual reports of our students' shortcomings in tests that purportedly evaluate their understandings of math and science (e.g., see O'Sullivan, 2003). Are we failing our undergraduates? Will our shortcomings in teaching biology imperil their ability to live full lives? Will their misunderstandings or lack of knowledge about science imperil our democratic way of life and national security?

My own teaching of nonmajors has been both liberated and enriched by the realization that the answer to each of these questions is, "No." As a result, I have abandoned the mistaken notion that unless I "cover" a particular list of "content," my students will be unprepared for the future and I will have failed them as a teacher. I no longer agonize about losing valuable lecture time to in-class discussions, group problem solving, or other activities that take time away from covering content. Instead, I purposefully include such activities in order to offer a richer, more valuable learning experience. This change moves toward a "lived curriculum" (Hurd, 1998) that provides meaning well beyond the particular facts and even beyond biology. Rather than focusing on covering key facts or principles, a lived curriculum in nonmajors biology focuses on helping students learn to *use* scientific knowledge to solve relevant problems. Content mastery emerges naturally as students seek out, evaluate, and organize the information they need to develop an informed understanding about an issue such as the genetics of race, stem cell research, or invasive species. In the context of a lived curriculum, benchmarks for student learning become potential destinations for deep exploration rather than a roadmap for a 10- or 15-week hovercraft tour across the contours of biology. By focusing our efforts on developing intellectual skills rather than simply covering a list of facts, a lived curriculum will have a long-term positive impact on students' lives and their ability to function as informed citizens in a democratic society.

THE SCHOLARLY HISTORY OF SCIENCE LITERACY SHOULD INFORM OUR CURRENT EDUCATION EFFORTS

> *That men do not learn very much from the lessons of history is the most important of all the lessons that history has to teach.*
>
> Aldous Huxley, English novelist, 1959

The idea that knowledge about science has value beyond the practice of science is hardly modern, although we lose sight of this fact (for reviews, see DeBoer, 1991,2000; Hurd, 1998). Scientific literacy has been promoted as an important goal since at least 400 BC, when Plato was leading discussions at the Academy in Athens. The goals of biology literacy have similarly been a part of higher education in Western civilization for centuries (Rudolph, 1977). In keeping with this tradition, biology has been included in American college curricula since the founding of Harvard College in 1636 (Mather, 1907). Modeled on the curricula of Oxford and Cambridge at the time, the Harvard College curriculum required students to take botany courses in both sophomore and junior or senior years. In the forms of botany, zoology, and physiology, biology education has also been part of the formal elementary and high school curricula in the United States from its beginnings.

Beginning with Thomas Jefferson's calls for improved science education during his vice presidency (Shamos, 1995), dozens of national studies, reports, and recommendations have offered potential solutions to science literacy in the United States. In fact, about every 20 years since the late 1800s, an influential national report has called attention to the failures of the past and offered solutions for the future. The sophistication of these reports is surprising, at least to one who discovered them only recently. For example, recommendations made in the "Committee of Ten" report, authored more than 100 years ago, reflect advocacy for what we would call today "inquiry-based learning." Twenty years later, another report called for making science education relevant to students' lives, promoting what we would call today "problem-based learning." Calls for a relevant science education continued until the 1940s and World War II.

After World War II, the failures of our education system to meet the rising need for scientists generated "back to the basics" curriculum reform movements that began in the 1960s (Hoopes and Oakland University, 1963). These movements, which advocated standardized courses of study with prescribed content, resulted in large monetary investments in science education by the National Science Foundation (NSF) and others. In spite of this infusion of resources, the failures in science literacy continued to be described by a myriad of influential reports (Boyer, 1983; Mullis *et al.*, 1988; National Science Board Commission on Precollege Education in Mathematics, Science, and Technology, 1982, 1983; Project 2061 [American Association for the Advancement of Science], 1989; U.S. National Commission on Excellence in Education, 1983, 1984a, b; Venezky *et al.*, 1987). Once again, as at the turn of the twentieth century, educators at the turn of the twenty-first are called upon to develop relevant, inquiry-based approaches to teaching science (Bybee, 1997; Center for Science, Mathematics, and Engineering Education, 1998; Fox *et al.*, 2003; Handelsman *et al.*, 2004; Hazen and Trefil, 1991; Hurd, 1998; McCray *et al.*, 2003; National Research Council, 1996; National Research Council Committee on Undergraduate Biology Education, 2003; National Research Council Committee on Undergraduate Science Education, 1997; Nelson, 1999; Project 2061 [American Association for the Advancement of Science], 1989, 1993; Tobias, 1992).

Even this brief overview illustrates the incredible amount of effort and resources we have invested over the past 200 years to define and deliver an excellent science education. However, this history also illustrates that none of these efforts has led to systemic, enduring changes in how we teach science or even what we expect students to learn. The problems we wrestle with today are basically the same as those faced at the founding of the United States, and before. Solutions have been proposed for decades, with little actual impact on our classroom practice. Such inertia might be a source of despair, if not for the remarkable progress we have made in science research. We have sent machines beyond the solar system and humans to the moon. We have developed medicines and therapies that can postpone death, sometimes for decades. We have deciphered the genetic heritage of hundreds of species and stand on the threshold of creating life de novo. Thus, achieving whatever it is we mean by "a scientifically literate population," however worthy and important, does not appear to be essential for making progress in science. As a result, some scholars conclude that the goal of scientific literacy is a Quixotic venture at best, a myth at worst (Shamos, 1995).

As we consider nonmajors college biology classes today, what should we take away from the history of science literacy? We should be aware that, in our efforts to improve science education, we tread well-worn paths. If we treated this area of investigation as a worthy scholarly effort and simply read this literature, we might not be doomed to reinvent wheels, axles, or wagons, but might truly build on the scholarship of the past, as we naturally do in our research. We should be aware of the many attempts to define science literacy in terms of content lists (e.g., see the Office of Education circular, Martin, 1948). These lists have evolved (somewhat) as our understanding of life deepens, but they have not provided long-term solutions to science literacy. Finally, we should take heart that relying on scientists to bring their expertise and passion to nonscientists has great and long-lasting value. It is the passion of the teacher for her subject that changes students, who in turn change the world. Whatever modes and mechanisms we construct to support science literacy should not dilute the opportunity for individual biologists to share themselves with their students.

LITERACY IS NOT CONTENT KNOWLEDGE

> *Science is built up with facts, as a house is with stones. But a collection of facts is no more a science than a heap of stones is a house.*
>
> Jules Poincaré, mathematician, 1908

All knowledge has some value. Some knowledge has great value. However, no knowledge exists in any field, including biology, that is so vital or essential that every literate person must know it. In reply to this assertion, I can hear my esteemed colleagues argue, "But what about evolution?" or "But what about how DNA works?" or "But what about the richness of species diversity on the earth?" Each of us will have a "What about..." (or several) that captures our own biases and expertise as practicing biologists. The answer to every one is "No, that knowledge isn't essential." All of it has value, but none is essential for all nonbiologists to know. Can a person live a worthwhile life, even a scholarly life, without knowing the mechanisms of evolution, or the function of DNA, or what a coelom is? Of course, they can. In fact, most people (even college professors) do. However, to be literate about biology, an educated person has to have the skills to ask and answer questions about biology in a scientifically valid way.

Thus, rather than mastery of content, literacy also requires the development of intellectual skills. Content is not irrelevant, since it provides the raw materials, Poincaré's "stones," that students can manipulate to develop these skills. However, creation of synapses that store biology content is neither the goal nor the measure of biological literacy. Moving away from biology may help us gain perspective. Consider mathematics as an example of the importance of intellectual skill over mere content. Memorizing the multiplication tables is not essential for using math, although it would speed up the process of problem solving. However, knowing when and how to use multiplication to solve a problem is an essential intellectual skill of a mathematically literate person. Memorization of multiplication tables would become essential only if it were essential to using multiplication as a tool. It is not. Interestingly, memorizing the multiplication tables is likely to evolve naturally through continued opportunities to solve problems that require multiplication.

Perhaps math is a poor example for the argument of the goal of skill over content, since math is a discipline that is inherently and obviously devoted to the skill of problem solving. Consider, then, American literature. I have never read *Catcher in the Rye* and would venture to guess that many of the readers of this article would acknowledge the same deficiency. However, because I am literate, I could certainly get a copy and read it with understanding. This understanding would undoubtedly be richer if I had access to discussions with teacher-scholars about the meaning and context of this work, as in a college literature class. However, if I am sufficiently interested, I could also seek out the writings of scholars and even pursue the issue to the point that I could provide new insights into this work from my own experience. Perhaps, then, the theoretical potential to contribute new ideas or raise new questions is what literacy, in any field, ultimately means.

When considering how to help students become biology literate, we would be best served to think about ourselves in the context of a field distant from biology, in my case, literature. How did I come to have the ability to read literature with understanding and insight? Certainly, not through reading particular works that experts regard as seminal, but simply through reading, mostly books or articles that I chose based on my own interests and that I read outside the context of a class, frequently for pleasure. It was not by mastering particular American Literature content. It was by mastering the skill of reading, of knowing how and when to look up words I didn't know, of learning which sources provided information that was likely to be trustworthy and valuable. I could have gained this skill by reading (almost) anything.

The foundation of my argument is that literacy in any field implies that an individual has the potential for deeper learning in that field. Literacy isn't committing a particular set of facts to memory, but the ability to use resources to find, evaluate, and use information in a manner that reflects that field. If my premise is correct, the definition of biological literacy is straightforward: biologically literate individuals can ask and answer their own biologically relevant questions. Unfortunately, my definition is not the goal of most of our undergraduate biology classes, whether for biology majors or not.

Based on dozens of biology course syllabi from diverse institutions, it is clear that we emphasize content over skill in our classes, including those for nonmajors. A typical syllabus describes the course as a succession of topics (cell structure, metabolism, mitosis/meiosis, the central dogma, populations, natural selection, etc.) along with the appropriate text chapters to be read and perhaps lab exercises to conduct. In many ways, our syllabi give the impression that biology is a foreign language and that all students really need to know about biology are the definitions.

Our content-centric syllabi, and the courses they describe, contrast sharply with what we actually want our students to learn in our classes. I have asked dozens of my colleagues what they hope students who successfully complete their class will have learned. They don't list the content of the class. Instead, they want their students to make connections between the content and their lives, to be able to critically evaluate information in the future, to see the world in a new way, to be more interested in biology than before. The disconnect between spoken goals and written syllabus is staggering. Unfortunately, because there is so much content to cover, we don't have time to help our students learn to use the content we teach with any sophistication or understanding. We expect students will gain these intellectual skills on their own, simply as a result of learning the content listed in the syllabus. We expect these intellectual skills to emerge as students learn the vocabulary of biology. We are disappointed when they do not. Like Poincaré's stones, such unconstructed, disconnected knowledge is the antithesis of literacy.

A LIVED CURRICULUM IN BIOLOGY: FIRST, DO NO HARM

> *From the viewpoint of general education the principal criticism to be leveled at much of present college instruction in science is that it consists of courses in special fields, directed toward training the future specialist and making few concessions to the general student. Most of the time in such courses is devoted to developing a technical vocabulary and technical skills and to a systematic presentation of the accumulated fact and theory which science has inherited from the past.*
>
> James Conant, president of Harvard, 1945

The basic skill that defines biology literacy is arguably the same as for any other discipline: the ability to pose a question and then find, evaluate, and use information to answer it in a manner that is consistent with the mode of inquiry of that discipline. What kinds of college biology courses enable nonscientists to attain a lifelong skill in asking and answering biological questions? Even more challenging, because a single course is typically all of the biology that a nonscientist will take during college, how can this goal be accomplished in 10 to 15 weeks?

Above all other aims for a nonmajors biology course, the most important is to do no harm. If students leave their single required biology class convinced that the material is too dull, too difficult, or too irrelevant to merit their attention in the future, that class has failed to promote biology literacy, regardless of its definition. Biologically literate students will have experienced both the vibrancy and utility of biology. Rather than snuffing out their curiosity, a successful biology course for nonmajors will encourage students to recapture or develop a curiosity about the living world around them and their place in it. Literate students will be more likely to read an article in the paper about a newly discovered gene or take their kids to a science museum. They will be more likely to consult their biology textbook (or, more realistically, the Internet) to find out more about birth control pills or flu shots or trans fats. And they will be able to evaluate the information to distinguish reliable sources from the junk. In short, they will be more likely to ask questions whose answers are based in the science of biology.

Now, I hear my esteemed colleagues argue, "You haven't faced students like mine. They have already lost the spark of curiosity, if they ever had it. They have already decided that biology is uninteresting and irrelevant. They have already learned that it is too hard for them to master. They would not even be here unless they had to meet their Gen Ed requirements." I've had those students, too. We should, at least, do no harm. Our classes should not validate their preconceptions. Our classes shouldn't make them even less likely to read a biologically relevant news article than they were when they entered our class. They should leave the class thinking, at the minimum, "Maybe this stuff isn't so bad, after all."

It is important to understand that the exhortation to "do no harm" does not mean "give everyone an A." Nonmajors courses should have high academic standards and be as rigorous as those offered to biology majors. To require less would not provide an authentic understanding of the practice of biology. "No harm" does not mean "no failures." However, I have found faculty consistently underestimate what students are willing and capable of doing when motivated. Nonmajors, even those on athletic scholarships, can learn to read primary research literature; to devise and evaluate experiments; to write high-quality essays in a scientific style; and to understand the most intricate, detailed aspect of any biological system they care to know. It just requires more modeling of those skills by the professor and more time for students to practice these skills and receive feedback on their performance. And it requires the professor to give up the (mistaken) idea that she must cover a critical list of content.

A LIVED CURRICULUM IN BIOLOGY: CONSTRUCT A CONTEXT FOR CONTENT

We must teach our science for the sake of the student and not for the sake of the subject.

Thomas Smyth, 1940

Does it matter what specific biology content we teach an individual who will not become a practicing biologist? Clearly, my answer to this question is, "No." In contrast, as future practitioners of biology, biology majors need to master a body of content knowledge, as well as to hone a variety of technical and intellectual skills that will prepare them for their future careers. Thus, the learning outcomes of biology classes for biology majors are vastly different from the learning outcomes for nonmajors. As we consider exemplary practices in nonmajors biology, we should recognize that those universities in which teaching of biology majors is separate from nonscience majors have made an important step in the right direction. Fortunately, this separation appears to be more the rule rather than the exception in U.S. colleges and universities at present.

Given this freedom from content coverage in nonmajors biology, we should not encumber ourselves or our students with a dumbed-down version of a biology survey course. In fact, a traditional survey course is least likely to meet the primary learning goal of helping nonscientists learn to pose and answer biological questions and most likely to "do harm." Instead, the best nonmajors courses are constructed around compelling problems about which students are inherently interested and with which the individual professor is passionately engaged. Within this context, we demonstrate how biologists analyze a particular problem, what methods are used to provide relevant data, how to critically evaluate these data, how to deal with complexity and ambiguity, and how to distinguish science from nonscience. Within this context, we exploit the principles of human learning to help students move toward being independent learners of biology (Table 1). Within this context, we help students learn a lot of biology content. (Think how much one would need to know to think critically about synthetic life, or genetically modified foods, or human evolution, or emerging diseases!) Within this context, we model within the course structure itself how biologists ask and answer questions.

What universities currently offer nonmajors biology courses that focus on developing problem-solving skills? To my knowledge, the best example comes from the University of Oregon's Workshop Biology Project (http://yucca.uoregon.edu/wb/), which aims to help students "make informed, critical decisions about important biological issues." Workshop Biology classes meet each week in two 90-minute "assemblies," which replace traditional lectures, and one 80-minute lab. In both venues, students participate in concept activities, investigative activities, and issues activities. Detailed descriptions of this exemplary program are available at http://yucca.uoregon.edu/wb/Materials/WB_Handbook.pdf, although the courses taught using the Workshop Biology paradigm are apparently no longer offered to nonmajors at the University of Oregon. Another example, still in its infancy, is the multi-institutional effort of the Associated Colleges of the South Reform of Introductory Science Courses for Non-science Majors. However, this effort largely supports individual course changes rather than promoting organized, systemic change.

In contrast to these limited examples of systemic approaches, many examples exist of individual nonmajors biology classes that take a contextual approach (see Table 2 for several). The richness of individual course examples and paucity of institutionalized efforts is consistent with the idea of empowering individual faculty to develop courses for nonmajors that reflect key issues in their research disciplines. Consequently, the absence of obvious systematic efforts to develop contextualized biology courses for nonmajors may be a positive rather than negative sign. However, it is distressing that the creativity and scholarship behind these individual courses are usually not publicly available. As a result, instructors are doomed to re-create courses de novo, rather than build on previous classroom scholarship. To help communicate this cryptic scholarship, I encourage those of you who are engaged in nonmajors biology to share your experiences via the discussion forum associated with this article.

Table 1. The implications of the seven principles of learning for nonmajors biology courses

Principle of human learning	Implications for nonmajors biology courses
Learning with understanding is facilitated when new and existing knowledge is structured around the major concepts and principles of the discipline.	Nonmajors courses should focus on a few major concepts and learning in depth.
Learners use what they already know to construct new understandings.	Nonmajors courses must connect with students' past experiences.
Learning is facilitated through the use of metacognitive strategies that identify, monitor, and regulate cognitive processes.	Nonmajors courses should encourage students to be aware of their personal learning strategies.
Learners have different strategies, approaches, patterns of abilities, and learning styles that are a function of the interaction between their heredity and their prior experiences.	Nonmajors courses must accommodate a wide variety of student learning styles.
Learners' motivation to learn and sense of self affects what is learned, how much is learned, and how much effort will be put into the learning process.	Nonmajors courses must motivate a wide variety of student interests.
The practices and activities in which people engage while learning shape what is learned.	Nonmajors courses should model the learning we want students to achieve.
Learning is enhanced through socially supported interactions.	Nonmajors courses should promote extensive student–student and student–instructor interactions that promote motivation and learning.

Source: National Resource Council (2003, p. 119).

Another excellent model of a problem-based approach that bears highlighting is in chemistry, rather than biology. Chem Connections (http://mc2.cchem.berkeley.edu/; http://chemlinks.beloit.edu/), an NSF-funded effort supporting systematic change in chemistry education, provides a modular, contextual approach to the first year of college chemistry for majors and nonmajors. The courses have specific content mastery goals, but content is embedded in the context of interesting problems, such as "What should we do about global warming?" and "How could life have arisen on earth?" The goals of the project include helping students develop increased interest in chemistry, greater conceptual understanding, and improved problem-solving skills. Assessment of this modular, problem-oriented approach shows that students' content mastery is as good or better in the modular class as in traditional courses, at both University of California—Berkeley and Grinnell College. Interestingly, students at Grinnell College appear to prefer the modular course, whereas students at Berkeley appear to prefer the traditional course (Gutwill-Wise, 2001).

A LIVED CURRICULUM: DEVELOP NEW ASSESSMENT STRATEGIES

We measure the success of schools not by the kinds of human beings they promote but by whatever increases in reading scores they chalk up. We have allowed quantitative standards, so central to the adult economic system, to become the principal yardstick for our definition of our children's worth.

Kenneth Keniston, Massachusetts Institute of Technology, professor of Human Development, 1976

Table 2. Examples of nonmajors biology systemic efforts and individual courses

Resource/example	Description and uniform resource locator
Workshop Biology	Exemplary example of contextual nonmajors biology course design http://yucca.uoregon.edu/wb/
Associated Colleges of the South Science Literacy Effort	A major effort to define science literacy for nonmajors; the "Working Paper on Science Literacy" frames the problem and provides resources http://www.colleges.org/sciencereform/science_literacy.html
Biology for Non-Majors	A section in Howard Hughes Medical Institute's publication, *Beyond Bio 101*; describes examples of "best practices" http://www.hhmi.org/BeyondBio101/nonmajor.htm
Biology 111: Biocatastrophes	A problem-based nonmajors biology course at Southern Illinois University, Evansville http://www.siue.edu/~deder/bio111t.html
Biology 301D: Biology for Business, Law, and Liberal Arts	Nonmajors biology course at the University of Texas, Austin; "A course about making decisions, evaluating information, and knowing what to trust" http://www.utexas.edu/courses/bio301d/
Ecology 206: Environmental Biology	Nonmajors course at the University of Arizona; has service learning component http://eebweb.arizona.edu/courses/Ecol206/206syllabus2005.pdf
General Biology 1114	Nonmajors course at Murray State University (Oklahoma) with well-developed and sophisticated learning outcomes http://www.mscok.edu/~bstewart/bstewart/classes/biology/biosylla.htm

Even if we can build an ideal list of content, as Michael Klymkowsky argues in his "Point of View" essay, even if we knew which parts of this list students learned well and which parts they did not, teaching this list is the wrong approach if our aim is authentic biology literacy. Instead, biology literacy requires that our students learn to think and communicate in biology, not simply recite a list of facts back to us. Teaching for mastery of even an ideal content list risks converting science literacy into a checklist for standardized testing. I have argued, instead, that biology literacy is the ability to ask a biologically relevant question and answer it in a way that reflects the science of biology. If this premise is valid, we face a serious challenge. How do we measure the ability of our students to pose biologically relevant questions and to find, evaluate, and use the information needed to answer them? What is a good question, and how can we assign it a grade? What are the standards by which we judge a students' facility to find, evaluate, and use information? How can we distinguish "A"-quality work from "C"-quality work?

This insidious assessment challenge may be the root of our centuries-long failure to effect systemic changes in science education. Our persistent focus on content transfer in our classes may reflect the ease with which we can measure content knowledge in large classes, with relatively little effort. We are facile at the use of selected-response (multiple choice, matching, true/false) or short-answer questions to determine whether or not a student remembers the definition of mitosis, or the DNA basepairing rules, or the nitrogen cycle. For classes with large enrollment, selected/short-answer exams are frequently the major (or only) assessment tools we use to assign grades. Assigning grades based on these assessments is similarly straightforward: simply map the average score to a curve or standard and mark the appropriate box on the grade reporting sheet.

Measuring how well students pose and solve biological problems is much more difficult and time consuming. It requires substantive individual evaluation of student work presented as written reports, oral presentations, posters, Web sites, portfolios, and the like. Even if we were willing and able to devote the necessary time to evaluating individual student work, we would be challenged to devise assignments and corresponding assessment strategies that fairly and reproducibly measure the student's ability to ask and answer questions. Consider reproducibility as one example of the challenge. Authentic assessment rubrics produce the same grade regardless of who scores the assignment. Where will we find the time or develop the expertise needed to devise and test our rubrics, as well as calibrate the scoring to ensure reproducibility among faculty teaching different courses?

A variety of resources concerning assessment are available, many of which can only be described as intimidating (Table 3). Thus, one of the most important things biology educators might do to promote biology literacy would be to develop assessment strategies that enable us to measure the skills that underlie the ability to ask and answer biological questions, including information literacy, critical thinking, data analysis, effective communication, and logic. Again, I invite the readers to share their experience in the discussion forum for this article.

A LIVED CURRICULUM: SHARE THE GRANDEUR

> *There is grandeur in this view of life, with its several powers, having been breathed into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being, evolved.*
>
> Charles Darwin, naturalist, 1859

Table 3. Assessment resources

Resource	Description
Classroom Assessment Techniques (Angelo and Cross, 1993)	A variety of strategies to evaluate what your students know before the final exam; very practical and usable ideas for use in classes
Effective Grading (Walvoord and Anderson, 1998)	Practical strategies for developing a comprehensive plan that links learning goals with assignments and grading; includes some information on rubric design
Understanding by Design (Wiggins and McTighe, 1998) and Understanding by Design Workbook (McTighe and Wiggins, 1999)	Excellent resource that guides course design beginning with devising goals for "enduring understanding" and the means to assess them; designed for K–12, but relevant to college classrooms at all levels
Assessing Student Outcomes (Marzano *et al.*, 1993)	Although targeted to K–12 instruction, very useful examples of designing assessment standards and rubrics
Scoring Rubrics in the Classroom (Arter and McTighe, 2001)	A myriad of examples of grading rubrics and standards; aimed at K–12 but extremely useful
Introduction to Rubrics (Stevens and Levi, 2005)	Useful manual for rubric design aimed at higher education; how to save time grading!
Designing and Assessing Courses and Curricula (Diamond, 1998)	Practical strategies ranging from individual classrooms to entire programs; very useful model for effecting course/curricular reform
Assessment Essentials (Palomba and Banta, 1999)	Thorough descriptions of a broad range of assessment strategies, aimed mostly at program-level assessment
Assessing for Learning (Maki, 2004)	The wealth of examples and models set this resource apart; useful for developing program-wide approaches
Assessment Clear and Simple (Walvoord, 2004)	Excellent resource for program-wide assessment; many useful examples
Knowing What Students Know (Pellegrino *et al.*, 2001)	A comprehensive and sophisticated treatise on the science of assessment; very detailed and oriented to readers familiar with the education assessment vocabulary

The biology I want to teach my students changes their lives. It is the biology of my grade school class where I first saw tiny paramecia in a drop of water and realized that a single cell behaved in complex ways. At that moment, I felt there was some hope that I might eventually understand a single cell. It is the biology of my college invertebrate zoology class, where I learned to really *look* at things. I felt that everything I saw afterwards had a new clarity and brilliance and meaning. It is the biology of the late-night observation, when the experiment failed to support the hypothesis but revealed a new truth and I was the first to discover it. I felt both humility and exaltation in that moment of knowing, as new ideas and understandings took shape.

The biology we want our students to learn is the same biology that captured us, that distilled our interests into our careers as biologists, and that continues to inspire us today. As we wrestle with the details and argue about definitions, let us not lose sight of the importance of sharing the grandeur of biology with our students, as it was shared with us.

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Can Nonmajors Courses Lead to Biological Literacy? Do Majors Courses Do Any Better?

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There has been a long, evolving, and often politically charged debate as to what the nonmajor student should know about science (Ravitch, 2000; Shamos, 1995). A recent view, presented by Robin Wright in the accompanying article, is that "No knowledge exists in any field, including biology, that is so vital or essential that every literate person must know it" and that "literacy implies that an individual has the potential for deeper learning in that field." This position raises some interesting issues, but before they can be addressed, it is essential that we define our terms, so that we are actually talking about the same things. First and most importantly, we must agree what we mean by scientific literacy. According to the Merriam-Webster Dictionary, literacy is "the quality of being literate," and literate means "1a: educated, cultured; b: able to read and write; 2a: versed in literature or creative writing; b: lucid, polished <a literate essay> c: having knowledge or competence <computer-literate> <politically literate>." Basically, to be literate means to be able to read a language with understanding and, in turn, be able to converse with some sophistication in that language.

If we bring this same approach to scientific literacy, we presumably mean the ability to read and converse in the language of science. So, is the language of science simply English or any other "common language," or is it more? The answer is clearly "it is more": it involves its own, often discipline-specific, vocabulary as well as common understanding of the nature of scientific experiment, argument, and proof. Basic concepts, such as "positive" and "negative controls," "allele" versus "gene," or how natural selection can act on random mutation to generate complex traits, are not commonly understood by students or the general public; in fact, they are the focus of deeply held misconceptions that actively block effective learning and clear understanding (K. Garvin-Doxas & M.W. Klymkowsky, unpublished observation).

The vocabulary required for biological literacy consists of terms whose meaning must be robustly and unambiguously understood. When we talk about biological literacy, we must also define the "reading level" that we expect students to achieve. That is a question that is rarely addressed, much less answered in a realistic way. While there are a number of suggestions of what basic science/biology literacy should entail, such as the American Association for the Advancement of Science's (AAAS) *Project 2061: Benchmarks for Science Literacy* (AAAS, 1993) or the *Bio2010* report (National Research Council, 2003), there is generally little thought given to whether these goals can be achieved given the resources available (a product of available student credit hours × learning per credit hour), nor has there been much of an effort to develop objective measures of student understanding. Such assessment instruments are not afterthoughts that can be hobbled together, but require a directed research and validation effort; their construction and testing require adequate resources and expertise, which few instructors have (or have access to). No competent biologist would start an experiment whose outcome relies on a specific instrument without having extensive data that the instrument measures what it purports to measure; in the same light, few biologists would have the expertise to construct even a simple instrument, such as a pH meter—and so it is with educational "experiments" and instruments as well.

The next question to be addressed is equally important: what is the best way to bring students to the desired level of biological literacy? If we follow the example of standard literacy, this can be accomplished only through having students read and converse in the language they are expected to master; they must be actively engaged in the learning process. Most courses in the biological sciences are divided into two general types, "majors" versus "nonmajors." How do these courses differ? (Table 1). While there are clearly differences related to instructor, design, and teaching philosophy, there is a more fundamental difference—nonmajors courses normally stand alone, whereas the typical majors course is part of an extended sequence or group of courses that are expected to be taken by the student. How

Table 1. Differences in majors and nonmajors courses

Course type	Course goals and characteristics
Majors	High level of "scientific/discipline-specific literacy" One of a sequence of courses Weed out "unsuitable" students
Nonmajors	Basic level of "general/biological scientific literacy" Stand-alone course Inspire students to take up the major Increase departmental student contact hours Appealing to the consumer

does this extended sequence of courses impact course and curriculum design and learning outcomes? Consider how much language fluency students might be expected to achieve in a single course in their nonnative language and you get the picture—it is almost impossible to imagine that they could converse above the most rudimentary level. Is this what we mean by scientific/biological literacy?

There are a number of secondary, but nevertheless important, differences between majors and nonmajors courses. Majors courses are commonly viewed as harder, more rigorous, and more comprehensive—unfortunately, there is little objective data that they actually produce better or more extensive learning gains compared with nonmajors courses. In a set of studies, Sundberg and colleagues (Sundberg and Dini, 1993; Sundberg *et al.*, 1994) found "an *inverse* [my emphasis] relationship between the amount and rigor of content presented and 1) positive change in student attitude and 2) increased conceptual understanding! Students developed more sophisticated conceptual understanding, and a more positive regard for science, when fewer specifics were taught" (Sundberg, n.d.); and "majors, who received a much more rigorous treatment of the material, come through the semester with the same degree of understanding as the nonmajors!" (Sundberg and Dini, 1993).

At the same time there is a common perception among students, and at least some faculty, that an important goal of introductory majors courses is to "weed out" those who are not appropriate (whatever that may mean) for the major. On the other hand, nonmajors courses are often (but not always) whirlwind, and necessarily superficial, tours through a subject. This is a design feature that often leads to the perception that such courses trivialize difficult subjects, although it is also possible that they can inspire students to study specific topics further. There are also the real institutional factors at work; a primary raison d'etre for many nonmajors courses is to capture student contact hours rather than to bring students to literacy in the subject. Because departments compete with one another for a limited number of student science requirement credit hours, there is a pervasive temptation to make these courses more appealing to the consumer, rather than designing them to optimize learning.

ARE EITHER MAJORS OR NONMAJORS COURSES ADEQUATE?

Most surveys of public attitudes indicate that ~50 percent of the general public are confused or misinformed about the nature of science. These surveys, which rarely query more subtle, but nevertheless critical, aspects of scientific methods or concepts, do not attempt to identify underlying misconceptions. It is therefore quite likely that the level of scientific literacy is actually much lower than is commonly recognized. The question then is, what level of scientific literacy is adequate for our society? This is a very difficult question to answer. Shamos (1995) argues that market forces will, over the long term, drive the production or the importation of all of the scientific expertise needed by the economy. But what about general biological literacy—isn't that important? Probably, but again the question is, what level of literacy are we seeking to achieve, and how much in the way of resources are we prepared to devote to its attainment? Presumably most would agree that a suitable goal is a level of fluency that enables one to make informed choices about health care issues, to judge in a reasonable way how to interpret the news, and to appreciate the beauty of our growing understanding of our living world.

At present there are few objective and validated assessment tools for measuring student comprehension of key biological concepts; it is therefore quite difficult, and often impossible, to determine which type of course, majors or nonmajors, will attain our learning goals. More importantly, the goals for both majors and nonmajors courses need to be clarified and made explicit, tested to see whether they are attainable; and if not, either these goals must be revised (i.e., made more realistic), or more resources (e.g., student credit hours, alternative teaching strategies) need to be assigned toward their accomplishment. While it is possible to believe that biological vignettes presented in many nonmajors courses can be understood in a meaningful way without the rigor of a learned vocabulary and syntax, there is little or no objective evidence to support the claim. Anecdotes of inspired students can distract us from the majority of students who pass through such courses with their misconceptions intact (if not actually strengthened) and little understanding acquired. At the same time, the structure of majors courses is too often based on the belief that the breakneck pace of progress in the biological sciences demands an equally frenetic pace through the material. Unfortunately this type of class structure often leaves fundamental concepts poorly grasped and ignores the fact that many of the basics in the biological sciences are as well established and essentially static as those in basic physics and chemistry. The failings of both majors and nonmajors courses can, I conclude, be recognized and eventually corrected only through the development and deployment of objective and validated instruments designed to measure whether course learning goals are actually achieved.

If biologists had assessment instruments analogous to the Force Concept Inventory for basic Newtonian mechanics (Hestenes *et al.*, 1992; Klymkowsky *et al.*, 2003) , introductory majors and nonmajors courses would converge toward a common focus on fundamental concepts, critical to communicating in the language of biology. Introductory majors courses will spend more time ensuring that students actually understand the material presented (which is likely to drastically reduce the quantity of material "covered" per credit hour), while nonmajors courses will be forced to cover basic concepts needed to understand biological processes.

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