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Note from the Editors

Points of View (POV) addresses issues faced by many people within the life science education community. Cell Biology Education (CBE) publishes the POV Feature to present two or more opinions published in tandem on a common topic. We consider POVs to be “Op-Ed” pieces designed to stimulate thought and dialogue on significant educational issues. Each author had the opportunity to revise or add to his/her POV after reading drafts of the other’s POV.

In this issue, we ask the question, “Are survey courses still viable for introductory biology?” The POV question is related to the ones asked by the National Research Council in the recent feature by Jay Labov (www.cellbioed.org/articles/vol3no4/article.cfm?articleID=132) and continues to be a subject of debate by many science departments, not just biology. Often the discussion is split not only by perceived value of the survey course, but also by the size of the institution. Therefore, we present four POVs, plus a framing POV to set the tone. The overview was written by Arri Eisen, who is a senior lecturer in Emory University’s Biology Department and the director of the Program in Science & Society. Representing the Anti-Survey, Large University is Janet M. Batzli, Associate Director of the nontraditional Biology Core Curriculum at the University of Wisconsin at Madison. The Anti-Survey, Small College perspective is presented by David Becker, who is an Associate Professor and Magdalena R. and John P. Dexter Professor of Botany in the Department of Biology at

Pomona College. Presenting the Pro-Survey, Large University perspective is Douglas M. Fambrough, Professor of Biology at The Johns Hopkins Department of Biology and Scientific Director of the Searle Scholars Program. Finally, the Pro-Survey, Small College POV was coauthored by Mary Lee Ledbetter and A. Malcolm Campbell. Ledbetter is a Professor of Biology at College of the Holy Cross and a 2003 NSF Director’s Award recipient. Campbell is an Associate Professor of Biology at Davidson College and a co-Editor-in-Chief of CBE. Readers are encouraged to compare the authors’ perspectives and share their thoughts and reactions using the online discussion forum hosted by CBE at <http://www.cellbioed.org/discussion/public/main.cfm>.

Running out of Hands: Designing a Modern Biology Curriculum

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What makes a good teacher? What makes a good curriculum? While these two questions are intimately related, they are different. And when I think about them, I find myself feeling like Teyve in *Fiddler on the Roof* dealing with a perplexing problem—that is, I quickly run out of hands. On the one hand, when I reflect on my best teachers, I can’t separate the person from what the person taught me. On the other hand, when designing a curriculum, we want to figure out what to teach and how, and leave out the person, because 1) personnel changes, 2) teachers have different styles, and 3) a good curriculum allows for these different styles. On the other hand, while personal style overlaps with pedagogy—the “how” of teaching—they are different. On the other hand. . . I have run out of hands.

Let’s simplify a little and just discuss key questions and issues that *should be addressed* in designing a rigorous biology curriculum. Since introductory courses set the tone, standards, and expectations for the curriculum, we’ll focus our discussion on introductory courses as a model for thinking about the entire curriculum. Because this is an “overview” for a series of Points of View articles (POVs), I can cheat some and not give you any answers (see the four POVs that follow for some possible answers). Instead, I’ll sneak into a discussion of these key questions and issues, which I’ll call The Big 5. These five key points are important to consider,

especially because we tend to lose sight of them since we're often too close to our own blackboards to have a broader perspective. Some of my comments may sound like common sense, but keep in mind that most everything those bestseller self-help books say is common sense, yet they're still bestsellers.

1) GOALS

What are the overarching goals of your curriculum? Teaching students how to think? Imparting fundamental information? Covering "need-to-know" information for an internal or preprofessional test? Offering a curriculum that looks similar to, or different from, other institutions? Teaching as little as possible so you have more time to do research? Making classes smaller or bigger?

At Emory University, where I teach, and probably at many other research/teaching universities, the answer to all these questions, however seemingly contradictory, is "yes." Thus, we have to prioritize, sweat, compromise, and wrangle—all crucial elements to any successful curricular renovation.

2) DATA

We are scientists; we base our professional lives on data. Why not our classroom life? There is a large, improving, and growing literature on learning, thinking, and teaching from neuroscientists, educators, psychologists, and others. Many journals are devoted to these topics, and many professional scientific journals have teaching articles and supplements. Explore them.

Some examples of lessons found in educational literature: 1) Different people learn differently. 2) Experts in different fields have common ways of accessing and synthesizing information to solve problems. 3) A key element of learning is the ability to transfer knowledge from one context to a new and previously unknown context. We can (should?) research our own curricula and how we design them. Again, there is significant expertise and literature on assessment and educational research.

3) CONTEXT, CONTEXT, CONTEXT

The literature from many disciplines agrees that we all learn things better, our brains grasp them better, when they are presented/explored in a rich context and connected to previous learning and experience. Metabolism can be boring; metabolism in the context of an Olympic sprinter or maple syrup urine disease is interesting and motivating. Including experimental history and context is vital, also. As a straight-"A," "highly and impressively trained" product of American science education, I was shocked to find myself clueless in my first year of a Ph.D. program in biochemistry. I had heard and regurgitated quite well; I had performed my lab exercises and gotten the right answers. But context was missing. I had learned very little.

An unfortunate, but well-established, notion with somewhat scary implications is that science taught in societal and interdisciplinary context is a great idea *for nonmajors' courses*. True, but who should better understand cardiac health in

terms of the rest of the body, diet, culture, and society than a physician or bench scientist?

4) LABS

The lab is where science happens. All we can do in lecture is get students excited, interested, thinking, and enthusiastic, but it's in the lab where scientists are made (or not). My old friend Warren from high school biology was a "C" student in an average high school, but in the lab he was a whiz kid, with incredible hands and knack for experimentation. Now Warren is a successful geneticist.

Integrating lab and lecture conceptually, with coordinated exercises and communicative instructors, is important. It seems sinful that students have to suffer through teaching labs where results are known in advance, students don't become familiar with one or two model systems, and they do not learn how or why experiments were designed. The consequence of these dreadful labs will be students like me lost in graduate programs, or worse, perhaps good students who never go into science in the first place.

5) STUDENTS

Who are your students? What are their science backgrounds? Where are they headed after graduation? Where would you like them to go? I put students as the last of The Big 5 because, while students are important and they shape our *teaching context*, I'm not sure the first four key issues are altered by the fifth. That is, your answers to the questions in the first Big 4 key issues might be, or maybe should be, the same regardless of your students.

At Emory, half of our introductory biology students have taken advanced placement biology, and half haven't had biology since the seventh or ninth grade. This is a challenge, but it has not kept us from currently designing a rigorous introductory series that attempts to "bring everyone up to the same level."

A careful exploration of The Big 5 and a long wrestling match with your colleagues should begin the focusing process toward a new curriculum, and the following POVs will help you even more in considering questions such as: should we adopt a traditional survey course approach or focus on covering advanced topics in significant depth? A careful reading of the POVs suggests superb models; great creativity; and a surprising amount of shared goals, structures, and pedagogies among very different institutions and departments irrespective of how a particular approach is labeled.

Even after running out of hands, Tevye usually made good and challenging decisions. If you were to ask him, I bet he'd say the process of reaching those decisions was nearly as important and educational as the decisions themselves.

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A Unique Approach? Four Semesters of Biology Core Curriculum

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“Why four semesters? How does this track differ from the two-semester course sequence?” These are the most common questions students have when they learn about the Biology Core Curriculum (Biocore), a unique four-semester honors biology sequence at University of Wisconsin–Madison (UW–Madison).

Before I began teaching in and sharing the administration of Biocore, I had the same questions. My only experience with introductory biology curriculum, prior to coming to UW–Madison 2½ years ago, had been at large research universities that offered the traditional two-semester foundation courses, with one course in “organismal biology” that included ecology, evolution, transmission genetics, a little bit of physiology, and a survey of all known phyla. The complementary course, offered either before or after the organismal course, focused on cell and molecular biology and covered cellular anatomy, metabolism, bioenergetics, and gene expression and regulation. A 1-year introductory pair of survey courses seems to be the norm, either as a lecture-only format or paired with optional/required laboratory courses. The two survey courses serve as prerequisites for upper-division course work that provides more in-depth, intermediate, and advanced material. Sound familiar? My experience working in Biocore has convinced me of the merits of a four-semester approach, expanding on and integrating concepts and skills with the continuity that the increased time and contact allow.

HISTORICAL PERSPECTIVE

Biocore was first taught at University of Wisconsin in 1967. At the time, it was felt by many administrators and faculty that the teaching of biology at the undergraduate level lagged behind the rapid advances in our knowledge of biological systems and that the curriculum was constrained by departmental boundaries, compartmentalized as either animal or plant based and taught as such in the Departments of Zoology or Botany. The introductory courses in these departments were somewhat redundant, were taught only by faculty within those departments (even though there were about 15 other departments on campus associated with biology at the time), and did not challenge students to recognize the fundamental similarities across all biological systems. In response to this problem, a group of faculty recommended that a core curriculum be established that was bolstered by courses in mathematics and the physical sciences. In designing such a curriculum, the faculty “founders” sought models for nontraditional, integrated, interdepartmental programs. Their ideas were influenced by leaders such as Clifford Grobstein. Grobstein was a forward-thinking cell biologist from Stanford and University of California–San Diego, a

nationally recognized researcher in embryonic development, and a great thinker and communicator of new ways to organize biological knowledge for teaching (Grobstein, 1966; Wessels, 2000). What the UW–Madison campus took from the work of Grobstein and others was a call to involve faculty from across the campus—from the medical school and from the Colleges of Agriculture and Letters and Science—in the teaching of biology. What the UW–Madison faculty developed was a challenging, four-semester honors course sequence intended for students who plan to go on to graduate or professional school. One main focus for the new curriculum would be a laboratory progression where students could experience and develop their understanding of the process of science firsthand. Key to the program’s success was the enthusiastic backing by the deans of the major colleges and the chancellor of the university.

Although the program has changed and evolved over its history, the basic goals, philosophy, program structure, and administrative support have remained the same. Four semesters (2 years) may seem a bit extreme, but the rationale was that modern biology cannot be taught effectively without a strong background in chemistry, math, and physics, and that true integration and development of students’ knowledge takes time and requires continuity. The impetus, goals, and recommendations outlined nearly 39 years ago are strikingly similar to those laid out in the recent *Bio2010* report (National Research Council, 2003). Although the curriculum lacks the emphasis in computer science and physics, it most highly resembles that of “potential curriculum C” outlined on p. 57 of *Bio2010*.

THE CURRICULUM

Students do not begin their biology course work in Biocore until the fall of their sophomore year. The rationale for this timing is that students cannot gain a deep understanding of biology without first establishing a firm grounding in chemistry and math. The sample course curriculum illustrated in Figure 1 allows for component Biocore courses to be integrated with one another and with chemistry, math, and physics courses that are taken previously or concurrently. The Biocore sequence begins with an overview of evolution, ecology, and transmission genetics in Biocore I; moves into cell and molecular biology in Biocore II, with great emphasis on chemistry and bioenergetics; continues with physiology in Biocore III, where students apply physics, chemistry, and math in their study of both plant and animal physiology; and culminates in a capstone experience in Biocore IV. In Biocore IV, students synthesize concepts and skills learned over the previous three semesters of lecture and lab and apply what they have learned to studies of the primary literature using a cooperative learning pedagogical model (Burgess, 2002). Laboratory courses focus on the process of science and challenge students to develop their own independent research projects, with topics drawn heavily from the lecture courses as well as their math, chemistry, and physics experiences. Labs are structured so that over three semesters students gradually gain a high level of sophistication and confidence in doing independent research in the language and conventions of the discipline. All laboratory courses stress making observations (Figure 2), designing tests for hypotheses, drawing conclusions based on evidence, and writing reports in the form of scientific papers. The courses

First Year	
<p>Fall</p> <ul style="list-style-type: none"> • Chem I or Chem I/II combination (and lab) • Math I (first semester calculus) • General Ed electives 	<p>Spring</p> <ul style="list-style-type: none"> • Chem II (and lab) • Biology Seminar (Ways of Knowing Biology) • Math II (second semester calculus) • General Ed electives
Second Year	
<p>Fall</p> <ul style="list-style-type: none"> • Biocore I lecture & lab (Ecology, Evolution, and Genetics) • Organic Chem I (and lab) • Statistics • General Ed electives 	<p>Spring</p> <ul style="list-style-type: none"> • Biocore II lecture & lab (Cell & Molecular Biology) • Organic Chem II (and lab) • Physics I (and lab) • General Ed electives
Third Year	
<p>Fall</p> <ul style="list-style-type: none"> • Biocore III lecture & lab (Organismal Physiology) • Physics II • Biochemistry I • Independent Lab Research 	<p>Spring</p> <ul style="list-style-type: none"> • Biocore IV (Capstone-Biological Interactions) • Biology Elective • Chemistry Elective • Biochemistry II • Independent Lab Research
Fourth Year	
<p>Fall</p> <ul style="list-style-type: none"> • Biology/Science Electives • General Ed electives • Independent Lab Research 	<p>Spring</p> <ul style="list-style-type: none"> • Biology/Science Electives • General Ed electives • Independent Lab Research

Figure 1. This example sequence shows a typical progression for a student through a biological science major at UW–Madison integrating Biocore into a 4-year course plan. The first two Biocore courses are introductory courses while the third and fourth are intermediate. Genetics is taught formally in Biocore I and II and integrated into Biocore III and IV so that many majors do not require an upper-level Genetics course. Students typically seek out and do independent research in research faculty labs starting in their sophomore or junior year unless they study abroad. This research experience usually sets them up for a senior thesis project in their fourth year.

are writing intensive and challenge students to analyze and think critically about scientific data.

The primary learning objectives for a Biocore student are to:

1. Utilize experience, knowledge, and creativity to solve complex biological problems.
2. Understand how we know what we know in biology through study of the nature of science, the primary scientific literature, and historical experiments.
3. Build a logical argument based on evidence, learn to think critically, be skeptical, look at evidence before believing, and understand that there is not always just one right answer to a question.

4. Use terminology accurately and effectively within appropriate conventions of the discipline.
5. Frame sophisticated biological questions, formulate testable hypotheses, design and carry out experiments, and make logical conclusions based on evidence.
6. Analyze a problem using a systems approach (“systems thinking”), recognizing levels of biological organization and emergent properties of the whole.
7. Express ideas clearly and logically in oral and written form.
8. Know how to find and evaluate information.
9. Work as a member of a productive, collaborative research team.
10. Identify how biological structure follows function and recognize how this phenomenon results from the process of evolution.

Admission to Biocore is by application only. Because we know that four semesters is a big commitment, we want to give students an opportunity to carefully consider their options. We ask them to fill out a short application and write a brief essay (see <http://www.biocore.wisc.edu/biocore> for the most recent application). The application also allows us to recognize students who we think will have the greatest likelihood of success. Although we look for students who have reasonable grades in their chemistry and math prerequisite courses, we know that the first year of college GPA does not always represent a student’s capacity for achievement in Biocore. Therefore, we also look at their motivation for applying, the achievement of which they are the most proud (this provides for the most interesting responses!), and how well they can formulate an argument in their essay.

Given the challenging pace and degree of sophistication that we expect, the courses quickly rise above introductory level. That said, not all students meet the challenge or “buy in” to the program’s philosophy, and there is attrition of roughly 10 to 15 percent per semester. Some students leave the program after two semesters because their major does not require the full sequence. Of the 150 to 160 students who enter the sequence and move through together as a cohort, approximately 85 complete all four semesters. These 85 students proceed to upper-level courses during their junior and senior years. In a recent survey of students’ future plans after leaving Biocore, 57 percent planned to apply for medical school, 22 percent graduate research in fields from genetics and bioinformatics to biomedical engineering and conservation biology, 8 percent public health, 7 percent dental school, 2 percent vet school, 2 percent law school, and 2 percent undecided.

Elements that have been crucial to the program’s success (or *staying power*) are: 1) strong advocates in higher university administration; 2) a dedicated and enthusiastic group of volunteer faculty who not only are outstanding scientists but are eager to experiment with their teaching; 3) program autonomy, such that our reporting and funding lines are independent from a department; 4) the same permanent academic staff in lab through three semesters, providing continuity and high standards for continuous intellectual development of students; and 5) a small and responsive program staff that can quickly help adjust curriculum as knowledge in the field advances. This last



Figure 2. Students in Biocore I lab (Ecology, Evolution and Genetics) take field measurements of foliage height in the Biocore Prairie. Students in this class are restoring a 5-acre, old agricultural field to tallgrass prairie. In the process, they are learning ecological principles and methods that they return to during the third semester lab when they utilize the prairie to study plant physiology. Some students choose to extend their studies into the summer months when they can spend concentrated time doing research during the growing season. The Biocore Prairie provides the context for authentic research experiences and a focus for teaching environmental stewardship.

point is very important, because integration and innovation require frequent communication among faculty, teaching assistants, and program coordinators. The courses are team-taught by faculty drawn from all over the campus. Typically, three faculty members participate in each course, attend each other's lectures, and meet regularly to plan and develop course materials. Each course is coordinated and led by one of the participating faculty, the course chair. Course chairs of all seven courses (four lectures and three labs) meet monthly to help maintain continuity, problem-solve, and develop new initiatives. Many faculty develop great loyalty to the program, demonstrated by the fact that of the 60 faculty who have taught in the program since its inception, 18 have taught for more than 15 years.

WHAT DO STUDENTS GET OUT OF THE SECOND YEAR?

Central to this question is the program focus on integration and intellectual development of students. Integration is especially important in the second year, when students are introduced to organismal (plant and animal) physiology

(which brings together study of seemingly disparate systems). Biocore III ties together the ecology and structure of an organism with organ-/tissue-/cellular-/subcellular-level functions utilizing an evolutionary perspective. The fourth-semester capstone course takes students a step further, allowing for deep exploration of a topic through readings and analysis of the primary literature, much like a graduate seminar. There are no textbooks (besides those purchased in previous semesters), and topics range widely and are dependent on the instructors' and students' interests. This provides for exciting discovery and discussion for both the faculty and students.

Although we have not systematically studied how students develop over the 2 years, we have designed many different types of assessments to get a handle on student learning. Given a smaller class size, instructors can assess learning in a qualitatively different fashion, including writing-intensive assignments and exams and many opportunities for discussions and oral communication of student scientific understanding. With greater student-to-instructor contact over four semesters, we are able to get to know students very well and can evaluate their level of under-

standing and development more effectively than we could in a large class over two semesters. Overall, there is an attempt to simulate the learning and teaching environment of a small college classroom rather than a large university survey course. All of these features are essential for maintaining quality control and ensuring a productive learning environment; however, the effort is quite resource intensive. The amount of “resources” consumed per student taught, when dollars and person-hours are considered, is undoubtedly higher than the alternative two-semester sequence.

One problem that complicates the issue is that students come in thinking that their success in biology courses depends on their ability to memorize. Much of the introduction to any domain of learning is driven by vocabulary and definitions associated with an unconnected basket of “facts.” Biology is particularly messy in that way because “the facts” depend so heavily on weaving together research approaches at several levels of organization (from molecules to biosphere) and a strong foundation in chemistry, physics, mathematics, and statistics. It takes time for students to mature beyond memorization and thinking that all knowledge is certain and absolute. Evidence of this lower level of thinking is the often-heard statements “tell me what I need to know” and “I read it in the textbook or heard it from my professor, so it must be true.” It almost comes as a surprise and epiphany when students recognize that “the facts” are constantly changing branches of knowledge that are relativistic and intertwined. We want students to appreciate that they have control and responsibility for constructing their own knowledge. In Biocore, a critical stage in maturation seems to take place at the end of the second and beginning of the third semesters, when students are familiar with the expectations, goals, their peers, and the learning environment, and they are ready to critically engage in the science of biology.

In uncommon circumstances, students may reach this higher level of intellectual development naturally. But the maturation process is much slower when they don’t realize the goal, or haven’t been challenged in that direction, or given the support and guidance to get there. If undergraduates have experienced this epiphany at a large research university, they likely attribute their development to one-on-one mentoring in a research lab.

I would argue that it is rare to find a curriculum at a large research university that actively fosters discipline-specific intellectual development in a systematic way. I would argue further that it is the responsibility of faculty at research-intensive universities to implement curriculum that facilitates this type of development. One could counter and say that not all students intend to pursue careers as scientists, and that it is the responsibility of upper-level courses to facilitate learning at this level of sophistication. However, it is rare that upper-division courses can provide an integrative treatment of biology, since they are often not well coordinated with introductory courses. Instructors struggle with students’ differential preparation and may complain that they spend too much time covering remedial material that students should have come in knowing.

It is only under unusual circumstances that I have observed students come out of upper-division courses in a traditional curriculum with a true appreciation of the big-picture questions in biology today: How do biologists ask questions and do their science? How is everything in biology

integrated and connected at multiple levels? Many students do achieve this level of intellectual maturity during their experience in Biocore. Their examples continue to convince faculty, administrators, and prospective students of the value of a four-semester approach at UW–Madison.

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A Case for Nonsurvey Introductory Biology Courses

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OUR MOTIVATION

In spring of 1998, the Biology Department at Pomona College changed from a two-semester survey introductory biology sequence to a core set of three courses, none of which is a traditional survey course. We had been wrestling for several years with a number of issues regarding the survey courses, including 1) what topics to include and exclude, 2) the perception by our students that these survey courses were “like high school biology,” 3) the anonymity felt by students in the large (for us: 90–120 students) lectures, and 4) the impersonality of giving those lectures. We finally made a breakthrough when we went through the exercise of starting from scratch to design an introductory curriculum that 1) we would enjoy teaching, 2) would introduce our students to the fundamental principles and methods of practicing biology, and 3) would excite our students about biology in general.

THE COURSES

We decided that the first course would be centered on the thread that runs through all types of biology: genetics

(see Table 1). Genetics is offered in the spring semester so students can take the first semester of general chemistry in the fall semester. The Introductory Genetics course (current text is *Genetics*, Hartwell *et al.*, or *Principles of Genetics*, Snustad and Simmons, depending on section) starts with transmission genetics, moves to the central dogma and molecular genetics, then finishes with population genetics. This introduction to biology via genetics sets the stage for the remaining two core courses: Cell Chemistry & Cell Biology and Ecology & Evolution. Introductory Cell Chemistry & Cell Biology covers basic biochemistry, membranes, membrane transport, action potentials, intermediary metabolism, and a number of additional aspects of cell biology. Introductory Ecological & Evolutionary Biology includes evolutionary and population biology, behavioral and community ecology, and conservation biology. Both Cell Chemistry & Cell Biology and Ecology & Evolution are taught as sophomore-level courses (text for Cell Chemistry & Cell Biology is *World of the Cell*, Becker [no relation], Kleinsmith, Hardin, and the texts used for Ecology & Evolution are *Essentials of Ecology*, Townsend, Begon, and Harper, plus *Evolutionary Analysis*, Freeman and Herron). Students are introduced to primary literature in both courses. The laboratory components of cell Chemistry & Cell Biology and Ecology & Evolution emphasize the *processes* of biology: hypothesis formulation, experimental design, performing experiments, analysis of data, and communication of results. In each course, students design projects, conduct experiments, and report (orally, in journal-article format, and/or by poster; Figure 1) their findings. Upper-level courses are available as a smorgasbord, each having either Cell Chemistry & Cell Biology or Ecology & Evolution as a prerequisite. Thus, students may start taking upper-level courses as early as the spring of their sophomore year.

Course Formats

For all three introductory courses, we opted for depth at the expense of breadth. The primary objective was to get beyond the descriptive aspects to more interesting and even unresolved issues. For Cell Chemistry & Cell Biology, for example, this meant talking about mechanisms and strategies for regulation of pathways and processes, while illustrating how models have changed over time and giving multiple examples when there are competing

models. To the extent that we can, we describe seminal experiments to include not only *what* we know about a topic, but also *how* we know it. The goal is to get students to think critically about what they are learning, gain an appreciation for the practice of biology, and find the process exciting enough to continue in biology. In addition, this format is much more interesting for us to teach. We want our students to understand that we are not biologists because we like to memorize information, but rather because we like to use the information to ask and answer questions about biology.

All three courses were developed by the three subsets of the biology faculty that teach them, and all three course designs were presented to and vetted by the department as a whole. Even with different faculty teaching the different sections, we felt it was desirable for content to be consistent. For each course there is an “equalizer” that describes in some detail the topics covered. Thus, those teaching Cell Chemistry & Cell Biology and Ecology & Evolution know exactly the extent of genetics background their students have when they enter each course. Likewise, for upper-level courses, we know quite specifically to what topics the students have been exposed and to what levels. Additionally we know they have begun to read the primary literature, so we can opt to make heavy use of it at the outset in upper-level courses.

Organismal Biology. I can hear the organismal biologists moaning (or worse) as they read about our core course contents. This is an issue that we discussed at length during the formulation of our introductory curriculum, and the decision to omit organismal biology *per se* from the core courses came with the following two conditions: 1) we would consciously choose a variety of organisms for use in the labs for the three courses and would spend appropriate time describing each organism, placing it in a larger context; and 2) our majors are required to select at least one upper-level course (with lab) that qualifies as organismal (addresses topics at the level of the organism for a majority of the course). Examples of organismal courses include Animal Physiology, Plant Physiology, Animal Behavior, and Comparative Endocrinology. Personally, I don't feel that we have been successful in these attempts to include biology studied at the organismal level. I expect that next year we will take up the organismal biology issue again. Some biology departments have four courses in their introductory/core sequences, and that is one of the possible solutions we will discuss. To keep the small sections in the introductory courses will be a challenge, however, if we add a fourth course. Maintaining small class sizes was one of the issues that led us originally to the sequence of three courses, and it remains to be seen if we would be able to staff a fourth core course.

Small Multiple Sections. Just as significant as the course content change, we also adopted the multiple-small-section model, à la calculus. A full-time faculty member teaches each section, including the weekly lab section. We currently teach four sections of Introductory Genetics each spring, three sections of Introductory Cell Chemistry & Cell Biology, and two sections of Introductory Ecological & Evolutionary Biology. Section sizes are typically 24–32 students, which permits the classes to be much more interactive. Because the faculty member teaches both class and lab, he or she gets to know the students quite well and vice versa. Small classes

Table 1. Introductory course sequence for biology majors^a

Sequence	Course	Semester/year
First course	Genetics	Spring/first year
Second course	Cell Chemistry & Cell Biology	Fall/second year
Third course	Ecology & Evolution	Spring/second year

^aGenetics and Cell Chemistry & Cell Biology are also required for interdisciplinary majors in neuroscience and in molecular biology. Genetics and Ecology & Evolution are required for a biology emphasis in interdisciplinary majors in public policy & analysis and in environmental analysis. Students also take the two-semester General Chemistry in the first year and two semesters of Organic Chemistry, typically in the second year.



Figure 1. Poster session in Cell Biology & Cell Chemistry. Student pairs design and carry out projects on photosynthesis in which they ultimately measure and express rates of photosynthesis as light-dependent oxygen evolution. Projects this year included ultraviolet B effects; comparisons among C-3 plants, C-4 plants, and Crassulacean acid metabolism plants; circadian rhythm effects; elevated CO₂ levels; and foliar iron application. Students present their work to each other in a poster session, in which peer evaluation is an important aspect. Their previous project (on succinate dehydrogenase) was presented via oral presentations and in papers written in journal-article style.

also permit more overt connections between classroom topics and lab activities. Students and faculty alike are much happier with the small sections, but a consequence of the increased staffing requirements is that fewer upper-level courses are offered.

DID WE SUCCEED?

Beginning with a genetics course addressed the issue of our students' first biology course not appearing to be a repeat of a high school class. Nearly all of our students have taken biology in high school, and significantly more than half have taken advanced placement (AP) biology. We did a study and an experiment prior to 1998 to address the question of whether or not we should place students who scored a 4 or 5 on the AP biology exam out of the first course in our survey sequence. The study compared AP scores of students who

took the first survey course with the grades they earned in the course. There was no correlation between AP score and college survey grade and, furthermore, students who had not taken AP biology in high school fell in the same distribution of grades as the students who had. We had no way to test our hypothesis directly, but we felt that the familiarity of topics in the survey course gave the students a false sense of competence, and our level of expectation for their performance exceeded theirs. This disconnect between performance and expectations resulted in a less-than-satisfactory situation. The experiment we performed was to offer students who had scored 5 on the AP exam the choice to skip the first course and enter the second one directly. Skipping the first course overwhelmed the handful of students who selected that option. They all performed quite poorly in the second course, probably due to a variety of factors. They had not experienced the adjustment to college biology courses (especially the labs and the exams), they

were first-year students in a class of sophomores and juniors, they had not been through a semester of general chemistry, and they were making the general adjustments to college life in their first semester on campus. Not surprisingly, we do not place any students out of Introductory Genetics in the new curriculum.

The smaller class sizes successfully addressed the other issues listed above. Faculty and students engage with the material together in the classes, with discussions in addition to lectures. Even the lectures can follow a more Socratic method. Anonymity and impersonality have disappeared from our introductory courses.

QUESTIONS OF CURRICULAR FIT

Nonmajors take the genetics course if they wish to take a biology course. Consequently, a number of examples used and topics discussed are of practical value and popular interest. For example, human genetic diseases are used frequently as examples, eugenics is discussed, and both genetic counseling and agricultural breeding applications are included in the quantitative genetics and population genetics content. If a student is going to take a single biology course in college, we feel genetics is the appropriate one, and typically one-half of the students in the Introductory Genetics class do not major in the three possible life science majors: biology, neuroscience, or molecular biology.

One difficulty that arises as a consequence of our new introductory curriculum is placing transfer students into the appropriate course. Typically, there is some redundancy with introductory courses they have taken elsewhere, but there is enough difference that in most cases the transfer students are best served by taking all three of our introductory courses. We have to consider transfer students on a case-by-case basis, and fortunately we do not have large numbers, so this does not present a major challenge. At an institution with larger numbers of transfer students, this would be a much larger problem.

THE BOTTOM LINE

Overall, we are pleased with our nonsurvey introductory sequence of courses, and we believe they meet our objectives better than their predecessors—a two-semester sequence of survey courses. We are not satisfied, however, with the current means to include organismal biology in our curriculum, and we will address this shortcoming again in the near future. It is impossible to determine the relative contributions by the structure of the courses versus the small class sizes to the apparent success (student satisfaction, faculty satisfaction, student success in post-Pomona biology-related endeavors) of the curriculum. Undoubtedly, both are important. What we particularly like are the increased level of student engagement with the material in the courses, the opportunity to emphasize the processes of “doing biology” in both class and lab, the increased depth of coverage of the topics in the courses, and the closer relationship that develops between teachers and students.

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A Case for Survey Courses in Biology

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In 2000 the Johns Hopkins University (JHU) Department of Biology began teaching year-long survey lecture and lab courses to majors and nonmajors alike. Last year, the lecture courses became required for biology majors (unless they choose to place out of these courses with biology advanced placement [AP] exam scores of 4 or 5). Prior to 2000, most biology majors took their first biology course, Biochemistry, the spring semester of their sophomore year, although some freshman seminars and a topical course called Physiology were options. Why were survey courses added to the curriculum? Just what are these survey courses? And do we know whether these courses enhance the major or improve the education of nonmajors in the life sciences?

WHY HAVE SURVEY COURSES?

About half of Hopkins biology majors took AP biology in high school. With our departmental focus on molecular, cellular, and developmental biology, it has always been a departmental tenet that strong foundations in physics, chemistry, and mathematics are essential to a deep understanding of these aspects of biology, and students were steered toward establishing these foundations before going on with biology courses. Even though the faculty widely shared the opinion that students completed the major without a broad biological perspective, the faculty took pride in the fact that the vast majority of graduates went on to medical school... perhaps the highest “premed success rate” in the country, which no doubt has contributed to Hopkins attracting a huge number of applicants whose professional goals are in medicine. Clearly, in some sense the system was not broken, so why fix it?

Among the strongest arguments for adding a survey course was that Biochemistry and Cell Biology were taught with the tacit assumption that students knew essentially nothing about biology. Many students took AP biology early in their high school years, and seemed not to remember much of it. Further, AP courses frequently fail to cover all the subject areas found in general biology textbooks, and the

depth of coverage is variable. Now that most of our students take two semesters of General Biology, instructors in the more specialized courses can confidently expect a certain level of biological knowledge.

A related argument for survey courses was that they provide a forum for presenting basic concepts not easily worked into advanced courses. Perhaps foremost among these concepts is that science deals with falsifiable hypotheses and verifiable observations. Another major concept is the degree to which different scientific disciplines intersect to provide a fuller explanation of our world: such diverse areas as atmospheric and earth sciences, paleontology, and systems analysis all come into play.

Another argument for a survey course was that our biology majors were frustrated by the scarcity of their favorite subject, biology, in their first 2 years of college. Likewise, nonmajors needed courses that might provide them with a broad foundation in the life sciences. One can hardly doubt that such a foundation is essential for full, thoughtful participation in our society as well as for making informed decisions about personal lifestyles and health.

It was hoped that the introduction of survey courses in the curriculum would help to counter negative attitudes that contribute to a loss of enthusiasm for learning. Because the new courses touch upon subject matter relevant to life in general, they should provide abundant opportunities for the instructors to show students that they care about students' quality of life and students' ethical strength, open-mindedness, and courage to deal with reality. A great deal of thought and hard work was put into providing enhancements that would help students stay in love with biology. These enhancements, which are described below, include team projects, weekly workshops, class participation technology, our Web site, and serious attention from Hopkins' Center for Educational Resources (CER) in conjunction with generous funding from the Howard Hughes Medical Institute (HHMI).

Finally, there was another aspect to the quality-of-life issue. People rarely see what they do not know or do not expect to see. A survey course has the potential for serving again and again as an eye-opener, hence the most life-enriching course imaginable. For example, if you can identify fungi, plants, and animals, then a walk in the woods (or even across campus) is a very different experience than if you can't.

WHAT ARE OUR SURVEY COURSES?

The biology survey courses consist of two semesters of lecture/project/workshop (four credits/semester) and two semesters of labs (three credits/semester) coordinated with the lecture material. The courses are team-taught by three faculty and one lecturer. Majors and nonmajors attend the same section together, and students with AP credit in biology may take the workshops separately as one credit/semester courses. Enrollment in the lecture courses is about 300, in the lab about 250, and an additional 40 take the workshops only.

The lectures cover the entire textbook (currently Purves *et al.*, *Life 7e*). The fall semester begins with animal behavior and ecology (the last section of the textbook). These subjects are among the most interesting to the students: they afford the opportunity to provide an understanding of organisms and their interactions with each other and the physical environment that is fundamentally different from the

"Disney" view most students bring to college. So, the beginning of the first semester is eye-opening and entertaining at the same time. This introduction to biology also avoids hitting students immediately with molecules/chemistry/energy, which they generally find either boring or scary.

Workshops are weekly classes in which guest experts (mostly from the Johns Hopkins faculty) present some aspect of research and/or current events related to lecture topics. Recent workshops addressed bird song, evolution of altruistic behavior, Chesapeake Bay ecology, cystic fibrosis, and bioinformatics (paralleling textbook-based lectures on animal behavior, ecology, cell membranes, and genetics). Laboratory exercises are also coordinated with the lectures.

The introductory biology survey courses pioneered the use of class performance system (CPS) technology on our campus. All students are required to have voting units (one-way devices much like a television remote control). Students use their voting units during lectures to answer questions posed by the instructor. Students earn points for participating, whether or not their answers to individual questions are correct.

All students also participate in team activities called "Biomes of Homewood." Teams of about five students are each assigned a "biome," a region of the campus, to follow through the semester. Special Web-based software, developed specifically for the course assignments, includes an interactive map of the campus and stores student responses from year to year. Students working in these teams apply concepts learned in class and from textbook material to complete simple weekly or biweekly tasks. Fall-semester tasks include identifying producers, herbivores, carnivores, etc.; examining effects of our recently emerged cicada brood; studying phylotaxy and leaf structure; and generally surveying the diversity of organisms within their "biome." (For further information about the Biomes project and demonstration, go to <http://www.cer.jhu.edu/index.cfm?pageID=272>.)

About 20 biology mentors (former students in the course) run regularly scheduled drop-in help sessions. Each mentor also serves as the contact person and provides guidance for three Biomes of Homewood teams.

WHY DO WE THINK OUR SURVEY COURSES ARE FULFILLING THEIR PROMISE?

We have been aided by a grant from HHMI and help from CER. HHMI has allowed us and the staff from CER to develop the Biomes of Homewood and Mentoring projects. Staff from CER attend most class meetings, conduct student interviews, lead focus groups, and help with software development and hardware issues. CER staff members also attend the weekly instructors' meetings and make suggestions for improving every aspect of the courses. Their data collection and analysis have allowed us to evaluate, sometimes quantitatively, our survey courses.

Last spring, nearly 70 percent of the students in the general biology survey courses considered themselves premed, but less than half will choose biology as their major. Since many nonmajors will become physicians, we feel justified in offering challenging courses for them rather than separate, less challenging nonmajors' courses. In fact, nonmajors report a high level of satisfaction with the breadth and depth of our courses.

Interviews with students in the introductory biology courses, conducted by CER, indicate that they greatly

appreciated covering the entire textbook. Feedback from former students of the survey courses consistently affirms that the courses were an excellent preparation for the Medical College Admission Test. An online discussion board has provided further confirmation of student approval of course coverage. Also, as part of a student-run schoolwide course evaluation system, students now give the survey courses much higher marks than they gave the starting courses under the old system.

In the spring of 2003, an anonymous survey of JHU students taking Genetics or Biochemistry found:

- 67 percent of respondents reported that taking General Biology was essential to their understanding of their current biology course.
- 84 percent were happy that they had had to take General Biology, in light of the demands of Genetics and Biochemistry.
- 63 percent of these students had taken AP biology in high school, with over 80 percent of them receiving a score of 4 or 5.

Interviews with the instructors in the upper-level biology courses have confirmed that students are better prepared. The instructors all said that they were able to teach their subject matter on a more advanced level.

Since the survey courses were introduced, Bioethics and several other majors at Hopkins have made these courses requirements for their majors. This attests both to the broader need for this course material becoming part of every student's knowledge base and to the quality of the courses themselves.

Introducing the CPS has provided a number of positives for the courses, as revealed by student interviews and focus groups. Students like CPS for self-quizzing, and they like seeing what the instructors consider important. They like the immediate feedback and ensuing explanation from the lecturer if their answers were incorrect. And they like the way CPS provides variation within class time and helps students stay alert. A side effect of the CPS system was a marked increase in class attendance. This effect has not been quantified, but the instructors estimate that attendance on a typical lecture day has increased from roughly 50 percent of students before CPS to 90 percent currently.

In addition to the evaluative information from students and faculty, the survey course instructors also have impressions that the courses have contributed importantly to some of the less-tangible aspects of student life and learning. Some of these impressions include:

- Students are developing better study habits and performing better on tests now compared with when the survey courses were first given.
- Students seem to appreciate the attention paid to their opinions about the course, and this has enhanced the enjoyment of the course for most students.
- Students entering the upper-level courses seem to have a firmer grasp of genetics and evolution.
- Students seem to have more perspective to put biochemistry and cell biology into a relevant context.
- Students are gaining fundamental knowledge in some fields not well represented elsewhere in the department, such as ecology, animal behavior, reproductive biology, and plant biology.

Finally, development of the survey courses has brought a group of Biology Department faculty together with several outside experts to build the best possible beginning for our students' undergraduate experience in learning and maturing. Weekly meetings of this group continue, and so there is continuous evaluation and continuous thinking about further improvements.

SUMMARY

The survey courses in biology at Johns Hopkins were set up fairly recently. They are significantly different from old-fashioned lecture courses; now they include workshops, team activities, drop-in mentoring, CPS usage, and monitoring of student points of view via an online discussion board, student interviews, and focus groups. With the survey courses in place, the amount and depth of instruction in the more advanced courses have increased. In addition to their function of helping students build broad foundations in the life sciences, the survey courses have provided a forum for addressing a variety of other needs, including development of study habits, development of collegial collaboration among students, and placing emphasis on connections between biology and society and between biology and personal life issues. Finally, the survey courses have required the faculty team to examine and challenge their approach to teaching biology to find innovative and, most importantly, effective pedagogical practices in the large-lecture setting. In this respect, the courses are always works in progress, and this will help maintain their value on campus.

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Argument Favoring a Survey as the First Course for Majors

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Reasonable people disagree about how to introduce undergraduate students to the marvels and complexities of the biological sciences. With intrinsically varied subdisciplines within biology, exponentially growing

bases of information, and new unifying theories rising regularly, introduction to the curriculum is a challenge. Some decide to focus immediately on one or a few of the subdisciplines, for example molecular and cellular biology or ecological and environmental biology, so that students may acquire sufficient depth during their studies to have mastered the subdiscipline, and so faculty can focus their efforts on areas within their expertise. Others continue to offer a general overview of principles and concepts, couched in examples drawn from various subdisciplines, and offering a comprehensive survey of the diversity of living organisms. Survey introductory courses generally require two semesters and are prerequisite to intermediate and advanced courses. Necessarily, surveys cannot cover all possible content, and faculty expertise may not be directly applicable to all aspects of such courses. Nevertheless we (and our institutions) favor this approach. In arguing for survey courses, we consider various aspects of teaching and learning in the context of liberal arts institutions such as ours.

In preparation for this essay, we surveyed the Web sites of the top 24 colleges, as identified by *U.S. News and World Report* in 2004. We examined the requirements for the major in biology, particularly whether they included a two-semester course that addressed aspects of organismal diversity (the area most likely to be omitted from other curricular models). The results are summarized in Table 1 and may serve as a foundation from which readers may want to discuss their own choices for introductory courses. From this survey, we chose seven questions that seemed fundamental to any discussion of how to introduce our students to the field of biology.

1) WHAT DOES IT MEAN TO BE A BIOLOGY MAJOR?

The word “major” implies to most students, educators, parents, and employers a significant concentration of course work in one of the traditional academic disciplines. It is understood to include both general familiarity with most elements that contribute to that discipline and often study of a specific area, in which the student has developed some expertise, in depth, perhaps even including research experience. A history major is expected to be conversant with not only European and American history, but also elements of world history, both classical and modern. A music major is expected to have studied both music history and music theory while developing some practical expertise in musical performance. By the same token, the credential of a biology major should say something about the student’s exposure to the range of subjects considered to be the biological sciences. Even upper-division students who specialize in a subdiscipline will be able to point to a broad foundation, a familiarity with animal, plant, and microbial diversity and the variety they represent, no matter in which area they subsequently focus.

And few students, even those with excellent high-school backgrounds, can know at the outset of college which area of specialization might ultimately attract them. High school education is too limited, and first-year undergraduates are too intellectually inexperienced to make selections that would set the path of their future education and career. At College of the Holy Cross and Davidson College, we find that even students with advanced placement (AP) courses in biology benefit from taking our Introduction to Biology

courses, as much for the intellectual approach as for the content. After completing those survey courses, they are well prepared to explore more specialized aspects of our curriculum, according to our resources and their interests.

Emerging after 4 years, sheepskins in hand, our biology majors are recognized by potential employers and by graduate/professional schools to have experienced the range of the biological sciences, if not in all its detail and depth, at least in representative ways that can serve as a foundation for further learning. Both technically and intellectually, they are prepared to contribute to society as scientifically trained.

2) WHAT SORT OF COURSE PROPERLY PROVIDES A FOUNDATION FOR THE WEALTH OF POSSIBILITIES FOR STUDY OF LIVING SYSTEMS?

We maintain that the introductory course should have three key features, no matter what its content:

- Exposure to a variety of ways to observe, manipulate, and understand living systems;
- Exposure to a variety of organisms to study; and
- Exposure to critical thinking and data analysis, no matter how the data are generated.

Such courses provide several pedagogical functions that serve first-year students particularly well. These courses can set a baseline for expectations of performance (study habits, integrative thinking, attitudes) that carry forward to upper-level courses. The courses can bring all students to the same level of basic understanding, despite their diverse high school experiences. Survey courses can build on the enthusiasm that motivated students to elect biology as a discipline for study in the first place, no matter whether that enthusiasm came from a love of outdoor exploration, fondness for pets, excitement from understanding biological mechanisms, or curiosity about human origins. As such, a good survey course can reduce the attrition that often occurs when students encounter inevitable difficulties.

It might be argued that little of the content of such a broad course will be learned thoroughly enough to be useful. That may well be true, but many aspects of learning benefit from repeated encounters. In addition, connections between different subdisciplines may be drawn among ideas that seemed peripheral when first encountered. Ask yourself how a person trained exclusively in molecular biology would appreciate the unique developmental and behavioral features of *Caenorhabditis elegans* or zebra fish as model systems. Even if the specifics are not recalled by a student after taking a survey course, the existence of strategies and organisms beyond a limited specialized area will be retained.

A final, practical issue is the “problem” of chemistry. Few students enter college with enough background in organic chemistry to benefit from studies of biochemical and molecular biological processes. Indeed, a number of institutions whose curriculum focuses on the molecular level do not let biology majors take any biology courses until their second year, so that students will have sufficient chemistry to profit from the focused curriculum. Enthusiasm for a biology major may wane if it must be put off for an entire year.

Table 1. Requirements for study of biological diversity for biology majors among schools ranked in the top 24 colleges in the *U.S. News and World Report* rankings for 2004

Ranking	Institution	Requirements
1	Williams College	101 (Cell); 102 or 104 (Organismal: <i>includes selected diversity</i>); six other courses, at least one of which is above cellular level
2	Amherst College	18 (Adaptation and the Organism: <i>includes selected diversity</i>); 19 (Molecules, Genes and Cells); five courses, with at least one mol/cell, one integrative, one evolutionary
3	Swarthmore College	001 (Cell/Molecular) + 002 (Organismal/Population) + six more courses with at least one each from Cell/Mol, Organismal, Population
4-6	Carleton College	125 (Genes, Evolution, and Development); 126 (Cellular Energetics, Metabolism, and Ecology); six courses, with representation from Cell/Mol, Organismal, Ecol/Evol, and a senior integrative exercise
4-6	Pomona College	40 (Genetics), 41E (ecol/evol), 41M (molecular) + five courses (four with lab) of which one must be organismal lab or field course + senior thesis
4-6	Wellesley College	111 (Intro organismal: <i>includes diversity</i>); 110 (Intro cell); four intermediate courses from cellular, systems, and community biology, two advanced courses (one with lab)
7-8	Davidson College	112 (second-semester intro) <i>includes animal diversity</i> ; also invertebrates emphasized on one group of distribution courses
7-8	Middlebury College	Two-semester intro; second-year requirement of choice of two among diversity courses
9	Haverford College	No straight biology major: specialize in molecular/cellular/developmental from the get-go, though cross-registration with Bryn Mawr is a possibility
10	Bowdoin College	104 (one-semester survey), 105 (lab investigations), one core course from each of three groups, and three additional advanced courses
11	Wesleyan University	205, -6, -7 series is introductory survey from cell through ecology. <i>Diversity is addressed in laboratory.</i>
12-13	Claremont-McKenna College	43-4 (Intro series; <i>second semester includes diversity</i>), six electives, and a thesis
12-13	Washington and Lee University	111 (organismal), 112 (cellular), 182 (literature), 220 (genetics), 295 (seminar). Additional electives selected from areas including diversity of living systems.
14	Vassar College	105-6: various topics explored in depth in class and lab/field as revealing general principles; topics chosen by individual faculty members. Diversity of plants and animals among intermediate electives.
15-16	Grinnell College	Intro to Biological Inquiry, then a semester of molecular/cellular and a semester of organismal/ecological plus five electives
15-16	Smith College	111-2 (cell/molecular in fall, organismal <i>including diversity</i> in the spring); four to six intermediate-level courses including organismal and evolutionary; advanced courses and electives
17-20	Bryn Mawr College	101-2 (Molecules to Cells, Organisms to Populations), six intermediate/advanced courses, one senior seminar
17-20	Colby College	163-4 (Cellular basis of life/ <i>Diversity</i> and Evolution); four courses in plant, evolutionary, cell/molecular, and organismal, respectively; one advanced course
17-20	Colgate University	Core courses in ecology, cell biology, genetics, <i>zoology, botany</i> , and two research courses
17-20	Harvey Mudd College	Core courses in Principles of Biology and Laboratory, Structure and Function, Molecular, Evolutionary, and Ecology/Environmental; additional advanced electives
21	Hamilton College	110 (Principles/organismal), 111 (Principles/cellular), 550-1 (senior thesis), and at least two advanced courses
22	Trinity College (CT)	152-3 (Organisms and Populations/Cells, Metabolism, Heredity), Genetics, six additional courses including at least one from each of four groups, including <i>Biodiversity</i>
23	Bates College	Two introductory-level and eight upper-level courses. Intro courses chosen from Invertebrate, Freshwater, Plant Diversity, Plants and Human Affairs, Microbiology, Human Genetics, and Biotechnology.
24	Oberlin College	Core courses: 118 (Organismal), 120 (Genetics, Evolution, Ecology), 213 (Cell/Molecular); at least two intermediate courses and one intermediate lab; additional upper-level courses and research/lab experiences

3) WHAT IS THE BEST STRUCTURE FOR AN INTRODUCTORY COURSE?

Various ways to design such a course can be imagined. It may be team-taught, taking advantage of faculty expertise while giving students a chance to meet several faculty members and build relationships. It may be designed around multiple small student groups, to provide students more intimate contact with their professor and a more individual approach to the subjects under discussion. It should have an

associated laboratory/field experience, so that from the outset, students realize that biology is not so much a body of knowledge as a process of understanding the living world, and that process involves constantly questioning and testing our understanding against observation and experimentation (Figure 1). If the course is associated with a lab, the lab experiences should be obviously relevant to the topics being discussed in the classroom. Ideally, lab experiences would include some opportunity for student-driven, open-ended



Figure 1. A first-year student prepares her pipette as part of a self-designed project to test the effects of environmental perturbations on an enzyme's activity.

discovery. Lab is also an excellent opportunity for students to learn to work cooperatively and collaboratively. It might even be possible to structure the entire course as lab based.

Content is conveniently managed with the help of one of the comprehensive textbooks currently available. These ideally would serve as a guide and a resource, not a hurdle to be surmounted. Fundamental principles should be identified and reinforced throughout the course, using both familiar and unfamiliar examples. Focusing on principles will help students keep in mind the “big picture,” which is often submerged in the wealth of detail, to the detriment of understanding.

Many students enter college with particular postgraduate plans in mind, particularly medicine. They often express impatience with any biology that is not directly “relevant” to human health and disease. Such students are particularly well served by a comprehensive introductory biology course, since it can reveal the true interconnectedness of the living world. Those who enter medical school will carry with them an appreciation for that world; other biology majors may discover that their true passion is something other than human biology, or become interested in the intersections of biology with other disciplines, either scientific or humanistic. The diversity of opportunities can be revealed within an introductory course, inviting students to find their passion based on exposure to areas they did not know they liked or did not know existed.

4) HOW CAN MEANINGFUL DEPTH BE PROVIDED IN A COURSE DESIGNED AS A SURVEY?

Survey courses can create the problem of “a mile wide and an inch deep.” But if the suggestion in #3 above for effective

use of a textbook is followed, the problem of lack of depth can be minimized. Most textbooks are jammed full of multiple examples of a relatively few fundamental principles. If the course focuses on fewer examples, but chooses them from equally diverse model organisms or levels of organization, then students can learn both the concepts and the diversity of their expression. If key biological principles are identified while the examples are presented, and the examples are used to enrich and bring these principles to life, then the course will not overwhelm students with factoids and trivia, but will help them recognize that “there is more where this came from.”

Here again, laboratory and field experiences are very helpful. Students can discover not only new concepts, but also new ways of learning. If research-based experiences are possible, students can design, perform, interpret, and communicate their own work, revealing connections between their own efforts and the subdisciplines of biology. Self-discovered knowledge is not forgotten quickly.

5) HOW CAN INDIVIDUAL FACULTY MEMBERS PROVIDE INSTRUCTION IN AREAS OF BIOLOGY FAR FROM THEIR EXPERTISE?

If we want our students to become lifelong learners, surely we can model this behavior ourselves and learn enough about new areas of our discipline to be able to convey the fundamental principles in class. All of us have had the experience of being asked questions, even in classes directly related to our expertise, for which we do not know the answer. Scientists have ways of finding the answer or helping students find it. We believe that reluctance to be found ignorant is a major obstacle preventing faculty members from undertaking more adventuresome teaching. Another obstacle is the time required to bring yourself up to speed in a new area. But the rewards for the effort to learn in a new area are great. By learning in wider areas of biology, our own ability to make connections among seemingly disparate ideas or facts is enhanced. Making new connections provides us with new insights that can inform not only our teaching but our research as well.

As a practical matter, an introductory course does not demand that the instructor master the same degree of detail or currency of information as a graduate seminar. Textbooks and resources on the Web provide suggestions for effective presentation. At the introductory level, limited detail does not significantly reduce the quality of the students' experience.

6) WHAT IN THE CURRICULUM MUST BE SACRIFICED TO OFFER THIS COMPREHENSIVE INTRODUCTION?

Choices made at the introductory level must compete with choices elsewhere in the curriculum. In particular, if we are to spend a year on “orientation” of the sort defended above, it may delay a student's access to more specialized courses and technical training. We maintain that an extra year of intellectual maturity and academic confidence will help a student gain the most from advanced courses. By that point,

too, many will have encountered organic chemistry and calculus, essential to understanding many advanced areas of biology. Intellectually, they are better prepared to think in statistical terms, too, after the first year of college. In subsequent years, progressively more specialized biology courses should be taken, reflecting the student's developing interests and the department's judgment as to the importance of certain key courses.

Inevitably, especially at liberal arts colleges, there will be gaps in a student's comprehensive biological education, either because courses are not offered or because the student's schedule prevents access to courses. Some faculty express concern that these deficits put students at a disadvantage in taking "gatekeeping" examinations such as the Medical College Admission Test or the Graduate Record Examination. And once admitted to graduate or professional school, students may be competing with students who have experienced more thorough curricula. We have found, however, that our students easily fill in any gaps that prove crucial for their future goals, simply because they are skilled learners. The specific curriculum that they have encountered is not as significant a factor for their success as the style of instruction that encourages them to develop their own curiosity, critical evaluations of data, self-discipline, and clear thinking. These valuable attributes have made our students highly desirable for programs offering further specialization after college.

7) DOES THE INTRODUCTORY SURVEY COURSE FILL THE NEED FOR SCIENCE EDUCATION FOR NONMAJORS?

At College of the Holy Cross and Davidson College, all students are expected to take courses in mathematics and natural science, no matter what their major. Math and science courses are part of the "common area requirements" associated with our liberal arts institutions. Many students

seek to fulfill these nonhumanities requirements by taking courses in biology. Often they elect courses designed specifically for nonmajors, focusing on a biological topic of current interest and using it as a vehicle to communicate the process of science and the value of scientific inquiry for society.

However, there is no reason that a general introductory biology course could not equally fulfill this function. Certainly science students fulfill humanities and arts requirements in courses designed for majors. At Davidson College, about 60 percent of the students who enroll in the survey courses choose majors other than biology. Their education benefits from the experience of authentic encounters with a variety of biological principles. Among the remaining 40 percent, some did not originally recognize their attraction to science. Thus, the course can serve both to recruit new scientists and to educate future nonscientist citizens.

In conclusion, we believe that two-semester survey courses are an ideal way to address the needs of students with diverse career interests and limited previous experience. Our model of survey courses can be modified to fit different faculty compositions and can be organized to begin at either end of the continuum of living systems (small to large or vice versa). Students are faced with real-world time constraints of a 4-year college curriculum, especially at institutions that value the breadth of the liberal arts. Each area within biology provides a burgeoning wealth of information that cannot be covered completely in any single introductory course. We do not believe that survey courses (or any courses for that matter) should be modeled on the old-style litany of facts to be memorized and regurgitated. Rather, survey courses should provide a broad perspective of biological principles illuminated with a limited number of wisely chosen examples. When a carefully crafted survey course is combined with active-learning methods, students can benefit regardless of their long-term goals.

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