The National Research Council-sponsored report, *BIO 2010: Transforming Undergraduate Education for Future Research Biologists*, describes a number of significant changes that should be made to the undergraduate biology curriculum if we are to adequately train students to become the researchers of the 21st century. What should be of concern to the physiology community is the lack of identifiable physiology in the proposed revisions. This article describes the report and suggests some steps that physiologists can take to enhance our discipline in the undergraduate biology curriculum.

**Key words:** education; interdisciplinary studies; comparative physiology

Recently, a colleague gave me a new book to read, *BIO 2010: Transforming Undergraduate Education for Future Research Biologists* (2). *BIO 2010* is the consensus report of a special committee convened by the National Research Council, supported by grants from the National Institutes of Health and the Howard Hughes Medical Institute. The committee was charged with considering how undergraduate biology education should prepare students for careers in biomedical research (p. 2).

As I read through the committee’s report, I became increasingly dismayed. It is not that I disagreed with what was said. Indeed, I wholeheartedly concur that our undergraduate biology students need a better foundation in chemistry, mathematics, and physics and more exposure to and practice with quantitative thinking. It is true that we need to engage our students actively in the process of science, both in the laboratory and in the lecture hall, and that our students must learn how to become independent learners. We should be emphasizing conceptual understanding instead of memorizing facts. We should be teaching biology as an interdisciplinary subject that draws from engineering and computer science as well as from the physical sciences and mathematics. This is all true. What scared me, as a physiologist, was the absence of physiology as an identifiable discipline in the book’s discussions of biology curriculum.

The Committee’s solution to how we should be training future biomedical researchers was “. . . a broadly based education in biology with a strong foundation in the physical sciences and mathematics. A well-educated biology major should understand the principles of population and evolutionary biology, ecology, cognitive neurobiology, and plant biology” (p. 24). What happened to physiology? Shouldn’t undergraduate students learn about the control systems and integrated functions of intact animals? Isn’t physiology the underpinning of most biomedical research?

It is not that the fundamental principles of physiology were missing from the committee’s report. In the chapter “A New Biology Curriculum,” the list “Concepts of Biology” includes the bullet points

- Biological systems maintain homeostasis by the action of complex regulatory systems. These are
often networks of interconnecting partially redundant systems to make them stable to internal or external changes.

• Communication networks within and between cells, and between organisms, enable multicellular organisms to coordinate development and function. (p. 33)

Isn’t this what we teach in a physiology course?

The recommendations for Physics include the statement:

...the whole notion of emergent behavior, pattern formation, and dynamical networks is so central to understanding biology... (p. 37)

This also sounds like physiology, both cellular and systemic.

One of the few explicit mentions of physiology in the entire report comes under the recommendations for inclusion of engineering principles:

Basic courses in physics and engineering should be developed specifically for life sciences students... This could be complemented exceptionally well by biology lecture or laboratory courses that assist students in their understanding of principles of physics and engineering (e.g., a unit on biomechanics taught in a physiology or anatomy course) (p. 39).

Many undergraduate physiology courses already include lectures and laboratory exercises on biomechanics! Overall, physiology courses already do an excellent job of incorporating basic principles of physics and engineering.

In the chapter “Instructional Materials and Approaches for Interdisciplinary Teaching,” the committee promotes the development of modules that “focus on important principles of mathematics and the physical and information sciences to demonstrate their relevance to biology.” They go on to give the following suggestion:

For example, a module on allosteric interactions in hemoglobin could enrich the teaching of respiratory physiology. Students could explore the following questions by carrying out interactive computer simulations: How does the cooperative binding of oxygen to hemoglobin increase the efficiency of oxygen transport? How much oxygen is released from hemoglobin when the pH is lowered? How is oxygen transport affected by high altitude?

Would any of us who teach respiratory physiology consider our instruction to be complete if we did not cover these questions?

The committee apparently was not aware of the quantitative nature of physiological processes and the fact that these are regularly taught in systems physiology courses. Indeed, they went so far as to suggest that it might be necessary to solicit help from colleagues in mathematics and physical sciences to develop course content that includes quantitative skills.

Initial teaching of, for example, a module on the fluid dynamics of blood flow in a physiology course could be done by a colleague in physics or math. For the biology faculty, incorporating such a module would be an opportunity to learn the underlying physical science and mathematics and potentially learn the skills necessary to teach the module independently (p. 103).

Are other physiologists reading this passage as upset by that statement as I was? We already teach the physics and mathematics of fluid dynamics! Have physiologists lost their identity to the extent that other biologists are not aware of what we do? Why would a biology department need colleagues from mathematics and physics to teach what physiologists teach every day?

It appears that physiology is invisible on many undergraduate campuses. In the chapter “Interdisciplinary and Project-Based Laboratories,” the committee proposes modifications to existing laboratories. One suggestion “incorporates ideas from engineering” and proposes “clinical biomedical studies such as”

...cell, nerve, and muscle potentials; electrocardiograms (ECG), electromyograms (EMG), body temperature, control of body temperature, heat loss from the body, blood pressure measurement, blood
flow and volume measurements, noninvasive blood-gas sensors...lungs... (p. 81).

Many of these studies are already standard exercises in undergraduate physiology laboratories.

The one place that the committee proposed physiology as a course was in the section “Interdisciplinary Lecture and Seminar Courses.”

At intermediate levels, a variety of course plans could incorporate material from the physical sciences and the mathematical concepts and skills that subsume these disciplines, into biological courses. Possible examples are a course in quantitative physiology (blood circulation, gas exchange in the lung, control of cell volume, electrical activity of neurons, renal countercurrent mechanism, muscle mechanics)... (p. 67).

These quantitative concepts are already part of any standard undergraduate physiology class. Perhaps we could do a better job of emphasizing the physical principles behind these physiological processes, but no physiologist would dream of teaching a course without including the examples presented in the paragraph above. The conclusion I draw from reading the report is that the biology faculty on the committee are not familiar with the content of a traditional undergraduate physiology course, whether human or comparative.

Why should the absence of physiology as a discipline in this report be of concern? The answer is that we need to be fighting for the recognition of physiology as a vital, exciting, core discipline that integrates all levels of biology with concepts from physics, chemistry, mathematics, and engineering. Physiology should be the new molecular biology. As scientists try to decipher the role and interactions of proteins coded by the genome, they should have a solid understanding, both quantitative and qualitative, of the complex organ systems of the intact organism, be it a fly, worm, mouse, or human.

Physiology has been experiencing decreasing graduate enrollments and declining numbers of young faculty members. Pharmaceutical companies are competing for scientists with expertise in whole animal physiology. If this document serves as the basis for revising biology curricula across the country, as proposed in the “Executive Summary,” the situation will only worsen.

In the chapter “A New Biology Curriculum,” physiology is not part of the core biology sequence; it is relegated to a list of biology electives proposed for the senior year. The Committee’s core courses are Molecular Biology, Cell and Development Biology, Genetics, and Evolutionary Biology/Ecology—topics that jump from the cellular and molecular level to populations of organisms (p. 56). What happened to organisms and the integrated function (i.e., physiology) of cells, tissues, and organ systems within the intact organism? When in these core courses will students be exposed to the big picture: how cells and molecules communicate and coordinate to create the complex entity we call an animal? Figure 1 shows the topics that will be missing in a core curriculum that leaves out physiology and illustrates how physiology integrates biology from molecules to populations of organisms.
It appears that physiology was not even considered for the BIO 2010 core sequence, because it has already effectively disappeared from the core undergraduate curriculum! The committee surveyed 104 institutions, and physiology was missing from their compiled list of required courses. The “consensus core [of courses currently required] . . . include[s] genetics, biochemistry, cell biology, microbiology, evolution/ecology, and a seminar” (p. 48). If this course list reflects what students currently study as undergraduates, it is no wonder that they are not applying to graduate programs in physiology!

In three of the four model curricula proposed by the Committee, the first opportunity a student would have to take physiology would be as a biology elective in the senior year. In the fourth model, physiology could be taken in the junior year. If physiology is relegated to the position of a seminar late in an undergraduate’s career (p. 67), we have lost the window of opportunity to have students become excited about physiology and involved in undergraduate physiological research before they solidify their career decisions.

I believe that the absence of physiology in this report was simply an inadvertent consequence of the Committee’s makeup. There were no animal physiologists among the eleven members. Four of the eleven mention neurobiology in their biographies, but one is a biochemist, two are molecular biologists, and the fourth studies the mathematics of self-organizing systems. The remaining members have research interests in organic chemistry (one), cellular or molecular biology (four), microbiology/immunology (one), and evolutionary biology and ecology (one). The unanswered question is why no physiologist was invited to participate on the committee or in any of the associated panels. Of the 25 faculty on the Chemistry, Physics-Engineering, and Mathematics-Computer Science panels, there was a cellular neurobiologist, two systems neurobiologists, and a biomedical engineer whose research focuses on biomechanics (none are members of the American Physiological Society). The 16 members of the Workshop on Innovative Undergraduate Biology Education did not include any physiologists.

Some of the blame for the absence of physiology in this report probably lies with us physiologists, as we have lost visibility in recent decades. When grant funding became tighter, comparative physiology, the mainstay of undergraduate physiology teaching, suffered because basic research on the physiology of crayfish, roaches, fish, lizards, and frogs was not going to cure cancer, heart disease, or AIDS. Even the mammalian physiologists among us have been so busy trying to retool research programs and learn molecular biology that somehow we failed to maintain our unique identity and promote the integrative nature of our discipline.

Physiology is on the upswing again, with research turning to proteomics and functional studies, but there has been a subtle shift in others’ perception of us. It appears that, to the members of the NRC panel, physiology is a discipline that is taught primarily in medical schools or in departments of biomedical engineering, or that it is a “service course” taught for premedical and health professions students. We must do everything in our power to correct this misconception.

One opportunity that physiologists missed by lack of representation on this committee was the chance to showcase the exemplary activities of the American Physiological Society in the realm of education. Naturally, the Committee brought their particular expertise and their professional society affiliations to the table. However, without a physiologist on the committee, not only were we skipped as a key discipline in the undergraduate biology curriculum but the American Physiological Society also did not receive the recognition that it deserves as one of the innovators in integrating education and research.

For example, a major premise of the report is development of teaching modules that could be introduced into otherwise traditional lecture classes. In this context, the committee describes both BioSciEd Net (BEN), the biology portion of the National Science Digital Library project, and “independent groups [that] have published modules or resources that could be used to enhance the teaching of undergraduate biology students.” In neither discussion was there mention of the rapidly growing APS Archive of Teaching Resources and its link to BEN, despite the fact that...
APS is one of the largest contributors of teaching modules to BEN.

In the discussion of how professional societies promote undergraduate research and education, only the American Society for Microbiology received mention, despite the fact that APS, like ASM, employs full-time staff devoted to education. The APS Education Office, under the expert guidance of Dr. Marsha Matyas, has a remarkable track record for obtaining extramural funding for APS initiatives, and APS spends $1.3 million in internal funds and grant money annually to improve physiology education and excite students about physiological research.

What can physiologists do to restore physiology to the undergraduate curriculum? How can we intervene? If this book is indicative of the national undergraduate biology faculty’s perspective, it may be difficult to act directly. At many smaller schools, the biology faculty includes only one physiologist. Even at some larger institutions, physiology is not a recognizable research unit unless a medical school is part of the same campus.

Perhaps one clue to what physiologists might do can be found in the following committee statement: “Another major impact on today’s curriculum are [sic] requirements for admission to medical school” (p. 48). We may be able to leverage our influence at the medical school level to restore physiology to the undergraduate core curriculum. Perhaps medical schools should add an entry requirement for an undergraduate animal physiology course. The biochemists have done this at a number of schools.

Adding a physiology entry requirement would ensure physiology’s place in the undergraduate curriculum, given the large number of students interested in the health professions. It would also allow the medical school physiology faculty to assume a basic level of physiological understanding in each cohort, and they could concentrate on teaching advanced topics rather than trying to start from scratch with naive students. Such a requirement would not add significantly to the hours taken by premedical students, as the Association of American Medical Colleges’ 2002 survey of graduating medical students (1) indicated that 75% had taken an undergraduate physiology course. In addition, these new MDs perceived physiology to be the undergraduate course most important in preparing them for medical school, with a ranking of 3.5 out of 5, ahead of genetics (3.0) and biochemistry (3.2). (Cell biology and molecular biology were not included in the survey.) Ideally, physiology would be placed early in the undergraduate course sequence so that students complete it prior to taking the MCAT in the spring of their junior year. From the graduate school recruitment point of view, an undergraduate physiology class would expose premedical students to what physiological scientists do in the laboratory and could encourage more students to consider summer research programs in physiology and careers in biomedical research.

I believe, however, that we have a lot of resistance to overcome if we propose this additional entry requirement for medical school. Committee recommendation no. 7, listed under the header “Harmonizing the Undergraduate Science Education of Future Graduate Students and Medical Students” says, “Medical school admission requirements and the Medical College Admissions Test (MCAT) are hindering change in the undergraduate biology curriculum and should be re-examined in light of the recommendations in this report” (p. 111). I suspect that many of us would disagree with this statement.

The broad requirements for most American medical schools are one year of biology (in other words, an introductory course in biology), chemistry through organic, and a year of physics. This requirement matches that for most undergraduate Bachelor of Science degrees and should not hinder change in higher-level courses in the biology curriculum. Furthermore, the most recent version of the MCAT minimizes memorization of facts and places a premium on the ability to think conceptually and to interpret data about a topic the student has never studied. These are two skills that the BIO 2010 committee would like to see promoted in the biology curriculum, and they are easily incorporated into a physiology course.

If a physiology entry requirement for medical school is to be viewed in a positive light by undergraduate biology faculty, we physiologists must show that a well-designed animal physiology course can achieve all the objectives put forth in BIO 2010.
and that physiology deserves a slot in the core curriculum. At the local level, we must work within our own institutions to ensure that physiology is adequately and identifiably represented in introductory biology courses and in courses offered for nonbiology majors. At the national level, those of us who teach at undergraduate institutions must make a concerted effort to become involved in the National Academy of Sciences’ proposed Summer Institute for Undergraduate Biology Education to ensure that physiology is represented in discussions of curriculum revisions.

Biomedical research is shifting back to whole animal studies. Proteomics and functional genomics are simply sexy buzz words for physiology. However, unless we physiologists take a more active role in the undergraduate curriculum and highlight how contemporary physiology uses modern research techniques developed by molecular and cellular biologists, no one will make the connection. If physiology is to survive and flourish as a discipline in the 21st century, we must educate everyone about what physiology is and what physiologists do.

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