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Editorial

From Vision to Change: Educational Initiatives and Research at the Intersection of Physics and Biology

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The authors of *Vision and Change* (American Association for the Advancement of Science [AAAS], 2011) issued the following call to action to biologists, physicists, chemists, and mathematicians:

To ensure that all students graduate with a basic level of scientific literacy and meet the challenges raised in *Bio 2010: Transforming Undergraduate Education for Future Research Biologists* (2003), *Scientific Foundations for Future Physicians: Report of the AAMC-HHMI Committee* (2009), *A New Biology for the 21st Century* (2009), and similar reports, biologists, physicists, chemists, and mathematicians need to look thoughtfully at ways they can introduce interdisciplinary approaches into their gateway courses. (AAAS, 2011, p 54)

The articles that comprise this special issue of *CBE—Life Sciences Education* (LSE) take important steps toward responding to this call by describing teaching and learning at the intersection of biology and physics. Broadly defined, the work aims to encourage the development of genuine interdisciplinary understanding, or “the capacity to integrate knowledge and modes of thinking in two or more disciplines or established areas of expertise to produce a cognitive advancement . . . in ways that would have been impossible or unlikely through single disciplinary means” (Boix Mansilla and Duraisingh, 2007, p. 219). Indeed, many of the most exciting recent breakthroughs in the life sciences have occurred at the intersection of these established disciplines. Physical laws help to predict, describe, and explain biological phenomena occurring at molecular to ecosystem levels, and the

development of new physical tools helps to visualize these phenomena in new and informative ways. Thus, the *Vision and Change* report stresses the urgency for undergraduate biology and physics educators to develop, assess, and revise content materials, pedagogical strategies, and epistemological perspectives for encouraging student learning in interdisciplinary biology and physics classes.

We received more than 50 abstracts in response to the call for this special issue, and we are pleased to publish 10 Articles, four Essays, and eight Features reflecting the state of educational transformation at the intersection of biology and physics. Several articles describe integration of physics into biology curriculum or biology into physics curriculum that goes beyond simple provision of examples from the respective disciplines (e.g., Batiza *et al.*, Christensen *et al.*, Svoboda Gouvea *et al.*, O’Shea *et al.*, Thompson *et al.*, Breckler *et al.*). A number of articles address cross-cutting themes, such as problem solving (e.g., Hoskinson *et al.*) and energy (e.g., Cooper and Klymkowsky, Svoboda Gouvea *et al.*), the application of mathematical laws to biological phenomena (e.g., Redish and Cooke), epistemology (e.g., Watkins and Elby), and assessment as a powerful tool for driving curriculum change, in this case the integration of physics and biological thinking (e.g., Svoboda Gouvea *et al.*, Momsen *et al.*, Thompson *et al.*). Other articles reflect research crossing disciplinary boundaries to introduce research approaches (e.g., Watkins and Elby, Momsen *et al.*) or innovative curriculum models (e.g., Manthey and Brewe, Donovan *et al.*, Thompson *et al.*) to help students develop reasoning strategies that move beyond traditional disciplinary boundaries. The Hillborn and Friedlander essay highlights potential impacts of cross-disciplinary collaboration in education on the revised Medical College Admission Test.

We were pleased by the number of articles coauthored by physicists and biologists working in teams to examine and recommend new directions for the future of biology education. These teams brought a richness and depth of knowledge in both disciplines that made it possible to move instruction and research forward at the intersection of the disciplines. Together, these articles start to provide the evidence base for responding to the calls for interdisciplinary teaching and learning. Further, they provide opportunities to compare and contrast education and epistemologies in biology and

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physics, allowing for more informed integration of knowledge from these disciplines.

Disciplinary Distinctions

Through the editorial process, we identified several noteworthy distinctions between physics and biology education. First, the introductory physics curriculum for biology students is essentially established, following a traditional progression through kinematics, forces, energy, and momentum. In contrast, the introductory biology sequence is more dynamic, highlighting considerably more current science. This difference is both a benefit and a challenge to each field. Biology faculty members are under constant pressure to innovate in their teaching due to the rapid pace of discovery in the life sciences. They must stay abreast of new biological knowledge and reflect the changing knowledge base in their teaching. Yet the rapid pace of biological discovery affords opportunities to teach with real, timely, and engaging examples that relate to students' daily lives. Introductory physics content is stable, which allows for research aimed at improving existing curricula and developing deep understanding of how students interact with and learn the material. At the same time, physics faculty members struggle to integrate current science into the curriculum and make physics relevant to students' daily lives. As is apparent in this issue, biology offers a notable entry point for the integration of current science into the physics curriculum.

Second, there is disparity between the topics that physicists view as "canonical," comprising a fundamental understanding of physical science and thus important for all students to learn, and the topics that biologists view as important for understanding and doing modern biology. Biologists argue that biology students should learn about random motion, diffusion, microstate thermodynamics, and fluid flow, which are often taught in graduate-level statistical mechanics and fluid dynamics courses. To many physicists, the problem with teaching these topics in introductory classes is that students lack the higher mathematics needed for sophisticated understanding. Yet biologists reference these topics in thinking about bioenergetics, metabolism, cellular activities, and physiology. In addition, the majority of introductory biology textbooks includes a unit on the chemistry of life, while the physics of life is scattered, qualitative, or even missing in action, as is the case with the role of entropy in processes such as the origin of membranes, protein folding into functional conformations, and virus "self-assembly." Questions arise that remain largely unaddressed by the work in this issue. How can sophisticated, biologically relevant physics topics be taught at the introductory level? And how should biology instruction be changed such that students are prepared to use physics knowledge and theory to understand biological phenomena?

Finally, physics education research (PER) and biology education research (BER) are distinct disciplines and have largely independently evolved practices. The PER community is more mature and has reached some level of consensus about education research methods and areas in need of education research. The PER community has also developed shared norms. For example, in physics and in many PER groups, it is commonplace to post drafts of manuscripts to the open-access repository, arXiv.org. For several biology education

journals, including *LSE*, this would be considered prior publication, precluding republication in the journal. BER is relatively younger and distributed across life sciences disciplines, with many professional societies including biology education sections in their national meetings. Although many would argue that this splintering has slowed the development of BER as a discipline, the diversity of perspectives in the life sciences could be considered an asset. For example, biology education researchers may be better positioned to offer diverse perspectives and employ a greater variety of methods in their research (e.g., experimentation, statistical and mathematical models, rich description). In addition, entire subdisciplines of biology focus on studying complex systems that cannot be controlled experimentally, similar to the classroom or institutional environments that serve as contexts for our work. We posit that collaborations between physics and biology education researchers have bipartite potential: development of the instructional interface between biology and physics, and enrichment of the theoretical and methodological perspectives of BER and PER.

Common Strengths

In addition to the divergences between BER and PER, several common features struck us during the review process. First, discipline-specific education journals have been critical to the development of both disciplines. *LSE* and journals such as *Advances in Physiology Education*, *Biochemistry and Molecular Biology Education*, and *Journal of Microbiology and Biology Education* have provided venues for sharing education research with fellow biologists. Similarly, the PER section of *American Journal of Physics* and the development of *Physical Review Special Topics—Physics Education Research (PRST-PER)* have been vital to the growth of PER as a viable subfield of physics.

Second, professional societies have offered leadership and support for both disciplines. *LSE* and *PRST-PER* are both published by professional societies. The American Association of Physics Teachers spearheads an annual Physics Education Research Conference and PER Central (www.compadre.org/per), an online repository of resources for PER. In addition, the American Physical Society has played a critical role in establishing the legitimacy of PER as a field of study (e.g., see the statement on Research in Physics Education at www.aps.org/policy/statements/99_2.cfm). Because there are so many life scientists, each of whom identifies with a variety of subdisciplinary communities (e.g., genetics vs. biochemistry as a methodological approach, ecosystems vs. cells as a subject of study, mouse vs. *Arabidopsis* as a model organism), a singular BER community has not arisen naturally. The recent establishment of the Society for the Advancement of Biology Education Research may offer a mechanism to bring the now distributed BER community together, and an entrée for PER colleagues to establish BER collaborations.

Finally, this special issue of *LSE* is only the first of several venues and events dedicated to highlighting the work of BER and PER collaborations. The *American Journal of Physics* will publish a special issue focused on the intersection of biology and physics (deadline for articles is August 15, 2013; http://scitation.aip.org/journals/doc/AJPIAS-home/2014_PaperCall.pdf), and the intersection of biology and

physics will be the topic of the next Gordon Research Conference on Physics Research and Education in June 2014 (www.grc.org/programs.aspx?year=2014&program=physres). *LSE* will also continue to welcome submission of manuscripts on teaching and learning at the intersection of biology and physics.

Future Prospects

In the process of assembling this issue, we came to recognize the following:

- Garnering rich perspectives on teaching and learning at the intersection of physics and biology requires biologists and physicists to work in teams, but further research is needed to understand the combination of BER, PER, biology, and physics expertise that is necessary to develop instructional approaches that effectively integrate physics and biology learning.
- Several lines of research have informed recommendations on how to teach energy transfer as a topic central to both biology and physics but challenging to integrate across disciplines.
- Biology can serve as a vehicle to integrate current science into the physics curriculum. Indeed, a more integrated perspective is critical to help prepare students for understanding and using imaging technologies and other modern biophysical tools needed to investigate biological phenomena.
- Crucial opportunities for educational transformation remain untapped at the intersection of biology and physics. Most of the papers in this issue focus on teaching and learning at the introductory level. There is a need for more study of integration of physics and biology in upper-level courses, wherein students' increasingly sophisticated

knowledge is likely to make them more capable of learning at the intersection between the two disciplines.

- There is a need to examine how undergraduate majors could be structured to encourage teaching and learning at the intersection. Despite the widespread availability of the biochemistry major, there are only a few biophysics major programs. At first glance, this would seem to interfere with integration of physics and biology instruction. How would increased prevalence of the biophysics major affect teaching and learning at both introductory and more advanced levels of these two disciplines? The extent to which current curriculum structures are an impediment to integrating physics and biology instruction remains an untapped area of research.

Finally, we recognize that the papers presented in this issue have identified many exciting opportunities for future collaborative study by biology and physics education researchers. We are grateful for *LSE's* willingness to contribute to that future.

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