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Feature
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Integration of Physics and Biology: Synergistic Undergraduate Education for the 21st Century

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This is an exciting time to be a biologist. The advances in our field and the many opportunities to expand our horizons through interaction with other disciplines are intellectually stimulating. This is as true for people tasked with helping the field move forward through support of research and education projects that serve the nation's needs as for those carrying out that research and educating the next generation of biologists. So, it is a pleasure to contribute to this edition of *CBE—Life Sciences Education*. This column will cover three aspects of the interactions of physics and biology as seen from the viewpoint of four members of the Division of Undergraduate Education of the National Science Foundation. The first section places the material to follow in context. The second reviews some of the many interdisciplinary physics–biology projects we support. The third highlights mechanisms available for supporting new physics–biology undergraduate education projects based on ideas that arise, focusing on those needing and warranting outside support to come to fruition.

PUTTING THINGS IN CONTEXT: A BIOLOGIST'S VIEW—TERRY WOODIN

The need for interdisciplinary approaches in all branches of science, technology, engineering, and mathematics (STEM) has been advanced in such recent documents on STEM undergraduate education as *Rising above the Gathering Storm* (National Academy of Sciences, 2007), *Discipline-Based Education Research* (Singer *et al.*, 2012), and *Engage to Excel* (President's Council of Advisors on Science and Technology, 2012). The need for interdisciplinary approaches, within biology specifically, has become increasingly obvious as the discipline becomes more quantitative and conceptual in approach. The importance of including other sciences, engineering, and mathematics in any consideration of undergraduate education in the life sciences was articulated clearly in *BIO2010* (National Research Council, 2003), a seminal document stating the need for reform of life sciences undergraduate education so that it truly reflects the rapidly changing nature of the science it serves. It has been restated and reinforced in more recent documents, such as *Vision and Change in Undergraduate Biology Education* (American Association for the Advancement of Science, 2011) and the articles in this volume of *LSE*. The contributions of physicists to our present understanding of cell structure and processes have been crucial to advances in molecular biology, biochemistry, cell biology, and other fields within the life sciences. The importance of an understanding of the laws of physics to understand the life sciences, and the value of using biological examples to illustrate physical concepts, have been recognized and emphasized in recent publications examining the needs of biology in the 21st century.

BIO2010 included comments by interdisciplinary panels in its discussion of actions needed to better prepare "future research biologists" for their life's work. The physics and engineering panel noted the need for physics courses to include biological examples and related problems when discussing physics concepts that biology majors should master. Among their suggestions, they specifically mentioned that "the notion of emergent behavior, pattern formation, and dynamical systems" is "central to understanding biology" and therefore advocated discussion of such topics in introductory physics courses taken by life sciences majors. They also suggested connections to engineering that could be added to the biology curriculum.

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The more recent documents discuss the importance of teams of biologists and physicists both designing and teaching interdisciplinary courses; such teams are needed to consider how best to introduce biological examples into physics courses and the principles of physics into biology courses at all levels of the curriculum. They emphasize the need to merge the strengths of both sciences. It is this approach, featured in the call to action in *Vision and Change*, that is gaining prominence in biology proposals submitted to the Transforming Undergraduate Education in STEM (TUES) program.

PUTTING THINGS IN CONTEXT: A PHYSICIST'S VIEW—GARY WHITE

Integrating physics and biology into appropriate undergraduate courses has at least two advantages for both physicists and biologists. The courses will be more relevant to more students (because many students find it more compelling to learn about physical principles via specific biological phenomena), and faculty will be better able to benefit from findings by both disciplines concerning effective teaching techniques. Physics educators were catalyzed by early research in the 1970s and 1980s on student conceptual difficulties and have taken action, producing robustly validated instruments to determine students' conceptual understanding of specific physical principles. As a result, researchers can compare the effectiveness of various teaching approaches (Hake, 1998) with regard to mastery of conceptual ideas and then advocate for those that are more effective. Effective approaches are highlighted in semiannual 3-day workshops for newly hired tenure-track faculty. The workshops are sponsored by a consortium of leading physics associations (American Association of Physics Teachers, 2013) and result in significant adoption of these effective approaches by the workshop attendees (Henderson *et al.*, 2012, and references therein). Personally, I have found that relaying physical principles using biological examples better motivates students to work at understanding the ideas. A typical student comment is, "Oh, I see, this does relate to my life." While much remains to be learned, deep progress in improving the teaching of physics to life sciences majors is possible and will have long-term impacts far beyond the classroom, because this group of students represents such a large fraction of the educated public in the United States.

RECENT PHYSICS–BIOLOGY PROJECTS[1,2]

We would like to illustrate trends in the projects we have supported recently that are particularly relevant for this special issue of *LSE*. The objective is to provide examples of how faculty are approaching the need to design more interdisciplinary courses and materials integrating physics and biology. We have listed 11 projects (see Supplemental Material); most of them feature production of materials for specific courses or modules that can be used in a variety of courses, all of them designed to be particularly suitable for incorporation into courses featuring active-learning approaches. In each case, we have: 1) listed the project award number (as an aid in finding the project on the NSF Web page), the principal investigator, and the institution involved; 2) given a brief description of the project; and 3) if the project is sufficiently mature, supplied a link to a project-related website that provides access to the materials produced thus far. Most of the principal investigators welcome inquiries about their work. We hope that this list and the many articles in this issue of *LSE* will stimulate formation of groups of like-minded faculty concerned with the need to help biology students understand the physical principles that underlie the workings of organisms and ecosystems. The existence of such groups will help initiate exchange of information on the challenges encountered and ways of dealing with those challenges. One of those groups is the Partnership for Undergraduate Life Sciences Education (PULSE) community, which "is a joint effort by the NSF, the National Institutes of Health, and HHMI to stimulate systematic changes within biology departments at all types of postsecondary educational institutions, based on the *Vision and Change* Report" (PULSE Community, 2013).

SUPPORT MECHANISMS AND FUNDING HINTS

Funding is available for those projects that warrant external support due to their potential to be transformative, because they either contain a novel approach or are adding substantially to what we know about existing approaches, thereby increasing the potential for good ideas to be disseminated, adapted, and implemented. Proposals should be clear in their goals and should specify how attainment of those goals can be determined and reported, so others can benefit from project findings. Goals can be centered on: initial implementation of the new ideas and further development of supporting materials; determining whether approaches effective at one site are effective in new settings or with different audiences; evaluating the resources in time and energy and the funding required for implementation of an approach; and establishing effective ways to help a broad spectrum of faculty adopt the new approach.

There are three NSF programs that could appropriately provide funds for projects that help advance education at the intersection of physics and biology:

- The Integrated NSF Support Promoting Interdisciplinary Research and Education (INSPIRE) program, a new agency-wide program introduced in 2012;
- The Research Coordination Networks–Undergraduate Biology Education (RCN-UBE) program; and
- The TUES program (NSF, 2006, 2012, 2013).

For details, see the program announcements listed in the references. Check the NSF website (www.nsf.gov) for current

[1]Some of the projects noted here are supported partly through the Howard Hughes Medical Institute (HHMI) Professors program or the HHMI Awards for Colleges and Universities program (submissions by invitation only). These projects developed components that complemented but were not part of the original HHMI project; some of the ideas that developed as the original project proceeded were strong enough to merit external support through the National Science Foundation (NSF) TUES program.

[2]Many but not all of these projects were developed in response to the call for integrated materials in *BIO2010* and the HHMI–Association of American Medical Colleges report on the undergraduate needs of future physicians; they are therefore very medical in their approach. However, the materials developed are generally applicable.

submission dates and guidelines; we anticipate some changes in the near future.

The INSPIRE program was established to address problems that lie at the intersection of traditional disciplines. It is intended to encourage investigators to submit bold, exceptional proposals; it is *not* intended for proposals that are more appropriate for existing award mechanisms. INSPIRE is open to interdisciplinary proposals on any NSF-supported topic, but proposals can be submitted *by invitation only* after a preliminary inquiry process initiated by submission of a required letter of intent (NSF, 2013).

The RCN-UBE program was established in recognition of the importance of networking activities to advance biology education. RCN-UBE proposals could focus on improving learning in "gateway" (or other) courses through a variety of mechanisms: the development and use of emerging technologies in the biology curriculum; strategies and approaches for engaging biology faculty in professional development activities related to undergraduate education; incorporating emerging subdisciplines (e.g., informatics research, proteomics, systems and computational approaches, ecological stoichiometry) into the biology curriculum; improving assessment of student learning; improving the transition of students from 2- to 4-yr institutions; and incorporating research experiences into undergraduate laboratory courses, with an emphasis on introductory and lower-division courses. RCN-UBE proposals are expected to be 5 yr in duration, and budgets should not exceed $500,000. Funds can be budgeted for "collaborative activities, such as short visits among member laboratories, exchange of visits of students, sharing of unique facilities, network retreats, and partial support of workshops uniquely tied to the network activities, etc." (NSF, 2012). To assist scientists and educators to develop budding networks, the RCN-UBE track will accept Incubator proposals for up to $50,000 for 1 yr. The due date is June 14 for 2013, and we anticipate that it will be approximately the same in 2014.

The TUES program, represented here by 11 example projects (see Supplemental Material) supported through the TUES program, requires the submitter (the principal investigator) to indicate the major discipline under which the proposal should be reviewed. This can be a bit of a challenge for projects that span more than one discipline; therefore, we have indicated in which discipline each of the 11 projects was reviewed. In general, projects representing the efforts of faculty from many disciplines to design courses or materials should be labeled as interdisciplinary projects. Those involving mainly biology faculty, with physics, engineering, or other faculty serving primarily as advisors, should be submitted as biology projects. In contrast, those submitted by physics faculty that are mainly projects to develop modules using biology examples as the base for illustrating and explaining concepts in physics, and that are intended for use in physics courses designed mainly for life sciences students, should be submitted as physics projects. Below are two hints to help you as you consider submitting a proposal to one of the programs listed above.

Hint 1: Are External Funds Needed?

Part of a faculty member's job is to teach and to constantly reframe courses so that the courses reflect advances in the subject being taught, as well as new information about effective teaching approaches. Normal, progressive revision does not warrant external funding. However, change often requires the infusion of some resources, because the effort to change is resource-expensive in terms of faculty time, new instrumentation, or other elements. Resources needed for gathering and analyzing data to ascertain whether your approach is helping students learn—expenses that might not be a normal cost of teaching the course—are also appropriate for grant support.

Hint 2: Is This Proposal Ready to Be Submitted?

One of the traps everyone tends to fall into when writing a letter of intent or a proposal for funding is to assume that what is clear to you is clear to everyone else. Be sure to have someone else read your proposal and ask them to be brutally frank in telling you whether you have made your point. Do not tell them what you plan to do. Ask them to read the proposal and tell you what they think you plan to do, and what you hope to accomplish by doing it. Ask them where you were unclear and whether they think that the need for external funds is clear and compelling. Projects that benefit only one small set of students or faculty at one institution with no outreach to share findings with others are not as competitive as those in which it is obvious to reviewers and NSF staff that results will be shared with a larger community—whether that larger community embraces others within a large department of the university, departments and divisions within an institution of higher education, or a community defined by your discipline.

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