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SYMPOSIUM

Introduction to the Symposium "Leading Students and Faculty to Quantitative Biology through Active Learning"

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From the symposium "Leading Students and Faculty to Quantitative Biology Through Active Learning" presented at the annual meeting of the Society for Integrative and Comparative Biology, January 3–7, 2015 at West Palm Beach, Florida.

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Synopsis The broad aim of this symposium and set of associated papers is to motivate the use of inquiry-based, active-learning teaching techniques in undergraduate quantitative biology courses. Practical information, resources, and ready-to-use classroom exercises relevant to physicists, mathematicians, biologists, and engineers are presented. These resources can be used to address the lack of preparation of college students in STEM fields entering the workforce by providing experience working on interdisciplinary and multidisciplinary problems in mathematical biology in a group setting. Such approaches can also indirectly help attract and retain under-represented students who benefit the most from "non-traditional" learning styles and strategies, including inquiry-based, collaborative, and active learning.

Introduction

The past 20 years have seen an explosion of interest in using quantitative tools to answer problems in the biological sciences. The National Science Foundation has funded several institutes devoted to strengthening the relationship between mathematics and biology, including the Mathematical Biology Institute at the Ohio State University and the National Institute for Mathematical and Biological Synthesis at the University of Tennessee at Knoxville. The NSF Division of Mathematical Sciences instituted a program in Mathematical Biology to fund mathematicians working at this interface. The National Institutes of Health and the Burroughs Wellcome Fund offer career awards for mathematical, physical, and engineering postdoctoral fellows who are pursuing research projects in the life sciences. The Army Research Office now has a funding program in Biomathematics. Most of these efforts have also incorporated education in quantitative biology as an integral extension of interdisciplinary research.

Despite the wide interest and support for quantitative biology across many departments, colleges, and universities, there are still significant challenges in its implementation. At the undergraduate level, often there is not a single group of students with the critical mass necessary to design a course focused on a particular subfield of biology or mathematics. Biology majors often are interested in medically oriented applications and have widely varying backgrounds in mathematics. Many have only taken one or two semesters of college level calculus. Most undergraduate mathematics, physics, and engineering majors often have either taken a college level introductory biology course or have not taken any life science course in college. In our experience, the students in most undergraduate courses in quantitative biology reflect this diversity of interests and backgrounds.

The challenges of collaborative research

In 2004, Cohen described a future in which mathematics and biology would be combined into a partnership that would revolutionize our understanding of biological problems and create new, powerful mathematics (Cohen 2004). In the decade following this prediction, this partnership between the two disciplines developed into an extremely rewarding endeavor for many interdisciplinary teams. People who work at this interface recognize that mathematics has many tools to help biologists with problems, and that biology provides many interesting problems for mathematicians.

Despite the enormous promise of melding these disciplines together, research in mathematical biology is difficult (Reed 2004). Many practical difficulties have been pointed out over the years: the inherent "messiness" of biology, the multiple levels on which biological problems operate, the difficulty of experimentation (Reed 2004), and the lack of cross-training of researchers in each discipline (Steen 2005). However, not enough attention has been paid to the fundamental differences and difficulties of interdisciplinary collaborations compared with working with researchers in one's own field.

We (the authors) have a common history of interdisciplinary research. Each of us began our careers as undergraduates in biology. Our paths diverged as Miller attended graduate school in biology (masters) and mathematics (Ph.D.) and completed a postdoctoral position in mathematical biology. Waldrop remained in biology (Ph.D.) for graduate school only to move to mathematics during her postdoctoral position. Having spent time in both research environments, we each have uniquely experienced the cultural differences and challenges of interdisciplinary research between mathematics and biology.

These cultural differences, while not obvious on the surface, run deep and are an important consideration when conducting interdisciplinary collaborations. Perhaps the greatest difference between mathematics and biology is what drives programs in original research. Generally, programs in biology, like many sciences, are driven by strong inference (Platt 1964). Research is structured around answering questions through the testing of hypotheses. In contrast, applied mathematics programs are often driven by the development of tools and methods to solve novel problems in mathematics. In many instances, the development of "new math" is preferred over the ability to apply existing mathematics to new questions; see, for example, Division of Mathematical Sciences (2015) Mathematical Biology program guidelines. These differences are reflected at all levels from funding bodies to the hiring of faculty, to how graduate students are trained. One particularly interesting point brought up in our workshop was the difference in how students are taught to read papers in each discipline (biologists read results first, mathematicians read methods first).

During our participation in interdisciplinary research teams, we have been a part of highly successful and of less successful collaborations. From these experiences, we have identified some major challenges that exist when forming new collaborations:

- Both parties must be experts in their fields.
- Both parties must know enough of the other discipline to communicate and understand each other.
- Both parties must be challenged intellectually and satisfied with the projects. This includes answering interesting and important questions for biologists and developing new models or mathematics for mathematicians.

Quantitative training in biology as training in interdisciplinary research

With such differences in culture, forming successful collaborations is not simply a matter of putting mathematicians and biologists in the same room. Cross-training is important, and this likely goes beyond simply asking biologists to take more mathematics or mathematicians to take more biology (Miller and Walston 2010). Researchers should undertake specific training in interdisciplinary collaborations. We believe that this training should start as soon as possible in a research career. Interdisciplinary training both of undergraduate and graduate students prepares them for successful and efficient collaborations in research in the future, whether they continue in academics, move to industry, or work in science policy.

We believe that these training programs should:

- Increase base knowledge of both parties so that communication is easier. For biologists, taking an additional course or two in mathematics prepares them for collaborations much more than the average current requirements for biology majors. For mathematicians, some biology courses can introduce them to the diversity of life and the way that biologists think about problems.
- Expose both parties to the variety that the other discipline has to offer. Exposing mathematicians to unsolved questions in biology and exposing biologists to more exotic mathematics will both enhance interest and help students make connections for future work.
- Create activities in which both parties work together on problems using their expertise under low-stress conditions. This hands-on experience is crucial for developing successful collaborations later when problems are more difficult and less tractable.

The role of active learning in training future interdisciplinary researchers

We organized the symposium ''Leading Students and Faculty to Quantitative Biology through Active Learning'' because we believe that undergraduate and graduate programs in quantitative biology, particularly those that use active-learning and collaborative-learning strategies, are well-positioned to provide the kind of training needed for future researchers to tackle major problems at the interface of mathematics and biology. Active learning removes barriers for both groups of students by relying on conceptual learning and problem solving in context, as opposed to relying on students working independently and passively in a lecture course (AAAS 2009). Additionally, an active-learning framework increases the diversity of voices in the classroom by providing a variety of tools for engagement and reducing the failure rates for women and students of color (Beichner 2008; Drew 2015), which will help to maintain mathematical biology as one of the most diverse research groups in mathematics (note that the Life Sciences Activity Group is the currently one of the most diverse activity groups of the Society of Industrial and Applied Mathematics (SIAM 2012)).

In this collection, we review a small section of the scientific evidence for the effectiveness of active learning, provide tools and resources for using active learning in the classroom, and call for the development of additional resources that will facilitate active learning in quantitative biology (Waldrop et al. 2015). Full et al. (2015) describe an interdisciplinary laboratory course that turns ''cookbook'' laboratories into an opportunity for original discovery. Battista et al. (2015) present an example of a classroom-ready exercise that integrates high-level computational modeling with basic physiology. Drew (2015) discusses the use of social media to enhance students' engagement in course material.

We hope that this collection serves to inform, facilitate, and inspire discussions of active learning in quantitative biology programs. In particular, we have compiled a brief review of the literature and a list of resources to help those interested in applying this approach to teaching quantitative biology (Waldrop et al. 2015). We have also assembled a website for hosting the most up-to-date versions of code and exercises (Waldrop 2015). Since current work in active learning and quantitative biology is large and growing, we encourage the reader to use our resources only as a launch pad for delving into the literature.

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