Science One: Integrating Mathematical Biology into a First-Year Program

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Name of Institution	University of British Columbia, Vancouver
Size	about 45,000 students on the Vancouver campus
Institution Type	large public medical-doctoral university
Student Demographic	recent high school graduates with interests across the scientific disciplines
Department Structure	Faculty of Science has separate departments for each discipline sending instructors to Science One

Abstract

Since 1993, the Science One Program at The University of British Columbia (UBC) has been integrating mathematical biology into a team-taught, first-year interdisciplinary science program. The mathematical biology component of this program introduces students to aspects of mathematical modeling and ensures that they have a solid foundation in calculus and elementary differential equations. About 70% of the students subsequently pursue life sciences majors. Science One has shown itself to be an enriching experience for both students and faculty. Strong support from UBC administrators was essential to its early success, and has enabled many lessons learned from Science One to be applied broadly at UBC.

Course Structure

- Weeks per term: 26 weeks over two terms plus two exam periods in December and April
- Classes per week/type/length: 12 1-hour lecture periods each week; 4 1-hour tutorials each week
- Labs per week/length: 3 3-hour laboratory periods each week
- Average class size: 75 students in one section broken down into three tutorial/lab groups of 25 students each
- Enrollment requirements: For students entering first-year sciences; students must apply for the program; admission based on an essay, list of science-related activities, and high school grades
- Faculty/dept per class, TAs: Team-taught by eight instructors, two for each discipline
- Next course: Prepares students for entry to any major program in the Faculty of Science.
- Website: http://www.scienceone.ubc.ca

Introduction

There has been much interest in improving the mathematical education of future research biologists (Bialek and Botstein 2004; National Research Council 2003). Something as basic, and essential, to 21st Century biology as improving our understanding of the structure of the information contained in a genome will require deep training in both the biological sciences and the mathematical sciences. Moreover, mathematical biology continues to make contributions to such diverse areas as ecology, evolution, the study of diseases (both at the cellular and population levels), and to neurobiology, for example. Because most life sciences majors are required to take at least some quantitative courses, it makes sense to use them as opportunities to show students the important roles mathematics can play in the biological sciences.

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In 1991, the Faculty of Science at The University of British Columbia (UBC) began to develop an interdisciplinary first-year program in science. The goal was to provide an educational experience to train new scientists who will be able to tackle problems that require tools from outside their specialized disciplines (Dryden et al. 2011). First implemented in 1993, the Science One Program is a learning community of students and faculty members that emphasizes scientific process and the interrelationships between disciplines (biology, chemistry, mathematics, and physics are the core disciplines in the program) while giving students essential technical skills for their majors or honors degrees. About 70% of the Science One students choose life sciences majors.

In the past seventeen years, Science One has proven to be a crucible for new teaching ideas and has been an inspiration for new programs throughout UBC (Benbasat and Gass 2002; Dryden et al. 2011). Moreover, there is evidence that Science One students outperform other B. Sc. students at UBC in upper-year courses, including students with similar grades who have participated in highly selective majors programs (Dryden et al. 2011; Dryden and Mac Lean 2004; Dryden and Mac Lean 2008). We hypothesize that the advantage Science One students have over their peers is some combination of self-selection, our admissions process, and taking the program (Dryden et al. 2011).

From the beginning, mathematical biology played a central role in the Science One curriculum. While mathematics is obvious in many parts of first-year chemistry and physics, it traditionally has remained hidden in biology. Our goal is to help students find opportunities to see mathematics in the biological world around them. This goal matches with the goal of the UBC first-year biology courses to have students see biology as more than a collection of fact. Furthermore, the richness of the biological sciences leads to excellent examples that provide contexts in which to learn both specific mathematical concepts and mathematical modeling. Mathematical modeling is an important contributor to the growth of students' critical thinking and analytical skills.

In this note, we will focus on key aspects of Science One related to teaching mathematical biology to first-year students, and on ideas we have found to be important to building institutional support.

Program Description

UBC is a large, public, research-intensive university offering a full range of PhD programs. Our 45,000 member student body (37,000 undergraduates, 8,000 graduate students) has strong international representation. The Faculty of Science attracts top students (Wieman and Sudmant 2008), and the Science One Program attracts first-year students who seek a challenging program of studies. More than half of Science One students go on to graduate and professional schools.

Science One is a learning community of 75 first-year students, eight instructors, and a program director who also contributes to the teaching. It is structured as a single 27-credit course (of a 36-credit typical load), taught over two semesters, that integrates biology, chemistry, mathematics, and physics. The students are selected competitively on the basis of their grades and their interest in science, as judged on the basis of an essay and a list of their science-related extra-curricular activities.

Each week, students attend twelve hours of lectures, which are led by one or more faculty members. In addition, there are two tutorial hours per week during which 24 students meet with one or two instructors for a structured activity, two hours of small groups in which nine students work with one instructor, and nine hours of labs. Each component represents a different kind of opportunity for integrating disciplines.

To give the course a clear interdisciplinary feel, at least two faculty members share the classroom at one time. Even during classes in which one faculty member is the primary instructor, the presence of a peer, usually from a different discipline, helps create vibrant dynamics, especially where there are exchanges of differing viewpoints. The students see how mathematicians and scientists talk to each other, and because of the comfortable environment in the classroom, they quickly become engaged in classroom discussions.

Students also do two independent research projects, one each term. Many of these projects incorporate mathematical models in one way or another. Students present the results of one project at a spring research conference. Samples of projects can be found online in the UBC Information Repository (https://circle.ubc.ca/handle/2429/6927).

A more detailed description of the Science One Program and its operation is found in Dryden et al. (2011).

Discussion

Integrating Mathematical Biology through Mathematical Modeling

The mathematical content of Science One is based on the UBC standard curriculum in differential and integral calculus. Additional topics include some elementary differential equations, basic ideas from probability, difference equations, and dimensional analysis. For each topic, we have a collection of examples that use those particular concepts in a biological context. This curriculum is consistent with our goal that students who complete Science One should be able to do well in higher-level mainstream mathematics courses. The data show this to be the case (Dryden et al. 2011; Dryden and Mac Lean 2004; Dryden and Mac Lean 2008).

We break from traditional first-year pedagogy by teaching mathematical modeling in Science One. Our goal is to help students develop mathematical modeling skills, including learning to see mathematical concepts in nature, learning to work with ready-made models, learning to modify a given model to better capture actual features of a real-world system, and learning to create and analyze their own models.

Our experience is that, over the course of a year, first-year students are capable of incredible growth as modelers. There are some key factors that contribute to their growth.

1. The best examples connect to real problems in biology. Students know when they are presented with a contrived example designed to teach them a bit of mathematics, and often this approach will cause them to disengage. One of our most successful units is on modeling aspects of HIV/AIDS. Students engage enthusiastically and deeply in this unit because HIV/AIDS is a serious issue that they wish to understand. Many of the models they construct are at the edge of current understanding (e.g., modeling HIV transmission dynamics on social networks represented by graphs). It is a powerful experience for them to learn that, even as first-year students, they are close to much of the mathematics they would need to work on such problems at a research level.

2. Embrace your own ignorance. Students learn a lot by seeing how mathematicians use their mathematical viewpoints to build understanding of biological systems, or by seeing biologists use their biological intuition to work through analyzing a mathematical model. Students fear their own ignorance, and work to hide it: In their past experiences, they have been penalized for being wrong. They need to learn that it is ignorance that drives curiosity and leads to discovery. Do not underestimate the value of the instructor as a role model in this. (I frequently declare my incompetence in biology to the class.)

3. Recognize that learning to become a mathematical modeler takes time. Deliberately design a progression of experiences that help students build skills over time, and be explicit in showing them how to use prior experiences to learn new tools or to build new models.

4. Be in control. Understand your expected learning outcomes for each modeling exercise and have a clear plan in mind as to how the students will achieve them. This does not mean that you should not try new teaching ideas, nor does it mean that you will avoid disasters (even the best teachers can get caught by a pedagogic problem they did not anticipate – this is part of what makes teaching exciting!). It is easy to be enamored by a bit of mathematical biology and to forget that it must be made approachable by novices.

5. Believe in your students. Even if students do not become mathematicians, they gain a lot from learning how to communicate using mathematics. Many biology professors at UBC talk about former Science One students in their upper-year courses who would spontaneously present mathematical models on examinations, even though no real mathematics had been taught in the course. Many Science One students, including those who had been judged as weak in mathematics, have gone on to do significant mathematical modeling in their life sciences graduate degrees, thus demonstrating that we are accomplishing our goal of having students reach beyond their own specializations when they solve real problems.

These factors have been identified through the experiences of the team teaching Science One. In some cases, they arose out of challenges faced by instructors in the face of their preconceived notions of the students and of teaching and learning. For example, the process of learning to understand the nature of even the simplest differential equation takes students much longer than most faculty members anticipated when they started teaching. The logistic equation, which seems easy to us, takes even the top students a long time to appreciate to the point where they can use it to tell scientific stories. At the outset, most of the faculty members believed the main barrier to understanding differential equations was student effort. Once instructors had seen the learning cycle in detail, they understood that there are cognitive processes that dominate what happens when students struggle to learn new ideas. The intensity (depth and frequency) of faculty-student interactions that happens in Science One gives the faculty opportunities to gain insight into student learning as it is happening. This does not happen in most standard courses. These interactions allow more insight into learning and reshape our understanding of the interplay between the roles of instructor and student.

Building Institutional Support

One of the questions we are often asked by people is, "How do you convince your administrators to support you?" Usually, what they mean is, "How do you pay for this?"

At UBC, the cost-per-student of the Science One Program is between 1.5 and 2 times the average cost-per-student for a first-year student taking mainstream courses. The main component of this cost difference is faculty time. We have a small student-to-instructor ratio, and the interactions between faculty members necessary to prepare interdisciplinary classes are time-intensive, meaning that Science One has been the full teaching load for each instructor. (Starting in 2008, we implemented a model of shared teaching between two instructors per discipline that improved the cost ratio and also makes it more attractive for early-career faculty to participate.) The "on stage" time is roughly equivalent to one course per semester, and a typical teaching load is 1.5 courses per semester. The additional time is spent preparing classes and materials, and attending classes taught by others. There is a large gain to be made from the spontaneous interactions that happen because of this high level of faculty participation. Space commitments, support staff salaries, and a small operational budget add to the cost. It is important to be able to justify the higher cost of such a program to the university community, not just to the administration, since the view will be that these resources could be used to support and improve existing programs.

It is critical to develop sustainable courses and programs. I am encouraged by the large number of initiatives to develop courses that integrate mathematics and biology at a wide range of colleges and universities. Often, the development of these courses and programs is funded by the National Science Foundation or private foundations. While much of the focus is naturally on curriculum development and its implementation, it is equally important to engage administrators in substantial ways from the beginning; ultimately they will be the ones who will decide on the future institutional funding for any project once the initial grant runs out.

Suggestions

A complete discussion of the implementation of Science One, including the many early administrative and pedagogic challenges, can be found in (Benbasat and Gass 2002). Some of the key ideas that contributed to our success are as follows:

1. We treated Science One as an educational experiment and received a five-year funding commitment from the Dean of Science, the final two years of funding contingent on a favorable interim review at the end of the first three years. Our Dean was willing to make this commitment because he was interested in interdisciplinary education, he felt in control of the expectations for our project, and he trusted that we were open to a serious evaluation of our efforts.

2. We engaged our colleagues one-on-one in our departments to keep them up to date on our work. The initial responses to Science One ranged from supportive, to skeptical, to hostile, and we knew that ultimately we would have to convince the participating departments to support the program in the long term. We hid from no one, taking any opportunity to talk about our work, even if the result was an agreement to disagree.

3. Our success is judged on how our students perform as they progress through their degrees. Some departments looked at the marks of Science One students in later courses for several years and were pleased with the results. We do detailed analyses of some key courses for our regularly scheduled program reviews. Ultimately, mathematicians and scientists like numbers, as do administrators, so it is helpful to spend some time considering what data would be useful in assessing whether or not the program is accomplishing its goals.

4. We recognize, and defend, the idea that some important data that can be used to analyze our successes and failures is not quantitative. Perhaps the most influential data that marked us as successful were the behavioral changes in our students that showed up in later courses: They spoke up more in class discussions than their peers, life sciences majors among them took more quantitative courses than usual, and a large number of our colleagues started recruiting them to work in their labs and on other research. These recruits included many students who had average looking transcripts.

5. Our views on teaching are challenged continually. All of the team members who teach in Science One are well-respected teachers. Because we interact with students so directly and so regularly, we quickly see when we succeed and when we fail, and all of us have been surprised and had some of our beliefs challenged. This happens also when we interact with our teaching teammates through our teaching.

6. Team meetings are important. We meet weekly as a team. Each week we set a schedule, which varies to accommodate our goals for that week. We discuss at a deep level what we hope to accomplish the next week, and how we might do it. We also discuss our students. These meetings are fun and often described as important to faculty development.

7. We export what we learn. Faculty members return to their departments after teaching Science One and bring a renewed sense of commitment to teaching. Standard courses in all participating departments have changed over the years in response to the lessons learned in Science One. As well, UBC has seen the growth of many exciting courses and programs inspired by the Science One model. This demonstrates how committed our university community is to creating new learning opportunities, and that our administration views such activities as valuable, and hence worth funding. Fortunately, this commitment goes beyond high-profile projects to the heart of our teaching mission.

Conclusion

Perhaps the main lesson we have learned over the past seventeen years is that it is possible to harness the energy and enthusiasm of faculty, students, and administrators to implement new teaching ideas. Given how much interest there is in increasing the mathematical expertise of future biologists, it is an exciting time to be building new courses and programs that integrate mathematical biology into the early undergraduate experience for life sciences majors. Perhaps Science One is simply an example to say that it can be done.

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