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# Parts of the Whole: Why I Teach This Subject This Way

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### Abstract

The importance of mathematics to biology is illustrated by search data from Google Scholar. I argue that a pedagogical approach based on student research projects is likely to improve retention and foster critical thinking about mathematical modeling, as well as reinforce quantitative reasoning and the appreciation of calculus as a tool. The usual features of a course (e.g., the instructor, assessment, text, etc.) are shown to have very different purposes in a research-based course.



### Keywords

undergraduate research, mathematical biology, quantitative reasoning, calculus, differential equations, biology education, mathematics education




### Cover Page Footnote


Dorothy Wallace received her B.S. in mathematics at Yale University and her Ph.D. at the University of California at San Diego, and is currently professor of mathematics at Dartmouth. She has broad background in many kinds of mathematics, with approximately 100 publications in pure, applied, and educational topics. From 1995 to 2000 she led the seminal Mathematics Across the Curriculum project funded by the National Science Foundation. She was 2000 New Hampshire CASE Professor of the Year and won the Dartmouth Graduate Faculty Mentoring Award in 2005. In the last 9 years she has supervised 45 undergraduates conducting research through internships, independent study, and senior theses. Her research papers in mathematical biology include 29 undergraduates among her coauthors. She was a charter board member of the National Numeracy Network and is a founding co-editor of this journal.

# Parts of the Whole

A Column by D. Wallace

The problem of how best to improve the numeracy of a society is a thorny one, embracing the learning process of a single student but rising in scale to include the management and alteration of an entire system of education. With the issue of quantitative literacy always in mind, this column will consider various aspects of the systemic workings of education: the forces acting on classrooms, teachers, and students, and mechanisms of both stasis and change. With the issues of volume 9, the column has pivoted to thoughts from developing and teaching "Math 4: Applications of Calculus to Mathematics and Biology," which Dartmouth biology students can take as an alternative to second-semester calculus (see Rheinlander and Wallace 2011).

## Why I Teach This Subject This Way

In the past few columns I have given some examples of how quantitative reasoning plays out in simple biological examples (Wallace 2016a; 2016b; 2017). Yet quantitative reasoning does not end with discussions of units and error margins—to me it is at its most useful when thoroughly integrated with traditional mathematical approaches.

Here I would like to address the importance of calculus and other more advanced mathematical topics in the biological sciences in general. In addition I suggest how undergraduate experiences can be structured to improve students' awareness of the growing role of mathematics, and to support the retention and transferability of mathematics learned in the process.

## Mathematics in the Biological Sciences

It is more important than ever that researchers and practitioners in biological fields know how to think quantitatively and use mathematical tools to their advantage. One can get a feel for the growth of mathematical tools in biology by comparing research articles found by Google Scholar, as in Table 1.

On May 31, 2017, a brief Google Scholar search revealed the following number of items under these categories. Two searches were done on six terms, one for the whole database and the other for entries since 2016. In the percentages given in Table 1, I assume that the items found with the modifier "mathematical model" would be counted in the larger search.

**Table 1.**
**Google Scholar Search Term Counts**

| Search term | Count | Mathematical search term | Count | Percent mathematical |
|---|---|---|---|---|
| *No specified time period:* | | | | |
| "ecology" | 3,540,000 | "mathematical model ecology" | 174,000 | 4.9 |
| "malaria" | 1,680,000 | "mathematical model malaria" | 55,000 | 3.3 |
| "tumor" | 3,730,000 | "mathematical model tumor" | 273,000 | 7.3 |
| *Since 2016:* | | | | |
| "ecology" | 110,000 | "mathematical model ecology" | 27,000 | 24.5 |
| "malaria" | 56,100 | "mathematical model malaria" | 5,270 | 9.4 |
| "tumor" | 144,000 | "mathematical model tumor" | 17,500 | 12.2 |

Although this table represents only a small sample of the literature, it appears that the role of mathematics in the biological sciences has increased. This development should not be a surprise, as mathematics gives extra predictive power beyond mere observations, and scientists want this predictive power. As one who does research in these three corners of mathematical biology, I can vouch for the fact that many articles are written by biologists who use mathematics to explain and extend the power of their results, and many are written by mathematicians inspired to study a biological system. Many are written by interdisciplinary teams. Not all models are of equal quality, of course. Some give predictions a practitioner might well believe, and others are no better than guesses.

Those who wish to read, understand, and use the insights gained in this research need to think critically and be knowledgeable consumers of this quantitative information. This statement has been made repeatedly in the pages of this journal and is no less true of research articles than it is of news articles. In both cases, an unwary consumer of information may be intimidated by the apparent authority of mathematics they do not understand.

## Sticky Mathematics, Sticky Biology

As one who teaches this material to a mixed class of biology students with little math background and math majors who have taken at least linear algebra and often differential equations, I can verify that both groups come to the course with remarkably little recollection of what they previously learned in either their biology or math classes. Colleges and universities typically require math courses, pre-medical education usually includes calculus and biology, and more recently quantitative reasoning courses are required at the college level or within a discipline. Such courses will do little good in the long run if the material learned is not remembered or cannot be transferred to new problems. So an important pedagogical problem to be solved here is this: How do we offer an education to both of these groups that fosters critical and creative thinking, and that sticks with the student after the course is over?

It is clear, to me at least, that the usual strategy of

1) learn some new technique,

2) apply it to a series of practice problems,

3) take a test on it, then

4) go on to the next new technique,

has not worked well for students in math classes. Some studies show that attitudes toward mathematics learning actually worsen as a result of the usual calculus sequence (Sundre et al. 2012). It is certainly the case that those of my students who have taken the differential equations course seem to remember very little of it in spite of all of the problems they are required to solve in that course. Problem solving evidently is not enough to make ideas stick. One of my students actually referred to this type of learning as "binge and purge."

It also seems to me that the usual biology class strategy of

1) read a huge amount of information,

2) use some of it in labs,

3) take a test on it, then

4) learn more information

has not worked well either, prompting experiments that shift the emphasis to different pedagogical approaches (Connell, Donovan, and Chambers 2016). So in my class we use another strategy, turning students into independent researchers and putting them in charge of posing and answering their own research problems (Rheinlander and Wallace 2011).

After a lifetime of being handed math problems to solve, any student might be forgiven for experiencing alarm at the question, "What problem would *you* like to solve?" And yet forceful arguments have been made that education that sticks is exactly the education based on this question (Freire 1996; Hooks 2014). Research experiences for undergraduates are known to improve learning and retention (Linn 2015), but usually these are relegated to internships and summer programs. By creating a rich experience for students right in the classroom, I hope to give them a chance to ask a question of interest *to them*, find their own unique answer to it, work with a team of enthusiastic peers, and write a paper of which they can be truly proud. All of these experiences are built to tie the mathematics and the biology to students' own emotions and motivations, thereby causing it to stick.

## Changing Roles

In such a classroom, the roles played by the various actors differ considerably from traditional educational forms. The contrast is summarized in Table 2 below.

**Table 2.**
**The Roles of Classroom Actors**

| Actor | Role in traditional format | Role in research- based format |
|---|---|---|
| Student | Absorbs assigned information, learns assigned computational techniques and reasoning. Takes tests. | Poses the research question and learns material necessary to solve problem. Writes research papers. |
| Teacher | Explains and describes, sets tasks to be completed, judges performance on intermediate tasks. | Asks additional questions, critiques thinking, helps modify approach, is a member of every team, does not judge the process of development but only the outcome. |
| Content delivered in class or textbook | Information to be tested on. | Ideas that might be helpful in students' own research. |
| Textbook | A resource for everything to be learned in the course. The whole mountain. | A platform from which students begin to form questions and strategies.<br>Base camp. |
| Assessment | Tasks set by instructor in homework and examinations on course material. | Research papers by groups of students on just about anything to do with biology. |
| Research literature | Peripheral (to learning) | Central (to research) |
| Final grade | Examinations made with the express intention that not everyone will get the same grade. | Papers judged against a standard, not against each other. Everyone can win. |

## Conclusion

By concentrating on getting the best possible solution to their own research problem, students encounter plenty of small problems in quantitative reasoning that arise naturally as they try to make the data from any experiment or field study relevant to their mathematical model. A deeper understanding of the meaning and importance of calculus happens equally naturally in the context of building systems of differential equations. They become critical evaluators of the published papers they are using to study their problem. They have an interdisciplinary research experience, without extra cost to them, a funding organization, or my institution. There is evidence that such an experience will contribute to retention in STEM fields (Lopatto 2007). Many of my students become so attached to their research problems that they continue working on them long after the course is over, even publishing their results (Johns et al. 2010; Madsen, Wallace, and Zupan 2013; Baumrin et al. 2011).

As an additional outcome, my attitude toward teaching is completely altered by this approach. It is *my privilege* to work with these students. I nearly always learn something new from them. I get an overview of potential research areas I would not have thought about otherwise. I build a base of colleagues with whom I may write papers in the future. All of these things compensate greatly for the additional time and attention this sort of teaching requires.

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