Math Bio or BioMath? Flipping the Mathematical Biology Classroom

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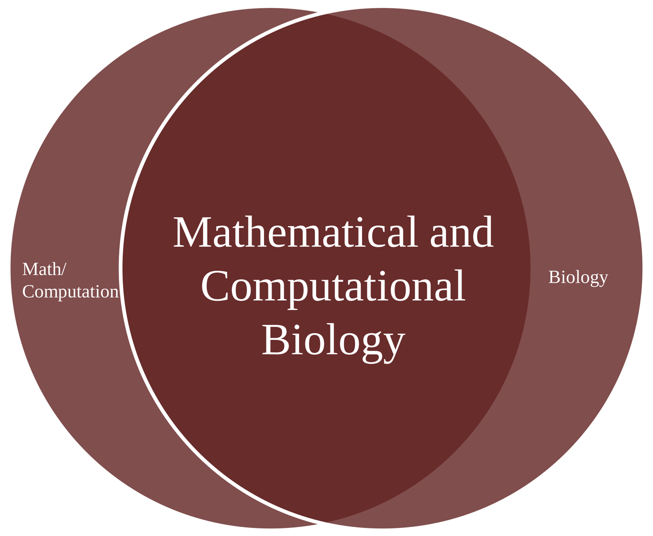
Motivation

- **Mathematical and theoretical biology** aim at the mathematical representation, treatment and modeling of biological processes, using a variety of tools from applied mathematics.
- Recent years have witnessed unprecented process in the biosciences, **much of this progress has been fuelled with mathematics** (Friedman 2010).
- These recent advances have elicited scores of open problems, and thus **plenty of opportunities for those trained within the entire spectrum of mathematical biology to make a contribution to science**.
- It is very important for us to not only offer courses in mathematical biology, **but to tailor them to the students taking the course**.

Most mathematical biology research today is done by individuals who develop (at least some) aptitude in both mathematics and biology, which has helped lead the steady increase in biological understanding aided by mathematics. Thus, when teaching mathematical biology we need develop student aptitudes in both areas!

However, more biologically-slanted researchers, instead of viewing mathematics as the main event, **simply use mathematics as a tool to solve problems**. Thus, mathematical biology courses for non-math majors should make the application of mathematics, not mathematics itself, the main focus of the course.



The Flipped Classroom

MTH 265 at UW-L is a course mainly aimed at biology and biochemistry majors. Because of this, I altered my approach to teaching MTH 265 by using a **flipped classroom**, focused on the applications of mathematics instead of the mathematics itself. The flipped classroom approach has gained significant momentum in recent years. In this approach, the students acquire most of the information outside of the classroom (the "transmission" phase of learning), while they use class time to work through challenging problems that apply what they have learned through the out-of-class lectures (the "assimilation" phase). **The assimilation phase of learning is often the more difficult of the two for the students, and thus having the professor at their disposal during those exercises is potentially a better use of time and resources** (Talbert 2013). In MTH 265,

- the students **learned the mathematical content** (definitions, theorems, proofs and major calculuations) for the course through watching 45-55 **video lectures**.
- the students learned the **mathematical modeling and computation processes** by exploring roughly 35 **case studies** derived from real biological problems. The problems in these case studies were similar to their homework problems, which they received weekly.
- the students used the skills developed in the course to **summarize and reproduce the mathematical results in two biological papers** published in the journals *Ecology* and the *Journal of Computational Biology* as their two **writing projects**.
- the students were additionally **assessed** using 6 bi-weekly quizzes and a final exam.

Course Overview

My **main goals** for this course are that students

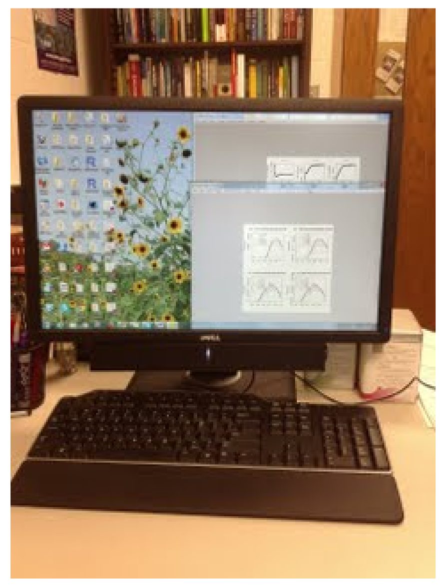
- develop an ability to **see the mathematical structures** underneath many of the biological and biochemical problems they encounter.
- cultivate a **comfortability with a wide range of mathematical structures/models**, so that they can pick the most appropriate one in a given situation.
- gain an appreciation and aptitude for **computer programming**.
- Understand **randomness** and how it affects biological systems.

The **biological topics** explored in this course spanned much of modern mathematical biology, including:

- population dynamics and epidemiology
- animal foraging
- parasitology
- genetics and natural selection
- enzyme kinetics and stoichiometry
- parameter estimation
- biological networks

The **mathematical topics** applied throughout in this course spanned much of modern mathematical biology, including:

- differential and difference equations
- dimensional analysis
- stability and bifurcation analysis
- sensitivity and elasticity analysis
- individual and computer-based modeling
- Markov Chains
- statistics and inverse theory
- Boolean Networks



Results of CLASSE Survey

To help assess the effectiveness of the flipped approach I, along with the Center for the Advancement of Teaching and Learning (CATL) at UW-L, had the students take part in two **Classroom Surveys of Student Engagement** (CLASSEs - Ouimet and Smallwood 2005). The results indicated that **students appreciated the flipped classroom approach**, specifically:

- All of the students agreed that the course made them a more effective scientist, roughly 50 percent of the students "strongly agreed".
- More than 50 percent of the students "strongly agreed" with the statement "I learn well from the case studies we do during our class time together".
- Roughly 75 percent of the students agreed that they could translate what they learned in class examples to other problems outside of class.

References

Friedman, A. (2010) What is mathematical biology and how useful is it? *Notices of the American Mathematical Society*, **57**(7): 851–857

Ouimet, J.A., Smallwood R.A. (2005) CLASSE the Class-level Survey of Student Engagement *Assessment Update*, **17**(6).

Talbert, R. (2013) Learning MATLAB in the inverted classroom. *Computers in Education Journal*, **23**(2):50–60.

Additional Student Reactions

- "I would suggest doing more review of calc in the beginning and a more detailed crash course in programming"
- "One gripe I have is that the whole class focuses on populations... I think more case studies should focus on chemical equilibrium"
- "The course was very interesting and showed some pretty neat biological applications of calculus"
- "Coding was difficult without a computer programming course"

Example Course Materials - Case Studies

The backbone of the course is the case studies, which provide motivation for the students to learn the mathematical content that is prevalent in modern Mathematical Biology. Below is an **example of a case study** used in MTH 265:

Math 265 - Spring 2013 - Case Study 10

Problem Description Suppose we want to model the growth of a fish population introduced in a newly renovated lake. The model cannot be very complicated because we have only a limited knowledge of the relevant facts. Presumably we have estimates of the vital rates of the population - birth, survival and growth-but only limited knowledge of the details.

a) Develop a conceptual model that incorporates the essential biological processes, such as survival of adults from year to year, birth and survival to the following year of newborn fish (which biologists often call *recruitment*). Ignore for now external effects such as natural migration (since our lake is relatively small), stocking, fishing or variations in the environment.

b) Draw a picture illustrating your conceptual model in part a)

c) Using your picture in part b), write down a discrete-time population model (a difference equation) for the plant population n_t with initial population n_0. Derive the solution of this discrete-time population model.

d) Derive conditions for which the population n_t in part c) elicits growth, decline, or equilibrium in terms of survival and recruitment.

e) Provide one critique of the model in this study. Where in the assumptions does this model break down? Why is this so? Provide an alternative assumption that alleviates this problem.

Conclusions and Future Directions

- **Not all mathematical biology students, even within the same major, are created equal, and the best way to account for this is a flipped classroom environment**.
- Insufficient algebra/calculus skills and a lack of computer programming experience were the biggest obstacles my students faced. **Most had very good biological intuition**.
- My students were **very resistant initially to a flipped classroom** (three drops within the first week), but **those that bought in made tremendous strides as the semester evolved**.
- **Introducing the students to research-level work** increased their overall motivation, and caused some of them to approach me with undergraduate research ideas.
- **Flipping the classroom is very time-consuming. Plan ahead**.

Future directions for this course, and this work in general, include

- the continued **documentation and modification of learning outcomes and goals**, respectively.
- the **broad dissemination of course materials** in the form of publications, course webpages, etc.
- the development of **new mathematical biology courses** (e.g. systems biology, bioinformatics, etc.) and a **Mathematical Biology Major** at UW-L.