Teaching Modeling to Biology Undergraduates

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Outline

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Introduction: Challenges and Opportunities

- Challenge 1: How biology students view math and programming
  - Biology majors avoid math, physics and programming courses
  - These subjects induce anxiety and a sense of incompetence
  - Yet students have deep understanding of complex biological systems
  - Modeling is another helpful tool for understanding biology
- Challenge 2: How math, physics and engineering students view biology
  - Memorization of structures and arbitrary names and abbreviations
  - No clear principles and abstractions deducible from first principles
  - Yet there are fascinating problems in biology that reward modeling

Educational Goals

- Learning to create dynamical models of biological systems.
- Learning to analyze dynamical models numerically and mathematically
- Learning to extend models to address novel questions
- Learning to write about models clearly

Textbook

- Goals
  - Interactive: student should be able to directly manipulate models
  - Students should be able to take code and use it
  - Should seamlessly integrate text, equations, and graphics
- Implementation
  - Written within *Mathematica*
  - Freely available to students to download

- https://canvas.case.edu/courses/35801/pages/course-overview-and-policies

Course Structure

- Students work in teams of two
- Each student is evaluated separately
- Class meets Tuesday and Thursday for 75 minutes
- First half: background needed to understand and recreate models
- Assignments due half an hour before class
- Fifteen minute mini-lecture at start of class
- Instructors talk with students in each team for remainder of class
- Focus: conceptual understanding
- Second half: reconstruct models; term paper benchmarks
- Instructors meet for an hour after each class
- Focus: student progress, point assignment
- Office hours throughout the week

Course Structure

- Students sit at hexagonal tables so they can interact
- Teaching assistants move from team to team to discuss results

First Half: Background

- First day of class:
  - Rationale for modeling
  - Going from novice to expert in one semester
  - Educational goals
  - Structure of course and assessment
- Mastering the fundamentals of *Mathematica*
- Iterative model construction: bacterial growth
- One dimensional dynamical systems
- Cell cycle checkpoints modeled using chemical kinetics
- Two dimensional dynamical systems; saddle-node bifurcation
- Modeling neuronal activity
- Oscillatory behavior, spirals; Hopf bifurcation

Second Half: Reconstructing and Extending Models

- Selection of paper to reproduce
- Term paper proposal
- Model plan: intermediate goals and timetable
- Benchmarks:
  - Introduction
  - Model Description
  - Results
  - Discussion
- Instructors meet with student teams every class to provide suggestions
- Instructors meet every class to assess student progress
- Extensions to model
- Student presentations
- Final term paper due on last day of class
- Each student writes his or her own term paper

Student Projects

- Examples of topics students have worked on last year:
  - Cancer growth and control
  - Dynamics of HIV infection, COVID-19, Avian flu, Ebola
  - Closing and opening of the Venus flytrap
  - Models of inflammation: neutrophils and macrophages
  - Predicting skeletal muscle force
- Student publication
  - Priscilla Ambrosi - doing research on *Drosophila* development
  - Reproduced model of *Drosophila* development in class
  - Served as the basis of publication:
    - Ambrosi et al., PLoS Computational Biology, 10(8), e1003807.

Summary and Conclusions

- Given appropriate guidance and support, Biology students can master the tools and techniques necessary to understand, reproduce and extend mathematical models.

- Math, physics and engineering students can also master considerable amounts of complex biology in the context of mathematical modeling.

- Providing the necessary intellectual support for students and regular feedback to ensure their success is very time intensive, and also very rewarding for the instructors and students.

- Giving students the ability to master interdisciplinary material and to write clearly about it provides them with skills that can help them throughout their careers.

Chiel, et al. Learning Biology by Recreating and Extending Mathematical Models. *Science* 336:993, 2012. 10.1126/science.1214192