Mathematical Biology Plan

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1 Introduction

Advances in computing power and vast increases in data have led to an increasing interest and growth in the field of mathematical biology. While not ubiquitous, more mathematics departments across the country are recognizing the positive impact of this field, both on biology and mathematics, by hiring mathematical biologists, developing coursework in mathematical biology, and in some exceptional cases, developing degree programs or centers in mathematical biology. To remain competitive with other institutions that are leading the way by developing mathematical biology groups and centers, we propose five avenues in which we can strengthen mathematical biology in the Department of Mathematics at the University of Kentucky over the next two years: through (1) the design of new courses at the graduate and undergraduate levels, (2) providing an alternate route for biology majors to pursue a minor in mathematics, (3) providing information to our students about career opportunities that the skills developed in mathematical biology make available, (4) development of internal and external collaborations and other synergistic activities, and (5) hiring of new math bio faculty. These five points are outlined and discussed below.

2 Proposed Coursework

2.1 Undergraduate level

David Murrugarra and Olivia Prosper are developing a course in mathematical modeling in biology, which will be titled "Modeling Nature and the Nature of Modeling". David Murrugarra, Olivia Prosper, and possibly Jeremy Van Cleve from the Department of Biology, will rotate as instructors for the course. The class will cover a core set of topics, namely Discrete Models and Differential Equations, with applications in biology selected at the instructor's discretion. Proposed topics for the Fall 2017 offering of the course are presented below. The topics presented in the Spring 2016 offering of the course can be found here: http://www.ms.uky.edu/~dmu228/AS320/.

1. Discrete Models

   (a) Single-species discrete population models, their equilibria and stability. Examples include: Simplified Logistic model, Ricker Model, Beverton-Holt model.

(b) Matrix population models. Examples will be taken from ecology.

(c) Analysis of multidimensional discrete models. Application: Discrete Epidemic Models.

2. Differential Equations

(a) One-dimensional continuous population models and their qualitative analysis.

(b) Introduction to Epidemiological Models: the Kermack-McKendrick SIR and SIS models with no demography.

(c) Properties of planar systems, their equilibria, phase plane analysis, linear stability analysis, Poincare-Bendixson Trichotomy and Dulac-Bendixson Criterion. Some applications: Lotka-Volterra predator-prey model, SIR model with demography.

(d) Linear stability analysis for higher order systems. Application: deriving the basic reproduction number R_0 in complex epidemiological models.

(e) Bistability in epidemiological models.

2.2 Graduate level

Regarding graduate education, both members are interested in offering topics classes that are related to their research fields. David Murrugarra plans to offer a graduate topics class about Discrete Dynamical Systems for graduate students that are interested in applications of discrete/algebraic methods in biology. This class will discuss mathematical tools for network inference, model selection, reduction techniques for model analysis, and network control of biological systems. Applications covered in this class will focus on systems biology. Olivia Prosper would like to teach a special topics course in mathematical epidemiology. The first course she envisions would focus on classical techniques for analyzing nonlinear ODEs, topics in model validation (parameter estimation, identifiability, model selection, etc.) and discrete and continuous-time Markov Chains. Although the applications would be focused on epidemiology, the tools developed would be useful beyond this topic. Down the road, she envisions a special topics course on applications of optimal control theory to biology, or a course that focuses on PDEs (age-structured models, time-since-infection models) and Delay differential equations in population biology. These classes will initially be offered as MA 5XX: Topics in Mathematical Biology that could attract graduate students in math as well as students from other departments such as biology and statistics. A targeted date to start offering this class is spring 2018.

3 Alternative route to math minor

We propose offering an alternate route to a math minor for undergraduate students in biology, and possibly other non-math majors that would benefit from this sequence of coursework. The goal is to provide a math bio track towards the math minor with a curriculum that increases the quantitative skills of biology majors in a way that is relevant to their field, and that will make them more competitive in the market place and for graduate school. See Table 1 for the proposed coursework.

Table 1: **Math Bio Track to Math Minor**

	Course Number	**Description**
Required:		
	MA 113 or MA 137	Calculus I or Calculus for the Life Sciences I
	MA 114 or MA 138	Calculus II or Calculus for the Life Sciences II
	MA 213	Calculus III
	MA 322	Matrix Algebra and its Applications
	A&S 320*	Modeling Nature and the Nature of Modeling
One of:		
	MA 214	Calculus IV
	MA 320	Introduction to Probability

Table 2: * Once approved, we plan to replace this course number with MA 337.

4 Job Market for graduates

4.1 Opportunities with B.S.

The job market for those with a B.S. in mathematics, with experience in math bio, will have similar job opportunities as other students in applied mathematics. Students who participate in the "Modeling Nature and the Nature of Modeling" course, or participate in independent study with David Murrugarra or Olivia Prosper, will develop modeling, model analysis, and computational skills that will be marketable in the private sector. Math students will have the opportunity to pursue graduate school in mathematics, and possibly biology, statistics, or biostatistics (particularly if they have engaged in undergraduate math bio research), while biology students will be much more competitive in their applications to biology doctoral programs.

4.2 Opportunities with Masters/Ph.D.

Because of the interdisciplinary nature of mathematical biology, the career opportunities for those with a background in mathematical biology are quite broad. For those with an interest in academia, job opportunities are available in both mathematics and biology departments at both the postdoctoral and tenure-track levels. Government labs are also interested in Ph.D.'s with a background in mathematical biology. For example, the Cold Regions Research and Engineering Laboratory (CRREL) in Hanover, New Hampshire was specifically searching for someone with expertise in math bio, and individuals at the Oak Ridge National Lab have expressed interest in this area as well. The modeling and coding skills that researchers in mathematical biology develop also makes these individuals marketable in the private sector. Pharmaceutical companies now hire mathematical biologists to develop pharmacological models to help inform drug discovery. In fact, the Society of Mathematical Biology (SMB.org) currently lists job openings for a modeler at Pfizer and a senior scientist position at Merck. Cancer centers, such as the Mayo Clinic and the Moffitt Cancer Center, also hire mathematicians to do research in cancer modeling. Our collaborators and former colleagues conducting math bio research now work in math departments, biology departments, pharmacy departments, government positions such as the NSA, and in the private sector - predominantly financial institutions such as Goldman Sachs. These individuals working in the financial sector often held Masters degrees in mathematics with a research focus in mathematical biology. Individuals with positions in government labs and universities often held doctorates in mathematics with a research focus in mathematical biology.

5 Synergistic Activities

5.1 Collaborations

Regarding research collaboration, both members of the math biology group have shown interest in developing collaboration with colleagues within and outside the department. David Murrugarra has been working with Dr. Randal Voss from UK biology since the fall of 2014. Their project involves a graduate student of Dr. Voss. Within the department, David Murrugarra and Dr. Qiang Ye are working on a project about using machine learning techniques for RNA folding. This project involves two graduate students of Dr. Ye. Olivia Prosper sees a number of opportunities for collaboration across departments. In particular, the research of Dr. Grayson Brown (director of Public Health Entomology Lab) and Dr. Stephen Dobson in Entomology seem the most directly related to her current work, and she plans to reach out to them about their respective projects on the Zika virus and Wolbachia, and more generally about their work on mosquito and sand-fly borne diseases. Both have an interest in mathematical modeling. For projects related to the spatial spread of infectious disease, collaborations with individuals in the Department of Geography are possible. Combining economic and epidemiological models is a developing field, and presents the opportunity for collaboration between math bio and math econ within the Department of Mathematics. Currently, Olivia Prosper is actively involved in numerous collaborations with both biologists and mathematicians outside of the University of Kentucky.

5.2 Math Bio on Campus

Regarding seminars, both members participate in the applied math seminar. They have been involved in other activities across campus. For instance, in fall 2015, they (along with Jeremy Van Cleve) hosted a small math biology journal club that attracted colleagues from other departments. In fall 2016, David Murrugarra and Olivia Prosper are participating in a reading club in population genetics that is organized by Jeremy Van Cleve from UK biology. These activities may open up some opportunities for interdisciplinary collaboration. There are also other seminars and events on campus that are interdisciplinary and that can be of interest for math biology faculty and students. For instance, the Systems Biology and Omics Integration (SBOI) Journal Club and Seminar Series in the Bioinformatics Department. Also the recently created Institute for Biomedical Informatics (IBI, http://ibi.uky.edu/) here at University of Kentucky might create opportunities for math biology faculty to interact with other colleagues across campus. In Spring 2015, Professor Lou Gross from the University of Tennessee and former director of NIMBioS gave a talk in our math-bio colloquium. We plan to continue this series, with the hosting department alternating between mathematics and biology. This spring 2017, renowned mathematical biologist Professor Carlos Castillo-Chavez will be visiting UK as our Hayden-Howard lecturer.

6 Hiring in Math Bio

Hiring a third mathematician with an interest in biological applications is important for the further development of the group. The research area of the new member should complement existing research areas. Some prospective graduate students expressed interest in mathematical biology, and a healthy mathematical biology group will help to attract these students as well as provide sufficient resources to adequately advise these students while maintaining regular course offerings in the subject of math bio. In July of 2016, three undergraduate students participating in a math bio REU at the University of Tennessee visited our department to learn more about our graduate program and our math bio group. A third hire will make our department more attractive to students like this who would be well-prepared for our program and ready to engage in research. Finally, the current math bio faculty both continue to engage in undergraduate research. A third hire in math bio will allow us, as a group, to accommodate more undergraduate students interested in pursuing research.