Quantitative Biology at The College of William & Mary

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Overview of our program:

Quantitative Biology is a collaborative effort among the departments of Biology, Mathematics, and Applied Science at the College of William and Mary. Students interested in combining mathematics and biology are encouraged to follow the core curriculum, which includes two semesters of Calculus for the Life Sciences (MATH131/132), followed by an introductory biological modeling course (MATH345) and a 3-credit seminar with 7 biology and 7 math students, co-taught by a team consisting of a math and a biology professor.

Applied Science has recently launched a minor in Computational and Mathematical Biology that uses these core courses plus new courses in that department to provide further opportunities for student development.

Two major funding initiatives support faculty and students both in terms of coursework and in enhancing research experiences.

- HHMI has supported two faculty positions in the Mathematics department dedicated to quantitative biology, as well as provided supplement support for researchers in Biology and Applied Science. HHMI also offers financial support for undergraduate research in all areas of biology, with special efforts to target projects that develop quantitative skills.
- A NSF Undergraduate BioMath grant provides stipends and research funds for undergraduates seeking to combine biology and mathematics in a faculty supervised research project. This grant also funds internships for community college students and assists them in transfer to a four year program. These students engage in summer research projects with a biology faculty member, and then work with that faculty member and a math faculty member on modeling their data. Funds also support seminars by internationally recognized quantitative biologists.

The support from these grants has expanded collaborative research among biology and mathematics undergraduates and faculty. This research has fostered new skills and altered career directions for our students. Moreover, it has resulted in a significant number of publications and presentations.

Maryse Leandre, Thomas Nelson Community College summer intern, samples an American goldfinch for mercury.

Curriculum Development:

The quantitative biology program at William and Mary has developed and expanded several new curriculum elements. The courses in the BioMath core curriculum noted at left are described in detail below. The core curriculum is also part of the new Applied Science minor in Computational and Mathematical Biology. That minor has contributed directly to the development of new upper division courses in modeling and bioinformatics. This interdisciplinary minor can be tailored to student interests in ecology and evolution, neuroscience, or physiology. Additionally, the teaching of these courses has forged new faculty connections among the three departments, contributing both to professional development and encouraging research collaborations.

Undergraduate Courses in Quantitative Biology:

APSC 312 Medical Imaging: Introduction to the modern clinical non-invasive diagnostic imaging techniques. The course will cover the physical, mathematical and computational principles of x-ray, ultrasound, radionuclide and magnetic resonance imaging techniques.

APSC 451 Cellular Biophysics and Modeling: An introduction to simulation and modeling of dynamic phenomena in cell biology and neuroscience. Topics covered will include the biophysics of excitable membranes, the gating of voltage- and ligand-gated ion channels, intracellular calcium signaling, and electrical bursting in neurons.

APSC 452 Self-Organization in Life and Chemical Sciences: Here we investigate self-organization and complex collective behaviors that emerge from simple dynamical principles in a variety of living and chemical systems. We consider, for example, oscillatory chemical reactions, single-celled organisms and their communal behaviors, as well as the spread of HIV in human populations using agent-based computer simulation to model and analyze these systems. The course culminates in a final research project wherein students, in consultation with the instructors, develop and analyze their own original model.

APSC 454 Bioinformatics and Molecular Evolution: An introduction to computational molecular biology and molecular evolution including nucleotide and amino acid sequence comparison, DNA fragment assembly, phylogenetic tree construction and inference, RNA and protein secondary structure prediction and substitution models of sequence evolution.

BIOL 401 Evolutionary Genetics: Evolution as an ongoing process, rather than as a history, is emphasized. Topics include theoretical and experimental population genetics, ecological genetics, interactions of evolutionary forces, genetic divergence, speciation and molecular evolution.

BIOL 404/MATH410 Ecology and Evolution of Metapopulations (Spring 2006); Game Theory (Spring 2007) These are two recent topics courses for students who have completed MATH345 or the equivalent. The courses are in seminar format, with an emphasis on reading papers and understanding the theoretical and quantitative foundations used in that research discipline. The readings are supplemented with computer assignments to allow students to explore key concepts.

BIOL 412 Vascular Plant Systematics: The study of the principles and research methods of vascular plant systematics, emphasizing classification, evolution and comparative morphology of the major families of vascular plants. The class includes hands-on learning of modern phyloinformatic approaches.

BIOL 425 Biostatistical Analysis: An introduction to statistics and research design, including statistical inference, hypothesis testing,and linear modeling. Emphasis is placed on the application of quantitative techniques in the biological sciences and the use of computers in data analysis.

BIOL 448 Evolutionary Biology: An introduction to the mechanisms and outcomes of evolution. Examples are drawn from many disciplines (e.g. genetics, behavior, and paleontology) to discuss how researchers study the evolution of organisms and develop evolutionary theory.

MATH 131/132 Calculus I and II for the Life Sciences. This two-semester course has two main goals: 1) to show how, when, and why mathematics can be used to model biological processes, and 2) to have students master the core concepts of calculus (i.e. limits, sequences, derivatives,

MATH 345 Mathematical Biology: This course introduces student to the art of mathematical modeling in the biological sciences. Students work in groups (typically a mixture of biology and physics/math majors in each group) to tackle biological questions by developing and analyzing mathematical models.

MATH490 Partial Differential Equations and Mathematical Biology: Reaction-diffusion systems are widely used models in situations where spatial dispersal plays a significant role. We cover spatial spread of genes and of diseases, random dispersal of populations, random and chemotactic motion of microorganisms, cellular maturation, and pattern formation in morphogenesis. While introducing many biology models, we will also develop related mathematical theory and methods including diffusion mechanisms, waves, bifurcation theory, Turing's instability mechanism. Computation and simulation of solutions will be used throughout the class.

Research Initiatives:

More than 20 William and Mary undergraduates have participated in HHMI or NSF-funded BioMath research projects over the last three years. Several of these projects have or will result in publications and presentations at national and international conferences (e.g. Ecological Society of America). The undergraduate researchers are fully involved in the conception and design as well as implementation and analysis of the projects. So far, undergraduate projects have included modeling predator-prey dynamics in metapopulation structures, modeling and analyzing the effects of avian community structure on human disease (e.g. West Nile virus) risk, developing new quantitative techniques for describing variation in visual signaling structures in birds, and modeling how neural circuits in the brain interact to produce rhythmic outputs that control respiration. Many of these students have been co-mentored by both Biology and Mathematics faculty.

NSF funding has sponsored 10 local Community College students over the last three summers in 10-week BioMath internships, including 9 women and 4 students from underrepresented ethnic groups. Almost all of these students have subsequently transferred to 4-year Universities, including two to William and Mary.

12 undergraduates have either published or submitted peer-reviewed papers to leading journals. Most of the BioMath students have presented their work at either our W&M undergraduate research symposium or at a national meeting. We are placing our students in prestigious biomath graduate (e.g. UC Riverside, UNC Chapel Hill, Duke, John Hopkins) and professional programs (e.g. NIH baccalaureate program).

Challenges:

We have expanded mathematics and statistics in both the lab and lecture components of our introductory courses, but we have limited feedback on math content in other life science courses.

Maintaining interdepartmental teaching and research in interdisciplinary areas such as quantitative biology challenges the department-based evaluation system. This is especially worrisome for untenured faculty.

Faculty with strong quantitative biology skills are in high demand, so retaining faculty has been a challenge for our university, which lacks a Ph.D. track in both Biology and Mathematics.

Faculty contributing to quantitative biology:

Dr. Martha Case, Biology
Dr. Dan Cristol, Biology (NSF UMB PI)
Dr. Christopher Del Negro, Applied Science
Dr. Christopher Funk, Biology (new in Fall 2007)
Dr. George W. Gilchrist, Biology
Dr, Paul Heideman, Biology
Dr. Ross Iaci, Mathematics (new in Fall 2007)
Dr. Tim Killingback, Mathematics (to Boston U in Fall 2007)
Dr. George Rublein, Mathematics
Dr. Margaret Saha, Biology (HHMI PI)
Dr. Sebastian Schrieber, Mathematics (to UC Davis in Fall 2007)
Dr. Junping Shi, Mathematics
Dr. Greg Smith, Applied Science
Dr. John Swaddle, Biology (NSF UMB PI)
Dr. Paul Tian, Mathematics (new in Fall 2007)