DIMACS

Series in Discrete Mathematics
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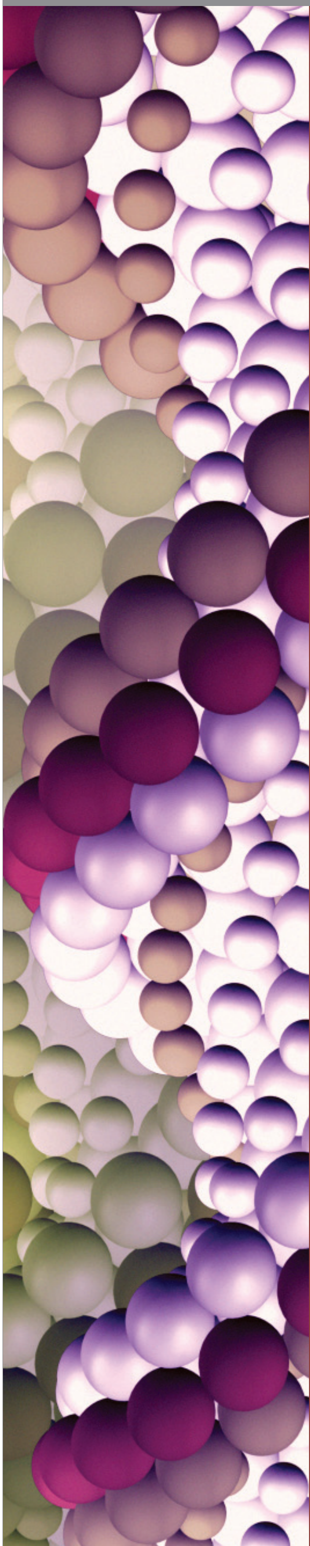
Volume 76



BioMath in the Schools

Margaret B. Cozzens
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https://doi.org/10.1090/dimacs/076

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Center for Discrete Mathematics
and Theoretical Computer Science
A consortium of Rutgers University, Princeton University,
AT&T Labs–Research, Alcatel-Lucent Bell Laboratories,
Cancer Institute of New Jersey (CINJ), NEC Laboratories America,
and Telcordia Technologies
(with partners at Avaya Labs, HP Labs, IBM Research, Microsoft
Research, Georgia Institute of Technology, Rensselaer Polytechnic
Institute, and Stevens Institute of Technology)

American Mathematical Society
Providence, Rhode Island

2010 *Mathematics Subject Classification.* Primary 00A06, 00A08, 92F05, 97–XX, 93A30, 00A69, 92–XX, 05Cxx, 68Uxx.

Library of Congress Cataloging-in-Publication Data

BioMath in the schools / Margaret B. Cozzens, Fred S. Roberts, editors.
p. cm. — (DIMACS series in discrete mathematics and theoretical computer science ; v. 76)
Includes bibliographical references.
ISBN 978-0-8218-4295-9 (alk. paper)
1. Biomathematics. 2. Biology—Mathematical models. 3. General—General and miscellaneous specific topics—Mathematics for nonmathematicians (engineering, social sciences, etc.). 4. General—General and miscellaneous specific topics—Recreational mathematics. 5. Biology and other natural sciences. 6. Mathematics education. 7. Systems theory; control—General—Mathematical modeling (models of systems, model-matching, etc.). 8. General—General and miscellaneous specific topics—General applied mathematics. 9. Biology and other natural sciences. 10. Combinatorics—Graph theory. 11. Computer science—Computing methodologies and applications.

QH323.5.B476 2011
570.15′1—dc22

2010045762

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Topics, Course Changes, and Technology

Evaluation of How the Integration of Biology and Mathematics Works

Foreword

Modern biology has very much become an information science, heavily dependent upon methods of the mathematical sciences (computer science, mathematics, operations research, statistics). This is reflected in the wide variety of undergraduate, graduate, and postdoctoral initiatives in mathematical biology, bioinformatics, and related topics. However, the groundwork for these fundamentally interdisciplinary topics needs to be laid well before the college level. The idea for this book came out of a conference "Linking Mathematics and Biology in the High Schools" held at the DIMACS Center at Rutgers University on April 29-30, 2005. The theme of the conference reflects a major DIMACS initiative on the interface between the biological and mathematical sciences in the schools, which has included teacher training, development of materials, and a heavy dose of evaluation of how things work.

This volume presents contributions from mathematicians and biologists, from high school math and biology teachers, from experts in science and math education, and from researchers active at the interface of mathematics and biology. There are papers dealing with curriculum, new topics that can fit into existing courses, training teachers in interdisciplinary approaches, how to introduce new courses and new ideas in biomath, and on the responses of students and teachers to exposure to these new topics.

We would like to express our thanks to the editors who put this volume together and to the many people at DIMACS who work to put together its programs.

The DIMACS BioMath in the Schools Initiative, and thus the development of this volume, has been generously supported by a series of National Science Foundation (NSF) grants to DIMACS: ESI-0421887, a supplement to the latter, a supplement to CCF-0432013, ESI-0628091, and ESI-0425752.

DIMACS gratefully acknowledges the generous support that makes its programs possible. Special thanks to NSF and to DIMACS' partners at Rutgers, Princeton, AT&T Labs-Research, Alcatel-Lucent Bell Labs, the Cancer Institute of New Jersey, NEC Laboratories-America, and Telcordia Technologies and affiliates at Avaya Labs, HP Labs, IBM Research, Microsoft Research, Georgia Institute of Technology, Rensselaer Polytechnic Institute, and Stevens Institute of Technology.

Fred S. Roberts, Director
Robert Tarjan, CoDirector
Rebecca Wright, Deputy Director

Preface

The interface between the mathematical and biological sciences is growing rapidly, fueled by such developments as the human genome project, modeling of the spread of diseases such as SARS and H1N1 influenza, climate change modeling, and the development of tools for developing sustainable environments. These problems and projects are inherently interdisciplinary, and reflect the fundamental mathematical sciences-based nature of much of modern biology. Increasingly, undergraduate students, graduate students, and postdoctoral students are being exposed to topics at the interface between the mathematical and biological sciences. However, very little has been done to explore this interface at the precollege level, and with the increasingly interdisciplinary nature of modern science, it is important to expose students to this interface as early as possible to prepare them for possible new educational and career choices, to make them better citizens who can help make decisions about health care, environmental issues, etc., and to enhance their appreciation for modern biology and modern mathematics. The high schools are a place to start, and this book explores the mathematical science-biological science interface in the context of what is desirable and what is feasible at the high school level.

The idea for this book came out of a conference "Linking Mathematics and Biology in the High Schools" held at the DIMACS Center at Rutgers University on April 29-30, 2005. The conference explored methods to establish connections between these disciplines, bringing together those who have tried it, those who have made it work on the undergraduate level, and those who know how to get new programs into schools. This book, like that conference, brings together ideas from those who have already experimented with bringing the mathematical sciences into the high school biology classroom or modern biology into the high school mathematics classroom; those who have integrated the mathematical sciences and biological sciences successfully at the undergraduate level and have advice for how to do this at the high school level; mathematics education researchers and science education researchers responsible for training high school teachers in mathematics or biology; high school biology and mathematics curriculum developers; high school biology and mathematics instructional materials developers; teachers and administrators who are knowledgeable about the opportunities for and obstacles against introducing the biology/mathematics interface at the high school level; and researchers and others with an interest in secondary education.

Among the topics of importance that are discussed in this book are:

- Topics in mathematics and computer science that could be included in biological sciences courses and topics in biology that could be included in mathematical sciences courses.

- Materials availability and development.
- What is happening at the undergraduate level that could be adapted to the high school level.
- What changes in the undergraduate curriculum have implications for high school education.
- How to train teachers to present biomath topics in their classes and interact with teachers from partner disciplines.
- How to assist/communicate with teachers who have never experienced the interdisciplinary point of view in college.
- Problems arising from biology teachers who are uncomfortable with mathematics and mathematics teachers who are uncomfortable with biology.
- Ways that biology and mathematics teachers can partner.
- Restrictions resulting from prescribed and rigid curricula.
- Difficulties arising from introducing new courses and new ideas into the classroom.
- The impact of technology.

The book is divided into four sections: The Rationale for High School BioMath; Curriculum Materials and Teacher Training/Development; Topics, Course Changes, and Technology; Evaluation of How Integration of Biology/Mathematics Works. These sections are somewhat arbitrary, since many of the papers cover more than one of these themes.

Section I on Rationale for High School BioMath consists of five papers giving the arguments for integrating mathematics and biology in high school classes and opportunities for doing so. It begins with a paper by Fred S. Roberts, one of this volume's editors, on why BioMath and why now, written through the lens of the author's own career. The author discusses the National Academy of Sciences BIO2010 Report, which focuses on undergraduate education of students in biology and mathematical sciences classes, and recommends that concepts, examples, and techniques from math and the physical and information sciences be included in biology courses and that biological concepts and examples be included in other science courses. Topics discussed include epidemiological modeling, biology as information science, - physical mapping of DNA, DNA and RNA chains and the "RNA detective game," systems biology, graph-theoretical models of the spread of disease, measurement of cough severity and fatigue, biosurveillance, and location of bioterrorism sensors, and others. Activities appropriate for high school Biology and Mathematics classrooms, and often combined classrooms, are described.

A second paper in Section I is one by Eric Jakobbson that describes the interdisciplinary scientist of the 21st century. The paper refers to a National Academy of Sciences report (Rising Above the Gathering Storm, 2007) that broadens the scope of the message of BIO2010 to warn that American competitiveness and prosperity are at risk because of the decline in numbers of our brightest and most capable young people entering scientific and engineering careers. Jakobbson contends that "a major failing of our institutions of higher learning is failure to come fully to grips with the fact that the deepest concepts in science, engineering, basic and applied mathematics, and computer and information science, transcend existing disciplinary boundaries. This results in our courses and curricula at all levels becoming circumscribed in a way that prevents us from presenting to our students a clear view of what modern science has become and where it could go in the future."

Few of the materials in biomath developed for undergraduate classes are appropriate for high school classes without modification. Laurie J. Heyer and A. Malcolm Campbell, in their paper on teaching bioinformatics and genomics in an interdisciplinary way, provides a good example of what can be done at the undergraduate level and be readily adapted for high school use. They describe the proliferation of courses and programs in bioinformatics and genomics, pointing out that it parallels the growing demand for a trained workforce, following the completion of the human genome project. They point out that students proficient in bioinformatics and genomics will be key to "unlocking the mysteries of the genome."

The paper by Nina H. Fefferman and Lainie M. Fefferman describes macrobiology, those fields dealing with the "larger scales," from individual organisms to ecosystems, and explores how these fields are dependent upon mathematical descriptions. Such areas include population ecology, behavior dynamics, epidemiology, conservation biology, forestry and agriculture, and neuroscience. In addition to giving the personal career perspectives of the two authors, the paper provides mathematical macrobiology lesson plans in epidemiological detective work; the understanding of scale, unit, and relative ratio of size; species growth and wildlife management in the field of conservation biology; and efficient communication among honeybees.

The final paper in Section I is by Asamoah Nkwanta, Dwayne Hill, Anasuya Swamy, and Kevin Peters and it deals with linking molecular biology and enumerative combinatorics through counting of RNA patterns. The authors describe a workshop methodology used with urban public school teachers that introduces them to the integration of these topics in the classroom.

Section II consists of five papers on Curriculum Materials and Teacher Training/Development. It explores the development of curricular materials for high school classrooms, high school teachers' responses to these new materials, and the integration of them into their classrooms. High school teachers need curricular materials that highlight the interconnections between biological and mathematical topics. The first paper of this section, by Margaret B. Cozzens, one of the volume's editors, describes work at DIMACS funded by a series of National Science Foundation grants designed to create modular materials, which can be used in either biology or mathematics classrooms, or both. It describes modules in computational molecular biology, mathematical epidemiology, and ecology and population biology, and describes work at DIMACS to utilize teachers, content matter experts, and science and math education experts to develop the modules, pilot and field test them, and evaluate them and student responses to them.

Kathleen M. Gabric's paper, "The Awakening of a High School Biology Teacher to the BioMath Connection," describes how a biology teacher became exposed to mathematical methods in biology and how it has expanded her horizons and those of her students and changed the way she teaches.

Linda J. Morris, Cynthia Long, and Jodene Kissler, in their paper, describe a beginning linking experience between a mathematics and a biology teacher. They describe the joint pilot testing of a module from BSCS, the Biological Sciences Curriculum Study, which provides an opportunity for biology and mathematics teachers to solve problems together. In particular, they describe the Genes, Environment and Human Behavior module, in which discrete mathematics is emphasized as students apply a chi-square analysis to test whether the differences observed in allele frequencies for a certain gene are significant in a formal statistical sense.

The paper by Katherine G. Herbert and James H. Dyer addresses issues to consider when creating a curriculum based on interdisciplinary studies, with an emphasis on bioinformatics and the use of Internet skills. It gives an indepth example of how to integrate these topics from the point of view of the biology instructor, chemistry instructor, mathematics instructor and computer science instructor. The specific example involves introducing students to the nature of the preproinsulin molecule and to the computational steps for comparing preproinsulin with other molecules through a sequence alignment search with a tool like BLAST.

The article by Maria Consuelo Rogers and Debbie S. Yuster describes the integration of mathematics topics into the courses of a biology and chemistry teacher. In particular, it describes that teacher's experiences in introducing an integrated mathematics and chemistry learning environment using technology, and including field work to gather environmental data. The article discusses differing challenges at different grade levels, the interaction with administration, and obstacles - such as time constraints and different "languages" in different disciplines.

Section III of this book is on Topics, Course Changes, and Technology, and consists of five papers on a variety of subjects. New technologies have driven the increasing need for integrating the mathematical and biological sciences in both research and education. These new technologies allow the processing and analysis of very large data sets, and acquisition of the data through the Internet. These technologies also significantly increase the number of topics and applications teachable in standard and new courses, including traditional courses such as Calculus and new courses such as Ecology. This section explores the interconnections of the biological and mathematical sciences in light of the new technologies.

The first paper in Section III is by Hal Scheintaub, Eric Klopfer, Madeline Scheintaub, and Eric Rosenbaum. The complex processes studied in modern biology (and other disciplines) require multi-disciplinary tools to understand them. The authors point out that incorporating complex systems modeling, facilitated by curricular innovation, can encourage the use of quantitative skills in the life sciences classroom. They note that "in the last twenty years rapid advances in high-speed computing and computer graphics have created a revolution in the scientific understanding of complex systems." Yet, they point out, computer simulations and complex systems have had only limited impact on classroom practices. The paper discusses "new tools and curricula [that] have been introduced into the classroom to enable learners to use simulations to explore complex phenomena in a quantitative way." In particular, the paper discusses agent-based modeling of complex systems and discusses how student understanding of population growth can be advanced with a simple agent-based computer simulation using a programmable modeling environment called StarLogo.

Joseph Malkevitch's paper connects basic ideas of "distance" between biological objects (DNA sequences, molecules) to fundamental mathematical topics such as trees and graphs. The paper describes some simple mathematical tools that can be introduced into both Biology and Mathematics classes and how these simple tools, not built on heavy abstraction and symbolism, can engage students in applications of mathematics even if they are "not enamored of mathematics." Starting with an example from diabetes involving insulin, the author describes how notions of distance arise in many important biological and daily life situations involving concepts of similarity, equity, closeness, etc.

M.E. Martin's paper discusses the use of methods of the information sciences in teaching biology. In particular, it describes the "availability, utilization, and creation of dynamic web tools as they relate to secondary and early undergraduate education in mathematical biology." As the author points out, "Although the graphing calculator is prevalent in most secondary math classrooms, computer software, such as spreadsheet and database programs, are the preferred tool for biologists and these tools are often accessed, perhaps unknowingly, through web pages maintained by biomedical and health organizations. Using software is not new in mathematics education, but its pervasiveness and availability on the internet now allows a great deal of benefit in both cost and synergy." This paper surveys some of the tools available for both high school and early undergraduate mathematical biology education and illustrates with models from drug dosage, heart rhythm, and red blood cell dynamics.

Much of modern biomathematics is based on ideas of continuous mathematics, much of it requiring sophistication in differential equations and other calculus-based tools that are beyond the scope of high school mathematics. Most of the papers in this book emphasize other types of mathematical tools, from discrete mathematics, probability/statistics, etc. However, some fundamental examples of biomath involving continuous mathematics are very much amenable to the high school classroom, and the paper by E.S. Marland and M.E. Searcy explores such examples. It explores an approach to teaching Calculus in high school that begins and ends with difference equations and recursion, and introduces biological modeling with the introduction of new Calculus topics. The paper includes practical classroom ideas for teachers and discusses, in a section aimed at teachers, administrators and curriculum specialists, how an "integrated discrete-to-continuous" approach can be incorporated into existing curricula.

In their paper, Charles Mullins and Daniel W. Cranston describe the experience of Mullins in mentoring a high school student's biomath research project. The paper describes the shortest superstring problem, a mathematics problem arising from the human genome project, where it was needed to cut the large DNA molecules into smaller strands and then reassemble them. The evolution of the project, difficulties encountered, and factors leading to success are described.

Section IV concerns Evaluation of How Integration of Biology/Mathematics Works and has one paper, by Andrea E. Weinberg and Leonard Albright. The authors are experienced evaluators who describe their evaluation of the DIMACS BioMath Connection project that is discussed in the paper by Cozzens in Section II. The authors talk about how to evaluate interdisciplinary materials, teacher use of such materials, and ways to assess the impact of those materials on students. It presents the finding that high school students do indeed respond positively to the teaching and learning of mathematics in biology classes and vice versa.

The editors are immensely grateful to all of the people who have made this book possible: the authors, the anonymous reviewers of the papers, Ricardo A. Collado, who helped the authors put their papers in correct AMS format, Christine Spassione at DIMACS, and Christine Thivierge, editorial assistant at the American Mathematical Society.

The editors' work on bringing biomath into the schools has been supported by a series of National Science Foundation (NSF) grants to DIMACS. Four of these grants have supported their work on teacher training and materials development: ESI-0421887, a supplement to the latter, a supplement to CCF-0432013, and ESI-0628091. A fifth grant ESI-0425752, supported the conference on biomath in the schools that led to this book. This volume would not have been possible without the support and encouragement of the NSF over the past six plus years for DIMACS' efforts in developing modules and working with high school teachers to implement them in schools across the country.

Co-editors:
Margaret B. Cozzens
Fred S. Roberts
August 2010

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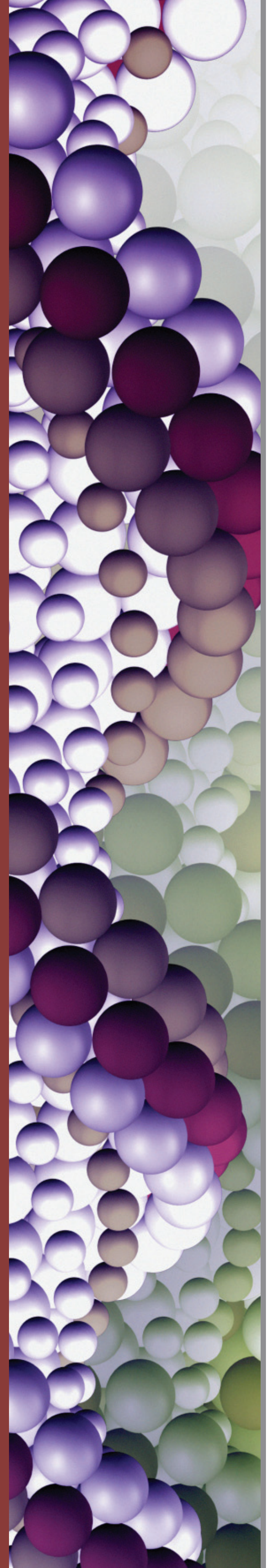
Even though contemporary biology and mathematics are inextricably linked, high school biology and mathematics courses have traditionally been taught in isolation. But this is beginning to change. This volume presents papers related to the integration of biology and mathematics in high school classes.

The first part of the book provides the rationale for integrating mathematics and biology in high school courses as well as opportunities for doing so. The second part explores the development and integration of curricular materials and includes responses from teachers.

Papers in the third part of the book explore the interconnections between biology and mathematics in light of new technologies in biology. The last paper in the book discusses what works and what doesn't and presents positive responses from students to the integration of mathematics and biology in their classes.



ISBN 978-0-8218-4295-9

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