

A Proposal for an Interdisciplinary Minor Degree Program in Mathematical Biology (For Fall 2008)

Jason E. Miller (Mathematics)
Jon Beck (Computer Science)
Laura Fielden (Biology)
Michael I. Kelrick (Biology)
Pamela J. Ryan (Mathematics)

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1 Executive Summary

The audience for this document is current and future students in Truman's Mathematical Biology program, faculty in the mathematical and life sciences at Truman, individuals in Truman's faculty governance system, and future coordinators of the minor program in Mathematical Biology. This document is a visionary document and as such shall illuminate but not supersede other operational documents generated to support the proposed minor.

The Mathematical Biology Minor at Truman has been proposed in response to a growing national awareness of the interdependence of the sciences and the mathematics as ways of knowing and to the need to increase the number of young people able to pursue careers in emerging interdisciplinary areas. Mathematical biology is an interdisciplinary field in which mathematical, computational and statistical tools are brought to bear on questions arising from the life sciences. To earn the proposed minor degree, students are required to have learning experiences in the following key proficiencies: data acquisition, modeling, computation, statistical analysis and research. To this end, each student will first design an individualized learning plan for the courses and experiences that will, taken as a whole, provide for all of the above key proficiencies as well as satisfy the requirement for a minimum of 15 credit hours with 9 credit hours above the 300-level.

The minor will also require students to produce a technical report on their research and present their work in an appropriate public venue such as the annual Truman Student Research Conference. The structure of the mathematical biology minor is purposefully flexible and designed to allow a variety of ways in which a student can satisfy the degrees interdisciplinary learning requirements. Minor requirements and their satisfactory completion will be tracked using a portfolio system monitored by an oversight committee for the minor. This oversight committee will consist of of four faculty members, two from each of the Departments of Biology and Mathematics and Computer Science. Portfolio categories will reflect five key proficiencies of learning experiences that are central to the minor program.

The freedom afforded by the portfolio approach embraces the many kinds of opportunities provided by Truman's curriculum, as well as by experiences like internships and undergraduate research programs both on- and off-campus. Central to the minor are courses to be identified by the new MABI rubric. The MABI rubric will apply to our four currently existing courses that have been jointly developed by faculty in the departments of Biology and of Mathematics and Computer Science to support the interdisciplinary training of undergraduates (Introduction to Scientific Computing, Introduction to Bioinformatics, Introduction to Mathematical Biology, Biostatistics), as well as to a 300-level seminar course and a 300-level undergraduate research course. In addition to courses offered under the MABI rubric, Truman's Departments of Biology and of Mathematics and Computer Science offer several courses which contain material that supports the minor.

Students can use the Mathematical Biology minor to create an interdisciplinary emphasis in any one of several specialized areas (*e.g.*, computational biology, biomedical modeling, medical image analysis, natural resource management). Support for the establishment of an interdisciplinary mathematical Biology minor at Truman is clearly demonstrated by strong student and faculty interest and participation in Truman's current Mathematical Biology program and its research-based learning communities (funded by the National Science Foundation).

2 Bill for the creation of the Mathematical Biology minor

WHEREAS a national acknowledgement of "...profound changes in the nature of biology and how biological research is performed and communicated..." has stimulated a clear call for new undergraduate curricular approaches addressing "...the importance of building a strong foundation in mathematics and the physical and information sciences to prepare students for research that is increasingly interdisciplinary in character" [1]; and

WHEREAS the State of Missouri continues to invest heavily in support of life science and biotechnology industries. Governor Blunt's proposed Lewis and Clark Discovery Initiative (2006) highlights the importance of innovative life science research to the economic well being of our state, and this, in turn, builds on the Life Sciences Research Board and Life Sciences Research Trust Fund, established by House Bill 688 (2003) during Governor Holden's administration; and

WHEREAS interdisciplinary education will become an increasingly important facet of student learning at Truman¹; and

WHEREAS our Mathematical Biology program together with Truman's *Science, Technology, Engineering, and Mathematics Talent Expansion Program*, have created a broad foundation of faculty collaboration between the Departments of Biology and Mathematics and Computer Science that has most recently been expressed in the Biology Department's *Center for Learning Integrative Mathematics and Biology* proposal to the Howard Hughes Medical Institute's 2008 competition for Undergraduate Science Education; and

WHEREAS there has been and continues to be substantial and demonstrable student interest in interdisciplinary training and research, at the interface of biology and mathematics and computer science; and

WHEREAS several interdisciplinary courses which were designed to support student learning at the interface of the life and mathematical sciences have been taught with very good success; and

WHEREAS there does not currently exist a mechanism by which the University can certify that a student has successfully completed a set of interdisciplinary learning experiences in mathematical biology that would be equivalent to a minor, much less one has a *bona fide* research experience which is used to encourage both breadth of preparation and depth of engagement; and

WHEREAS supporting a minor in Mathematical Biology will contribute both to the uniqueness of our undergraduate curriculum and to the visibility of what distinguishes our university (a stated objective of the University Strategic Plan, FY 2008-2010);

BE IT THEREFORE RESOLVED that Truman State University offer a minor in Mathematical Biology, whose philosophy and structure for administration is detailed in the following document.

¹University Strategic Plan, FY 2008-2010, approved June 2007 by the Board of Governors. The *Open Letter to the Commission on Undergraduate Curriculum and the Truman Campus Community* of 31 January 2008, also supports this assertion.

3 Introductory Remarks on Mathematical Biology

This section provides an introduction to the national, regional, and institutional importance of mathematical biology. It also outlines Truman's accomplishments in providing students with high-quality interdisciplinary experiences in this area. A detailed assessment of Truman's program is contained in Section 5 (see page 15).

A nationwide movement in undergraduate science education is underway to modernize life science training so that it conveys the increasingly important role played by the mathematical and computational sciences in life science research. This reform is seen as key to America's long-term international economic and scientific competitiveness, and among its promoters are major professional societies such as the American Society for Microbiology, the Ecological Society of America, the Mathematical Association of America, and the American Mathematical Society. Major funding agencies such as the National Science Foundation (NSF), the National Institutes of Health, and the Howard Hughes Medical Institute (HHMI) are also promoting this interdisciplinary reform by funding educational grants targeted at undergraduate institutions such as Truman. These reforms aim to meet the growing need for people who can operate in an interdisciplinary context that melds a more traditional life science background with mathematical knowledge and skills.

A widely disseminated report [1] published in 2003 by the National Research Council (NRC) of the National Academy of Sciences called for a comprehensive reform of undergraduate life science education so that it and its partner disciplines would convey the interdependence of the sciences and mathematics as ways of knowing. In particular, the report says, "Undergraduate biology students who become comfortable with the ideas of mathematics and physical sciences from the start of their education will be better positioned to contribute to future discoveries in biomedical research." This report makes comprehensive recommendations for reform, noting rightly that life science researchers of the future will require quantitative expertise and the ability to collaborate in interdisciplinary teams; likewise, those trained in mathematics, statistics and computer science will need to understand the contexts, in this case the life sciences, where their knowledge and perspectives can be usefully and creatively brought to bear.

Since 2003, and largely in response to student interest and the NRC report, members of the Departments of Biology and of Mathematics and Computer Science at Truman have established cross-disciplinary research and teaching collaborations for the purpose of building infrastructure for this more modern, interdisciplinary life science education. Support from the National Science Foundation (NSF) has allowed Truman to expand upon proven expertise in undergraduate research to create an interdisciplinary training program in mathematical biology that is gaining national recognition for its quality. Funding has also allowed these faculty to develop interdisciplinary courses that bring students of the mathematical and life sciences together to learn in new ways (see Table 2). In the NSF's third-year review of Truman's Mathematical Biology program, the Foundation commended Truman's "particularly exemplary aspects" of "involvement by a large percent of the biology and mathematics departments that has resulted in a highly qualified group of faculty mentors from both biology and mathematics" and the "continuation of UBM students into graduate school or work at the intersection of the mathematical and biological sciences." Building on these strengths, the Biology Department recently proposed to the quadrennial HHMI Undergraduate Science Education competition a program of enhancing their introductory biology courses with mathematical concepts and techniques.

For these reasons, it is time that Truman provide students with institutional recognition of the interdisciplinary training they are already receiving via an interdisciplinary minor in Mathematical Biology. The availability of this minor would be immediately beneficial to students for their future placement in professional and graduate schools and it would identify Truman as one of a handful of American institutions where such interdisciplinary work is available to undergradu-

ates.

3.1 What is Mathematical Biology?

Mathematical biology is a subject in which mathematical, computational, and statistical tools are brought to bear on questions arising from the life sciences. For this reason, we use the modifier “mathematical” in its broadest sense so that it includes all facets of the mathematical and computer sciences including abstract and applied mathematics, statistics, computational science, and computer science.

This emerging field is primarily associated with the application of existing mathematical approaches to illuminate biological phenomena, so many regard it as a subdiscipline of biology (*a.k.a.*, quantitative biology). But recent explosive growth in the field (*e.g.*, the Human Genome project) and its use of very sophisticated mathematics has led others to regard the field as a subdiscipline of applied mathematics. Professionals agree that the mathematical sciences provide biology with tools that are akin to new and powerful instrumentation to describe and predict complex phenomena, and it is widely recognized that the complex phenomena that biologists study with the collaboration of mathematicians will lead to the development of new and original mathematics.

An excellent expository article explaining the increasing importance of the mathematical sciences to the life sciences (and *vice versa*) is [2].

3.2 Truman State University’s Mathematical Biology program

Truman’s Mathematical Biology program provides support for faculty and students involved in the interdisciplinary area of mathematical biology. A true mathematical biologist must be able to balance and wield the epistemologically distant mathematical and biological ways of knowing. Such mastery is not possible to attain at the undergraduate level. For this reason, Truman’s program does not try to turn a mathematics major into a biology major nor does it try to turn a biology major into a mathematics major; rather, the program provides learning experiences that lead students from both majors to understand the perspectives, language, and tools that the other uses. As a result, the mathematics students develop an intuition for the biological phenomena closest to their studies and the biology students develop a conceptual mastery of the mathematical approaches used to illuminate their work. Each also develops a respect for the partner discipline and displays a propensity to pursue future work that involves both. Program assessment, professional literature, and conversations at national meetings strongly support the notion that such training is an ideal preparation for interdisciplinary graduate studies, medical school, and early careers in emerging interdisciplinary sectors.

Many faculty in the Departments of Biology and of Mathematics and Computer Science have been involved in the interdisciplinary Mathematical Biology program since its start in 2003 (see Table 1). We have secured approximately \$1 million in external grant funding for a program that has been recognized as producing excellent graduates. Additional opportunities for external funding will continue to be available for many years, especially as we work to include faculty and students from allied fields such as Agricultural Science, Chemistry, and Physics.

4 Structure of the Mathematical Biology minor

This section details the philosophical underpinnings for the proposed interdisciplinary minor in mathematical biology, the proposed requirements for the minor, and a management plan for the

Table 1: Faculty involved in Truman’s Mathematical Biology program to date. Shown is their departmental affiliation along with their contribution to the program (grants, course development and teaching, or interdisciplinary undergraduate research (UR) mentoring). Members of the current grant program oversight committee are also indicated.

Name	Grant	Course	UR	BIO	MT	STAT	CS	Notes
Brent Buckner			*	*				
M. Scott Burt			*	*				
Laura Fielden-Rechav	*		*	*				co-Director
Diane Janick-Buckner			*	*				
Jon Gering		*	*	*				
Michael Kelrick	*	*	*	*				co-Director
John Ma			*	*				
Tim Walston			*	*				
Tony Weisstein		*	*	*				
Jon Beck	*	*	*				*	co-Director
Dean DeCock			*			*		
Hyun-Joo Kim		*	*			*		
Carol Thatcher		*				*		
Michael Adams		*	*		*			
Todd Hammond			*		*			
Jason Miller	*	*	*		*			Director
Pam Ryan		*	*		*			
Phil Ryan		*	*		*			
Scott Thatcher		*	*		*			
Amber Johnson								Anthropology
Robert Baer			*					ATSU
Jim Rhodes			*					ATSU

program.

For students majoring in biology, the proposed minor degree certifies a mastery of mathematical and computational approaches to questions arising in the life sciences as well as an ability to communicate with mathematical scientists. For students majoring in mathematics or computer science, the minor degree certifies an ability to apply their skills to questions arising in the life sciences and to collaborate with life scientists. For students of other majors (*e.g.*, physics) the minor will certify an ability to do technical interdisciplinary work that involves the life and mathematical sciences.²

Achieving learning outcomes in the minor that differ according to student specialty requires a structure that allows flexibility while holding fast to some key principles.

4.1 Minor Philosophy and Requirements

To earn the proposed minor degree in mathematical biology, an undergraduate student will seek out experiences that lead to the following key proficiencies:

Data Acquisition: Acquiring data on biological phenomena in a lab, in the field, or both.

Modeling: Developing or applying mathematical models in a biological context.

Computation: Developing or applying computational tools in a biological context.

Statistical Analysis: Applying statistical testing of biological hypotheses.

Research: Investigating an open-ended question by conducting research at the intersection of the life and mathematical sciences.

Evidence for each of these should be roughly equivalent to what might be done for a substantial end-of-term project in a three-credit course.

A minor will be awarded to those students who design a learning plan for the courses and experiences that will, when taken as a whole, provide evidence of acquiring the above key proficiencies. At its most basic, a minor learning plan will show when and how students will satisfy the minor's course-based requirements. But beyond this, the learning plan will require the students to explain how the courses and experiences they select for their minor relate to one another and how they will provide the evidence required for the minor. The plan will require students to anticipate how they will use the courses to come to a deeper understanding of how to conduct interdisciplinary work at the interface of the life and mathematical sciences.

4.1.1 Basic Minor Requirements

The most basic requirements of the minor are the following:

- a minimum of 15 credit hours in residence at Truman with at least 9 credit hours at or above the 300-level, including
 - *Introduction to Mathematical Biology* (currently co-listed as BIOL 345 and MATH 345; 3 credits)
 - at least two *MABI Seminar courses* (1 credit each, described on p. 8)

²Such a certification of ability could be of value to students pursuing pre-med degrees (*e.g.*, in Health & Exercise Science), as well as other degrees that may be connected to biotechnology and related industries.

- at least one credit-bearing interdisciplinary research experience (3 credits),
- all courses must count toward a Biology, Mathematics, or Computer Science major or minor (or their required support), with no more than one course “double-counted” for the requirements of a single major, and
- attendance at a combination of 10 meetings (over two semesters) of interdisciplinary professional seminars of the Mathematical Biology program and its allied programs.

The for-credit interdisciplinary research requirement reflects the importance of learning through open-ended inquiry. Students who participate in high-quality, faculty-mentored interdisciplinary research (such as that offered through the Mathematical Biology program’s *Research-focused Learning Communities in Mathematical Biology* program) engage in learning that leads them to construct new knowledge and that often leads them to reexamine their understanding of the web of knowledge they have acquired through studies in their major. Such research experiences are ideal for interdisciplinary training, and it is these types of experiences that students in this minor program will seek. The minor’s research requirement will require a student to enroll in three credit hours of undergraduate research, produce a technical report on their research, and present their work in an appropriate public venue, such as Truman’s annual Student Research Conference, honors degree seminar in biology, senior capstone presentation in mathematics, or relevant professional meetings.

The seminar attendance requirement of the minor will be tracked using on-line tools (*e.g.*, PHP-based web forms with a MySQL database backend) that students will use to submit attendance reports. These submissions will be monitored by a member of the minor’s oversight committee.

4.1.2 The Mathematical Biology Minor Portfolio

The mathematical biology minor’s structure balances the variety of ways a student can satisfy the degree’s interdisciplinary training requirements with the long-term needs of program consistency, quality, and sustainability.

All minor requirements and their satisfaction will be tracked using a portfolio system³. Portfolio categories will reflect the five key proficiencies central to the minor program (see page 7) as well as the expectation of seminar attendance, the existence of a learning plan that (largely) precedes pursuit of the minor, and a reflective statement written at the end of the student’s time at Truman. The freedom afforded by a portfolio approach embraces the many kinds of opportunities provided by Truman’s curriculum, as well as by experiences like internships and undergraduate research programs (both on- and off-campus). Management of the portfolio and granting of the minor degrees to graduates is described in Section 4.2.

As a student progresses through the program, his or her portfolio will be monitored by an oversight committee for the minor (described later). The contents of the portfolio will be accessible to his or her program advisor(s), and the student may be allowed to share portfolio information with other students.

4.1.3 The MABI Rubric

While the learning that happens in the Mathematical Biology minor occurs in concert with and supports learning in multiple major degree programs on campus, it is distinct from them all. For

³We are currently investigating a product of the Open Source Portfolio Initiative (OSPI); see <http://www.osportfolio.org/> as well as a plug-in for the Blackboard courseware already deployed by Truman.

this reason, the minor warrants a rubric for specialized courses that represents this distinctive nature. Currently, the Mathematical Biology program has four courses developed with funds from the National Science Foundation⁴ that qualify as interdisciplinary by design and would warrant such a rubric (see Table 2). We propose that these courses be offered under a new rubric “MABI” similar to the way courses created for the Environmental Studies minor have the ENVS rubric.

Beyond the four existing courses, the Mathematical Biology program will propose two additional courses under the MABI rubric: a 300-level seminar course and a 300-level undergraduate research course.

The Mathematical Biology program has used seminar courses (both semester-long and block courses) as an effective way to quickly deliver specialized information to a small group of people. This mechanism for providing a variety of topics and experiences to students and faculty has been admired by faculty from other mathematical biology training programs. We envision using the *MABI Seminar* to offer three variations on a seminar course, at least one of which would be offered each semester. The envisioned variations are

1. a readings and discussion format (*e.g.*, a journal club),
2. a research methodologies seminar that might concentrate on familiarization with a particular class of mathematical approaches, instrumentation, lab techniques, or particular software environments, and
3. a practicum seminar in which teams of students (and faculty) are presented with a challenging question and must perform modeling to create solutions to the questions.

The seminar course would be named *MABI 3xx Seminar: Readings*, *MABI 3xx Seminar: Methods*, and *MABI 3xx Seminar: Practicum*, respectively, to reflect these course variations.

Although the departments of Biology and of Mathematics and Computer Science offer their own courses for undergraduate research, the unique nature of the experiences we expect of students merits a separate course with the MABI rubric. This would allow the oversight committee to recognize the many opportunities that students have for conducting undergraduate research, many of which do not currently have formal course credit as part of their structure. And having a separate course with the MABI rubric would facilitate continued long-term program assessment like that begun with National Science Foundation funding.

4.1.4 Other Courses

In addition to the MABI courses designed specifically to support an interdisciplinary training program in mathematical biology (see Table 2), Truman’s departments of Biology and of Mathematics and Computer Science offer several courses which contain material that would support the minor (see Table 3). While the courses themselves vary enough so that they do not *a priori* provide one or more of the key proficiencies sought by the minor program, they have great potential for providing learning experiences of value to and at the level expected by the minor (see p. 7).

4.2 Governance

In consultation with the Director of Interdisciplinary Studies, the proposed interdisciplinary minor in mathematical biology will be the responsibility Mathematical Biology program. This section describes how the Mathematical Biology program is organized and how it will provide the

⁴National Science Foundation’s *Interdisciplinary Training for Undergraduates in Biology and Mathematics* (supplement) program under Grant No. 0337769.

Table 2: Courses designed to integrate mathematics and biology. The Introduction to Mathematical Biology course is team taught by a biologist and mathematician. Each of these existing courses would acquire a MABI rubric.

Course Number	Course Name	Credits
MATH 288	Topics: Introduction to Scientific Computing	3
BIOL 3XX/CS 325	Introduction to Bioinformatics	3
BIOL 345/MATH 345	Introduction to Mathematical Biology	3
STAT 380	Topics: Biostatistics	3

Table 3: Courses in MATH, BIOL, or CS that have been offered in a way that supports the interdisciplinary training of students. These are likely candidates for courses included in a Mathematical Biology minor learning plan.

Course Number	Course Name	Credits
BIOL 502	Biometry	3
BIOL 510	Ecology	3
BIOL 518	Advanced Topics in Biology	3–4
CS 284	Introductory Topics in Computer Science	3
CS 484	Topics in Computer Science	3
MATH 288	Topics in Mathematics	3
MATH 488	Topics in Mathematics	3
MATH 530	Topics in Mathematical Modeling	3
STAT 387	Topics in Statistics	3

necessary oversight for and administration of the proposed interdisciplinary minor. The proposed interdisciplinary minor in Mathematical Biology will be managed in a manner similar to that of the interdisciplinary minor in Environmental Studies (ENVS).

Currently, faculty become associated with Truman’s Mathematical Biology program when they become involved in program activities. Faculty are eligible to join the Mathematical Biology program after they have co-mentored a student (or student team) with a colleague from a partner discipline in an interdisciplinary research project at the intersection of the life and mathematical sciences. For example, current members of the program have mentored in Truman’s *Research-focused Learning Communities in Mathematical Biology*. Faculty have also become eligible to join the program if they have made significant contributions to the creation of an interdisciplinary course in the program area or if they have revised an existing course to be more interdisciplinary.

As it stands, membership in the program has been informally granted. Upon formal creation of the minor and the MABI rubric, membership will be clarified. Faculty will be eligible for the Mathematical Biology program faculty if they meet one or more of the following criteria:

1. they have successfully co-mentored with a faculty member from a sister discipline a student (or team of students) in an interdisciplinary research project in the last three years,
2. in the last three years, they have made significant contributions to the creation of an interdisciplinary course in the program area or revised and taught an existing (multi-section) course to be more interdisciplinary,
3. they have taught a MABI course in the last two years,

4. they have submitted a grant (internal or external) or sabbatical proposal for the purpose of pursuing a project consonant with the objective of the Mathematical Biology program in the last two years, or earned such a grant or sabbatical in the last three years, or
5. they have served as a minor advisor to at least one student in the program in the last three years.

When a faculty member fails to meet this criteria, they will be notified 6 months in advance of their formal association with the program being suspended. In extraordinary circumstances, the program coordinating committee can grant or extend membership a person not meeting this criteria.

The Mathematical Biology program's coordinating committee is made up of the Project Director and co-Directors on the National Science Foundation grants⁵ that provide the program with its primary source of funding: Jason Miller (Mathematics, Director), Laura Fielden-Rechav (Biology), Pamela Ryan (Mathematics) who is substituting for Jon Beck (Computer Science) during his sabbatical, and Michael Kelrick (Biology).

4.2.1 Minor Advisors

Each student in the minor will be assigned a minor advisor from the list of Mathematical Biology program faculty (see <http://mathbio.truman.edu/people> for the current list of faculty). The minor advisor will be someone not in the student's major area, who will assist the student in the creation of a learning plan (and its revision, when necessary), the selection of courses and research experiences, and the completion of his or her portfolio. The minor advisor will also monitor the student's progress on completing his or her portfolio according to the timeline set out in his or her learning plan. He or she will also provide the student feedback on portfolio contents and, if asked, advise the minor program oversight committee on decisions it needs to make about the student's portfolio.

4.2.2 Oversight of the minor program

The minor in Mathematical Biology will be guided and administered by an oversight committee of four faculty members, two each from the Department of Biology and the Department of Mathematics and Computer Science. As a subcommittee of the Mathematical Biology program, it will report to the membership of the program and the program coordinating committee. The minor oversight committee will coordinate their administrative work with the Director of Interdisciplinary Studies. The committee will consist of two mathematical scientists and two biologists, each with staggered three-year terms; this will provide continuity of the committee's activities from year to year. Initial membership of this minor oversight committee will be Jason Miller (Mathematics), Laura Fielden (Biology), Jon Beck (Computer Science), and another biologist to be identified when the minor is approved.

To serve on the oversight committee in the future, a faculty member should have served as the advisor of at least two students in the minor in the three years prior to appointment to the position. While serving on the minor oversight committee, each member should continue to advise students in the minor and must continue to provide leadership to the Mathematical Biology program in other ways.

⁵National Science Foundation's *Interdisciplinary Training for Undergraduates in Biology and Mathematics* program under Grant No. 0436348, "Research-focused Learning Communities in Mathematical Biology," and Grant No. 0337769, "Mathematical Biology Initiative."

Duties of this Mathematical Biology minor oversight committee include ongoing evaluation of courses for their appropriateness for the minor; approving or assigning advisors for the minor; review and approval of proposed learning plans for the minor; continual monitoring of student portfolios; maintenance of the program's Continuous Improvement Plan (CIP), an assessment of the program and provision of summary information to department heads and to the Director of Interdisciplinary Studies (especially for further dissemination and use in recruitment and departmental reviews), providing content for the Mathematical Biology program web site (see <http://mathbio.truman.edu>), and organization of venues for presentation of students' research efforts, when needed.

Most importantly, the committee will be responsible for receiving and evaluating applications from students seeking the minor, and for evaluating students' portfolios as they make progress through the minor requirements.

4.2.3 The Application and Approval Process

The application process will have two components. First, as a student prepares to undertake the minor, he or she will create a learning plan consisting of a list of courses and/or experiences that will prepare them to demonstrate that they meet the key proficiencies of the minor (on page 7). This plan will include a statement that conveys a rationale for linking particular courses or experiences with each proficiency. (An example worksheet for the learning plan is included in this document on see page 20.)

Second, in a separate document, the student will describe the research project he or she will use to satisfy the minor requirement. This description could be submitted at the same time as the learning plan, but will probably be submitted later as the student understands the type of research in which he or she will be engaged. The statement will make clear for the program how the nature of the research project is interdisciplinary.

To be accepted into the minor program and to be assigned a minor advisor, the minor oversight committee must first review and approve a student's learning plan. At that point, a student will be invited to start contributing evidence and reflective material to their minor portfolio.

A student completed portfolio will consist of evidence demonstrating their realizing each of the key proficiencies, a written research report, and a reflective statement on how they see their learning plan having led to understanding of interdisciplinary work at the interface of the life and mathematical sciences.

Insofar as the intent of the portfolio approach is to provide students with maximum flexibility in determining the kinds of experiences that will be used to demonstrate the required proficiencies, we expect (and it stands to reason) that our sense of how the portfolios support the students' ongoing work will evolve as the minor program itself develops.

4.3 Example Minor Configurations

Students can use the Mathematical Biology minor as it is proposed to create an interdisciplinary emphasis in any one of several specialized areas. Such areas could include computational biology or bioinformatics, biostatistics, biomedical modeling, medical image analysis, ecological modeling, systems biology, resource management, multi-scale modeling, or mathematical physiology. The courses for each emphasis would depend upon a student's major. The portfolio-based and learning-plan-driven minor gives students great flexibility for customizing their learning experience without sacrificing accountability.

We include example sets of courses for learning plans related to bioinformatics. These plans give a rough indication of how the set of courses and experiences fulfill the expectations of the

Table 4: Courses a computer science major interested in computational biology might use in a learning plan for the minor.

BIOINFORMATICS FOR A CS MAJOR Course	PROFICIENCIES				
	D	M	C	S	R
Introduction to Math Bio	*	*			
MABI Seminar: reading		*			
MABI Seminar: model validation			*	*	
Bioinformatics		*	*		
BIOL 107	*				
Genetics	*			*	
Undergraduate Research					*

Table 5: Courses a biology major interested in computational biology might use in a learning plan for the minor.

BIOINFORMATICS FOR A BIOLOGY MAJOR Course	PROFICIENCIES				
	D	M	C	S	R
Introduction to Math Bio	*	*			
MABI Seminar: reading		*			
MABI Seminar: scripting			*		
CS 170			*		
CS 191			*		
Bioinformatics (M)			*	*	
Genetics (M)		*		*	
Undergraduate Research					*

minor (list on page 7) for students from different majors. Any course in the plan list that is followed by '(M)' is taken to satisfy a major requirement but is also an integral part of the learning plan.

An emphasis in computation biology or bioinformatics is accessible to students from computer science, mathematics, and biology, though their learning plans would reflect the different perspectives they bring to the topic. A computer science major would bring a computational strength (see Table 4); a biology major a genetic strength (see Table 5); and a mathematics major an algorithmic strength (see Table 6).

These configurations show that the learning plan may use courses in the major (and outside the major) as sources of evidence that the student meets the proficiency expectations of the minor. It also shows how a non-course experience could be used as a source for such evidence (see Table 6). At this time, we regard it as *highly unlikely* that a single three-credit course or lab can prepare a student in more than two of our minor's key proficiencies.

4.4 Staffing for the Minor

To be successful, this proposed minor will require human resources. The minor is designed take advantage of many existing courses and research programs offered by Biology and by Mathematics and Computer Science. However, the minor does rely on the continued scheduling of some specialized interdisciplinary courses taught by faculty from the client departments.

Table 6: Courses a mathematics major interested in computational biology might use in a learning plan for the minor.

BIOINFORMATICS FOR A MATH MAJOR Course	PROFICIENCIES				
	D	M	C	S	R
Introduction to Math Bio	*	*			
MABI Seminar: reading		*			
MABI Seminar: scripting			*		
Bioinformatics		*	*		
BIOL 107	*			*	
CS 170 (M)		*			
Genetics	*			*	
Monsanto Co-Op Program (M)			*		*
Undergraduate Research					*

As mentioned in Section 4.1.4, funding from the National Science Foundation allowed faculty to create four interdisciplinary courses. At that time, the Division Heads of Science and Mathematics and Computer Science made a commitment to offer two of these MABI courses each semester. The schedule we have established offers both Biostatistics and Introduction to Scientific Computing in the fall semester and both Bioinformatics and the team-taught Introduction to Mathematical Biology in the spring semester. This requires 5/6 of a position distributed between 5 faculty (one or two from Biology, depending on who teaches Bioinformatics, and the balance from Mathematics and Computer Science).

In addition, the minor asks faculty to teach MABI seminars on various topics, several of which would run each semester. Ideally, this work would be factored in to a faculty member's workload somehow, but it is not clear to the authors how this ought to be done. This is a detail that needs future resolution. Work done by members of the oversight committee and by advising of student will be recognized as service to the University in the context of tenure and promotion.

Currently, faculty turnover in Biology and in Mathematics and Computer Science is challenging each department's ability to provide the courses to support the minor. For this reason, and because this proposed minor (and the Mathematical Biology program which supports this minor) has demonstrated potential to draw regional and national attention to the University, this proposed minor program merits new resources from the University. To speculate what form resources would take is premature, but natural mechanisms include postdoctoral or temporary positions, or faculty reassignment. Although the Mathematical Biology program is committed to the pursuit of external funds to support the minor and its other activities (e.g., interdisciplinary research with faculty and students), only evidence of buy-in from the University will make those future funding proposals competitive.

5 Indicators of Program Demand

There is demonstrably strong student interest in a University program that certifies skills and habits of thought acquired through a program of interdisciplinary study in mathematical biology. We draw our evidence from the following:

- the motivation (history) for our two projects that have been funded by the National Science Foundation;
- the number of students who have applied to and/or participated in these programs;
- student attendance at the ongoing Mathematical Biology seminar;
- the postgraduate activities of students who have participated in our program; and
- the mathematical biology projects pursued by students not in our programs.

Each of these indicators illuminates student interest in a mathematical biology minor from a different perspective. Taken together, they show significant interest for the proposed minor.

5.1 History

Student interest was one of the strong motivations for our submitting the two grant proposals to the National Science Foundation that have helped us develop the infrastructure to support a minor degree program in mathematical biology.

Prior to 2003, there were only isolated professional communication and collaboration between the biology and mathematical science faculty, and curricular overlap was minimal. While discipline histories and epistemological distance were responsible for this curricular “stovepiping,” our students were picking up on the growing importance of mathematical and computational approaches to questions in the life sciences (*e.g.*, the Human Genome project). Noticing that some students were earning double majors in biology and computer science so they could participate in the New Biology, our eyes were opened to an opportunity to better serve our students.

5.2 Number of NSF program applicants

With the support of funding from the NSF, we have offered two research-driven programs in mathematical biology. Keeping in mind that many opportunities for high-quality research experiences compete for the attention of Truman students, the number of student applications to our NSF-funded programs can be taken as an indicator of student interest in a mathematical biology minor.

From 2003-2005, our *Mathematical Biology Initiative* (MBI) provided funds for interdisciplinary teams of students and faculty to pursue questions at the intersection of life and mathematical sciences for 10 weeks during the summer. In 2003 and 2004, a total of eleven undergraduates in biology, computer science, and mathematics participated in this program. There was no application procedure for this program; participants were individually selected by faculty mentors. The MBI has matured into what we now refer to as our Mathematical Biology program.

From 2004-present, our *Research-focused Learning Communities in Mathematical Biology* (RLC) program has provided funds for interdisciplinary quartets of students and faculty to collaborate on research for a minimum of an entire academic year, including an intense 10-week research experience that is coordinated through the STEP Office’s Summer Undergraduate Research Experience program. Note that the intellectual maturity required by the projects leads us to actively

discourage first-year students from applying; however, some interdisciplinary projects in mathematical biology are available to these students through the STEP Program (see page 17).

Table 7: Demographic attributes of RLC Program applicants and participants. In 2006, students already involved in the program were not required to reapply, so the “All” column represents new applicants. In 2005 and 2007, some participants reapplied, while others did not.

	2005		2006		2007	
	All	Cohort	All	Cohort	All	Cohort
N=	20	11	12	13	23	15
Gender						
Males	9	5	9	10	12	10
Females	11	6	3	3	11	5
First Generation	5	1	4	2	5	3
Primary Ethnic Background						
Caucasian	17	8	11	10	21	15
African American	0	0	1	0	1	0
Asian	2	2	2	0	0	0
Hispanic/Latino	1	1	0	1	0	0
Academic Standing						
Freshman	0	0	0	0	0	0
Sophomore	3	2	4	6	12	9
Junior	11	7	7	5	9	5
Senior	6	2	1	2	2	1
Major						
Mathematics	7	3	3	4	10	6
Biology	12	7	7	8	9	7
Computer Science	1	1	1	1	2	2
Mathematics+Biology	3	1	0	1	1	0

5.3 Student Attendance at the Mathematical Biology Seminar

Our biweekly Mathematical Biology seminar brings together the RLC community and others with a shared interest in illuminating life science questions with mathematical or computational tools. It is the only multi-disciplinary seminar in Mathematics and the Sciences, and its regular attendees include faculty and students from physics, chemistry, and anthropology, as well as from mathematics, computer science, and biology.

Since the seminar is open to all faculty and students, attendance by students who are not involved in our NSF-funded research programs can be taken as an indicator of student interest in our proposed minor. Attendance is regularly 15-25 individuals.

5.4 Postgraduate activities of our students

Because our Mathematical Biology program receives funding from the NSF, we are obligated to report to the Foundation regarding the postgraduate pursuits of our students. What our graduates do can be taken as an indicator of the quality of our training program and the seriousness

with which the students take their experience in mathematical biology. Therefore, these students represent future potential value of a formal program in mathematical biology.

Below is a list of the postgraduate activities of the 18 graduates of our mathematical biology programs. Many of these graduate programs are explicitly interdisciplinary; in addition, we know that students in other graduate programs which are not explicitly interdisciplinary are nonetheless pursuing interdisciplinary opportunities.

- Graduates from RLC program: 10
- Graduates from MBI program: 8
- Graduate school: 11
 - Northwestern University (Computer Science)
 - University of Missouri, Columbia (Statistics and Natural Resources Ecology)
 - Iowa State University (Statistics, Bioinformatics and Computational Biology)
 - Baylor College of Medicine (Bioinformatics)
 - Truman State University (Biology)
 - Case Western University (Molecular Biology and Microbiology)
 - Villanova (Conservation Biology)
 - Cornell (Entomology)
- Industry: 1
 - Monsanto
- Medical School: 2
 - Saint Louis University
 - University of Wisconsin, Madison
- Other Professional: 1
 - University of Tennessee Law School
- Teacher preparation: 3

All signs point to a very high proportion of the students in our 2006 and 2007 cohorts pursuing interdisciplinary graduate degrees and career paths.

5.5 Other Student Projects in Mathematical Biology

While most of our program's assessment concerns program participants, we have also tracked the broader impacts of our activities. That students not directly involved in our program have pursued training-type experiences in mathematical biology is a powerful indicator of broad student interest in a formal program in mathematical biology.

We have three kinds of records showing that such activity is occurring: the record of senior capstone projects in mathematics, the record of presentations at Truman's Student Research Conference, and the record of research activities supported by the Truman's STEP Program.

As of March 2007, 11 mathematics majors have used a project in mathematical biology to satisfy their Capstone Integrating Experience graduation requirement. Of these, 8 were not involved in Truman's mathematical biology program in any way other than possibly attending the Mathematical Biology seminar.

Since 2004, at least 8 students (not counting our program participants, who are required to present) have presented projects in mathematical biology at Truman's annual Student Research Conference.

Since 2004, the STEP Program has provided summer research experiences to approximately 60 students in computer science, mathematics, or science. Of these students, 10 were involved in interdisciplinary research projects in mathematical biology.

6 Conclusion

This proposed interdisciplinary minor in Mathematical Biology reflects the scholarly and professional interests of a large number of Truman students and members of the faculty. External funding has allowed many Truman faculty to work at the intersection of the life and mathematical sciences, and by doing so, develop the skills and understanding necessary to support and guide students in the sort of interdisciplinary training described in this document. Insofar as our Mathematical Biology program is primarily grant-funded, limited external funding restricts the number of students that can take advantage of this new expertise. Offering our students a minor that leverages existing courses in constituent departments will allow vastly more students to participate in this interdisciplinary program *and* it will make Truman more competitive for external funds to support the program, its students, and its faculty.

Although the above blueprint for the minor is detailed and thorough, the authors understand that the program must remain flexible and responsive to the changing environment. The minor will evolve as the faculty, students, and University evolve.

References

- [1] National Research Council of the National Academies, Committee on Undergraduate Biology Education to Prepare Research Scientists for the 21st Century, Board on Life Sciences, Division on Earth and Life Sciences. 2003. *Bio 2010: Transforming undergraduate education for future research biologists*. The National Academies Press, Washington, D.C., USA.
- [2] Cohen, J.E. "Mathematics Is Biology's Next Microscope, Only Better; Biology is Mathematics' Next Physics, Only Better." *Public Library of Science Biology* 2 (12). 2004.

Individualized Mathematical Biology Minor Learning Plan

Name:	
Email:	
Graduation Year:	
Academic Advisor:	
Major(s):	

Do you plan to enter Truman’s Master of Arts in Education program: Yes, No.

Write a brief statement about your reasons for earning this interdisciplinary minor and about your post-graduate plans. This statement should be attached to this form and submitted electronically to the Mathematical Biology Minor oversight committee.

List the degree-related activities in which you are participating or planning to participate (*e.g.*, student organizations, attending Biology Seminars or Mathematical Biology Seminars, tutoring, grading):

The mathematical biology minor will be awarded to those students with experiences that demonstrate ability to work in an interdisciplinary way between (and within) the mathematical and life sciences. Specifically, a student must demonstrate work and experiences of the following nature:

Data Acquisition (D): Acquiring data on biological phenomena in a lab or field setting or both.

Modeling (M): Developing or applying mathematical models in a biological context.

Computation (C): Developing or applying computational tools in a biological context.

Statistics (S): Applying statistical testing of biological hypotheses.

Research (R): Investigating an open-ended question, by conducting research at the intersection of the life and mathematical sciences.

Use the table below to list courses and experiences you will complete and indicate to which category, above, each will contribute. You must have courses that

- total a minimum of 15 credit hours with 9 credit hours at or above the 300-level, including
 - *Introduction to Mathematical Biology* (currently co-listed as BIOL 345 and MATH 345; 3 credits)
 - at least two *MABI Seminar courses* (1 credit each)
- a for-credit interdisciplinary research experience.

List all courses that will contribute to a cohesive interdisciplinary experience. At most two course in the minor may be used to satisfy major requirements, but list all courses in your major that play a role in your interdisciplinary learning plan; indicate all courses counting toward your major by placing a check in the “Major” column.

Then write a statement (approximately 500–700 words) that describes how your learning plan prepares you to do interdisciplinary work. Use this opportunity to convey aspects of your plan that are not represented in the above table, such as a theme that unifies the courses and experiences (*e.g.*, bioinformatics, modeling of physiological phenomena, agricultural genetics). This statement will be used to evaluate your proposed learning plan. This statement should be attached to this form and submitted electronically to the Mathematical Biology Minor oversight committee.

Course	Cr	D	M	C	S	R	When	Major
Introduction to Math Bio	3							
MABI Seminar	1							
MABI Seminar	1							
Undergraduate Research	3							

Before submitting this plan to the Mathematical Biology Minor oversight committee, discuss your minor proposal with your academic advisor to indicate that the two of you have discussed your plan and believe it to be ready to submit.

Advisor signature: Date: