

Essay

Mentoring Interdisciplinary Undergraduate Students via a Team Effort

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Submitted March 15, 2010; Revised May 30, 2011; Accepted June 6, 2011
Monitoring Editor: John R. Jungck

We describe how a team approach that we developed as a mentoring strategy can be used to recruit, advance, and guide students to be more interested in the interdisciplinary field of mathematical biology, and lead to success in undergraduate research in this field. Students are introduced to research in their first semester via lab rotations. Their participation in the research of four faculty members—two from biology and two from mathematics—gives them a first-hand overview of research in quantitative biology and also some initial experience in research itself. However, one of the primary goals of the lab rotation experience is that of developing teams of students and faculty that combine mathematics and statistics with biology and the life sciences, teams that subsequently mentor undergraduate research in genuine interdisciplinary environments. Thus, the team concept serves not only as a means of establishing interdisciplinary research, but also as a means of incorporating new students into existing research efforts that will then track those students into meaningful research of their own. We report how the team concept is used to support undergraduate research in mathematical biology and what types of team-building strategies have worked for us.

INTRODUCTION

Biology by nature is an interdisciplinary field of science. For example, the best known major transition in biology, namely that between the world of chemicals and the living cell, has been one of the biggest challenges of biology (Maynard Smith and Szathmary, 1995). The interdisciplinary bridge between biology and chemistry or biology and physics has been natural and smooth because biology shares solid roots and a common language with chemistry and physics (Karsai and Kampis, 2010). Contrary to the very important influence of mathematics on biology (Jungck, 1997; May, 2004), building the bridge between mathematics and biology has been more problematic, partly due to their motivations and approaches and partly due to the fact that undergraduate training in the

two disciplines lags behind modern integrated biological research (Gross, 1994; McComas, 1998; Abell and Lederman, 2007; Kerfeld and Simons, 2007). More recently, a meeting hosted by the American Association for the Advancement of Science targeted a goal that classroom teaching of biology should reflect the way modern biological research operates (Mervis, 2009; Summers, 2009; Woodin *et al.*, 2009; Brewer and Smith, 2011). Specifically, the biologist of the near future will need to have a broader background in mathematics, computation and computer skills, physics, and chemistry than does the biological researcher today. One of the main recommendations of the advisory board was that we need to encourage undergraduate students to pursue research as early as possible in their career.

That science is best learned by doing research is an idea that has been around for decades (Roth, 1995), as has the emphasis on the importance of undergraduate research (McComas, 1998). It seems that successful approaches to mentoring undergraduates in mathematical biology research still need to be developed. Biologists and medical scientists traditionally obtain results by relying heavily on observational schemes and experimental methods. Often, it is only after such efforts that biologists might realize the need for elaborated analysis, complex modeling, or some other computational or mathematical tool that is beyond the expertise of the biologist who initiated the project (Couzin, 2004). Thus,

DOI: 10.1187/cbe.10-03-0027

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collaborations with mathematicians and statisticians are commonly formed only after the data are collected, in which case collaborators may attempt to contribute to the solution of a problem from within the strict framework of their familiar disciplinary approaches (van den Besselaar and Heimericks, 2001; Hukkinen *et al.*, 2006). For example, a biologist might collect data without regard for the methods that will eventually be used to analyze it and start to collaborate with a statistician only when the work is prepared for publication. Although a statistician may be able to analyze such data, a failure to understand the biological context may lead to statistical results that have little relevance to the original question. The publications that may result from such multidisciplinary collaborations may contain flaws and, indeed, the mathematical or statistical analysis in biological research papers published to date is inadequate or omitted entirely (Bialek and Botstein, 2004). Many publishers have started to use a statistical advisory board or consultation service to remedy these problems.

In this paper, we report on a novel paradigm based on a team approach for mentoring undergraduate research using interdisciplinary teams of students and faculty. The students are mentored by different interdisciplinary teams of faculty and student groups from the freshman level until graduation. At the freshman level, students are introduced to research early on via a series of lab rotations. These lab rotations—in conjunction with an innovative curriculum and related synergistic activities—serve as an introduction to interdisciplinary work. One of our main goals is to develop teams of students and faculty that combine mathematics and statistics with biology and the life sciences. The team concept is carried forward into more substantial research settings, such as summer research experiences and faculty/student publications. Thus, the team concept serves not only as a means of establishing interdisciplinary research, but also as a means of incorporating new students into existing research efforts that will then track those students into meaningful research results of their own.

INSTITUTIONAL BACKGROUND AND THE TEAM-ORIENTED APPROACH

East Tennessee State University (ETSU) is a regional state university with ~14,000 undergraduate and 2000 graduate students. ETSU became a research-intensive university a couple of years ago, and it is in a transitional phase where new challenges related to research administration need to be solved. Because this paper focuses only on mathematical biology research, we center our discussion on the cooperation between two departments at ETSU. In many ways, these departments are typical of similar departments in a number of institutions. Both departments (Department of Biological Sciences and Department of Mathematics and Statistics) have master's programs, and both are deeply committed to undergraduate education and research. In fact, the Department of Mathematics and Statistics *requires* undergraduate research as an integral part of each student's curriculum. Both departments are medium in size with faculty size fluctuating between 15 and 20. Many faculty members have external support for research or education development. Both departments have faculty members who have been working on mathematical

biology alone or with external collaborators, and many of these faculty members are also adjuncts in the corresponding department.

As is typical in similar departments in other institutions, limitations on time and resources must be overcome in order to develop meaningful collaborations. Scientific collaborations are commonly dissuaded or delayed by the time required to attain a background in another field and similar complications that come from working outside of one's particular research area (Tadmor and Tidor, 2005). However, a team-oriented approach can ameliorate the demands of forming interdisciplinary collaborations and can allow greater results collectively than would have been obtained individually. In the fields of business (Katzenbach and Smith, 1992) and engineering (Oakley *et al.*, 2004), the importance of teams has been long recognized, and already in many scientific fields, the tendency of a scientist to work in isolation is giving way to a team-based research model (BECON, 2003; Humphrey *et al.*, 2005). In biology and the health sciences, this trend is no less significant, as evidenced by calls for the development of collaborative teams in systems biology (National Heart, Lung, and Blood Institute Systems Biology Collaborations [R01]) and the well-documented importance of collaborative teams in addressing a wide variety of systems biology problems (Allarakhia and Wensley, 2005).

In general, teams are formed as part of the process of collaboratively defining and interpreting a specific research problem. Members of the team need only attain the background in another field sufficient for understanding the statement of the problem (as long as there is a team member whose expertise is in that field). The statement of the problem must be specific enough to allow each team member to individually contribute to the solution of the problem, so that each team member benefits not only from his/her own contributions but also from the contribution to the team from other members. Integrated platforms and information systems, such as Visual Cell, the Virtual Physiological Human (Kohl and Noble, 2009), and others (see Sauro *et al.*, 2003, for more examples), provide templates where data, mechanisms, models, simulations, and theories are represented in a uniform and transparent manner, making it easy for members of interdisciplinary teams to collaborate (Karsai and Kampis, 2010). At ETSU, the Institute for Quantitative Biology (www.etsu.edu/iqb) was formed as a vehicle for initiating and supporting the emergence of interdisciplinary teams and to foster the development of integrated platforms (Karsai and Knisley, 2009).

Our focus on team-oriented efforts not only promotes research among undergraduates but also provides a variety of educational opportunities for those same students. Because students, like everyone else, are more likely to join an existing group than to start something on their own, the team approach provides relatively larger cohorts of students than do traditional integrative approaches (e.g., independent studies, student-student collaborations). In turn, these relatively larger collections of students are available to be recruited for a variety of courses, seminars, and enrichment activities in support of both education and research in the integration of biology and mathematics. For example, in the academic year(s) leading up to the summer programs, we were able to fill up courses in systems ecology, complexity, and mathematical modeling in preparation for the team-oriented research. Likewise, surrounding each of the team efforts

described below are a variety of activities, including innovative curricula, hands-on use of software focused on quantitative biology, and student-oriented seminars, mentoring, and discussion sessions. Although the focus of this paper is on the team-oriented approach itself, we will nonetheless allude to some of these important by-products of the team-oriented approach throughout the paper.

INTRODUCING FRESHMAN STUDENTS TO RESEARCH

There are many advantages both to a student and to a faculty research advisor in involving students early in their career in interdisciplinary research (Brewer and Smith, 2011). For example, it allows sufficient training and an extended period of research that can lead to publication. The BIO2010 report states that “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” (National Research Council, 2003).

This commitment to an early introduction to undergraduate research is foundational to our National Science Foundation (NSF) science, technology, engineering, and mathematics (STEM) Talent Expansion Program (STEP) project entitled “Talent Expansion in Quantitative Biology” (TEQB; NSF 0525447). The main goals of this project include a) providing several opportunities for students to prepare for and engage in research and b) exposing the students to well-defined, multifaceted problems in quantitative biology. Students were recruited into the program by means of mailing information about the program to the region’s high schools; by emailing an invitation to apply to all ETSU freshmen applicants with a certain grade point average, and to those with Biology or Mathematics listed as their intended major; and by supporting existing students’ recruitment trips to their former high schools. Hiring high school teachers to act as liaisons to high schools was found to be the least effective way to recruit students. The majority of students entered TEQB as incoming freshmen, but occasionally late freshmen or sophomores joined too. We did not encourage postsophomore students to join.

The Lab Rotation Course

As a way to facilitate an early exposure to research, we proposed, instituted, and regularly offered a lab rotation course (MATH/BIOL 2390, Introduction to Research in Quantitative Biology) for the TEQB freshman students (Table 1). Stu-

dents were required to participate in a research project in four different labs during their freshman year. Mathematics majors signed up for 3 h of BIOL 2390 each semester, and vice versa, in an effort to facilitate earning of a minor in the “other discipline.” Specifically, the TEQB program requires at least one biology and at least one mathematics lab per semester (Godbole *et al.*, 2007), thus resulting in student participation in two biology-led and two mathematics-led faculty research efforts in their freshman year (Figure 1). Table 2 lists projects available for lab rotation students in 2006–2010.

Lab rotations, modeled largely after similar programs existing in many graduate schools, solve two problems: 1) They give students an early exposure to research techniques and methodologies; and 2) they allow students an informed choice of the laboratory and faculty advisor for their future thesis work. Many undergraduate students in a regional university do not have a clear understanding of the way a research laboratory works, and thus they are unprepared to make such choices before lab rotation participation. In addition, lab rotations allow hosting faculty access to research-oriented students, and many reported it as a useful recruiting tool.

Faculty hosting lab rotations were stimulated by small stipends that funded research supplies and travel (but not salary). Hosting lab rotations was viewed positively by the departments’ chairs; however, faculty members were not given any credit toward credit hours generated. The search for lab rotation hosts was accomplished by email solicitations through department chairs and directly to faculty members of all relevant departments across campus. A more targeted search included the solicitation of faculty members, who had posted announcements on the ETSU student research opportunities database, seeking undergraduate research assistants, as well as targeting newly hired faculty. Occasionally, a student would find a host not previously available for lab rotations; this was of course encouraged. We estimate that a campus of our size, including the medical school campus, can easily provide ~50 undergraduate lab rotation placements per year.

Each lab rotation consisted of 4–6 wk spent in a research lab, 5–10 h/wk, at the discretion of the hosting faculty member. Some students voluntarily form a group, which rotates through several host labs as a team; others proceed individually or form a team for just one lab rotation. We made no recommendations about this, and both models seem to be working well. The biggest challenge for the hosting faculty member is to ensure that all students are adequately involved in lab rotation activities, a difficult task given students’ and hosts’ schedules.

The outcomes of lab rotations ranged from a one-page report to a poster at a student conference to a full-fledged coauthorship in a peer-reviewed publication (e.g., Dick *et al.*, 2011). Students’ performance was evaluated and grades assigned based on written reports, focusing on concepts and techniques learned in each lab rotation, and on written faculty evaluation of each student. Clear articulation of course requirements and the grading procedure was the main requirement, which each lab rotation course had to meet in order to be listed as an academic course by the ETSU Curriculum committee. In the future, we might pay more attention to more rigid scheduling of the 2390 course, making it easier for students to actively participate in the lab rotation

Table 1. Participation of different departments in lab rotation at ETSU

Department participating (number of faculty members)	Number of faculty hosting lab rotations
Department of Mathematics and Statistics (23)	6
Department of Biological Sciences (17)	7
Department of Physics and Astronomy (8)	1
Department of Health Sciences (14)	1
Department of Biochemistry and Molecular Biology (8)	3

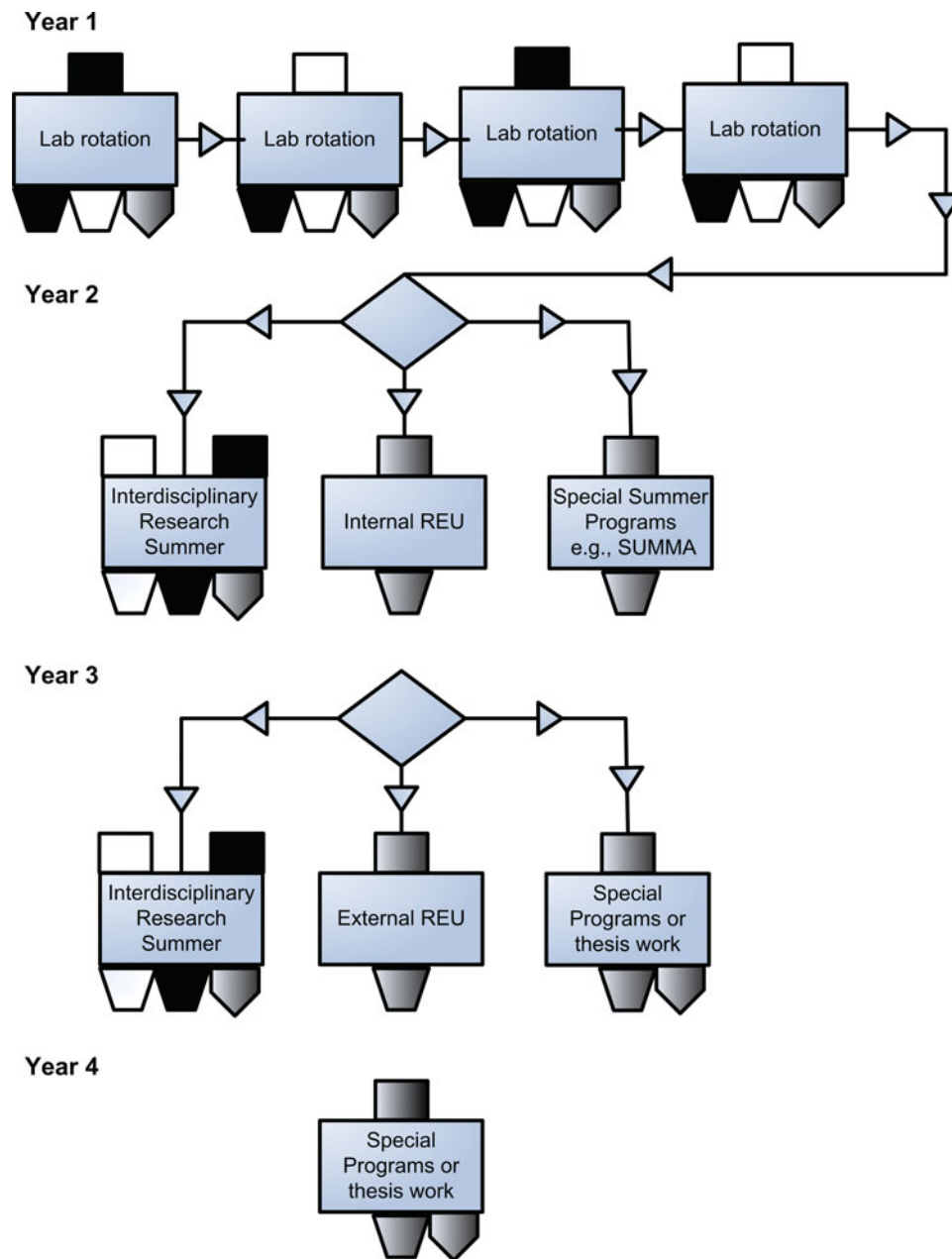


Figure 1. Schedule of the “team approach” mentoring strategy for an undergraduate student. The first year, each student participates in four lab rotations. In consecutive years, especially in summer, they choose between different interdisciplinary programs, and in the last 1–2 yr they typically focus on their thesis work. In concert with our team approach, each student is working as a member of several teams during his/her undergraduate years. All students are exposed to collaborate with undergraduate and graduate students as well as faculty members with different background. Legends: black, biology; white, mathematics; gray, either math or biology; square, faculty advisor; polygon, undergraduate student; pentagon, graduate student.

activities, as well as budgeting salary stipends for hosting faculty, making it easier to recruit lab rotation hosts.

Increase of Personal Interactions and Connecting Programs

Student–student interactions—in particular, interactions between mathematics students and biology students—are now and have been very important to our efforts. However, we have found that such interactions require guidance in deter-

mining what questions to ask and how to ask them. Thus, we have tended to develop student–student interactions within the context of a larger faculty–student, mathematics/biology team-oriented collaboration. For example, most lab rotations feature group projects in which students with different backgrounds interact with each other and with graduate or senior undergraduate students. Students in the TEQB project have regular group meetings with the PI of the project (A.G.), where they share their experiences with each other.

Table 2. Projects offered for lab rotation in 2006–2010 and the number of students participating

Project offered for lab rotation	Number of students participating
Evolutionary genetics of dietary restriction of lifespan in <i>Drosophila</i>	7
Modeling in biological systems	12
Genome dynamics, DNA damage, and repair and aging	2
Probability and sequence analysis	6
Biochemistry of disease resistance signaling	8
Mathematical Epidemiology	4
Computational Biochemistry	4
Quantitative analysis of soil fungi diversity	2
Behavioral Neuroscience	2
Fly lifespan, behavior, molecular analysis	7
DNA damage induced by radiation and UV light	8
The role of nuclear lamins on cell cycle	2
Graph theory applications in biology	8
Neuroscience models	2
Molecular Mechanism of ATP synthase	8

In many lab rotations, assignments are partitioned among students by the hosting faculty; in others, research role assignments are performed by the students themselves. For example, a team of three students may be given a task to measure *Drosophila* lifespan and fecundity under a variety of dietary conditions (Dick *et al.*, 2011). The students themselves then decide on specific assignments, such as media preparation, laboratory measurements, and data entry. In a different lab, students working on modeling microparasitic disease as their lab rotation project may distribute assignments relating to their background and interest. For example, one student codes the simulation or writes up the equations, another student collects data for the parameters from the literature, and a third student may run the simulation and collate the results.

Although NSF funding occurs through the STEP grant to the Department of Mathematics and Statistics and the Department of Biological Sciences, faculty from other departments have participated in hosting lab rotations, including Physics, Psychology, Health Sciences, and the Quillen College of Medicine. Medical school faculty participation in lab rotations is particularly important for recruiting undergraduate researchers into their lab, because medical school faculty members typically do not have direct access to undergraduate students.

Students have reported lab rotation as one of the successful components of the TEQB program in general and as an important stepping stone toward engaging in long-term research projects. In particular, students emphasized that knowledge acquired during lab rotation was immediately used for practical applications, which made their experience especially rewarding. Students also mentioned that working in groups, being mentored by graduate students, and working on the interface of different scientific disciplines were attractive components of lab rotations. The success of the TEQB lab rotation prompted us to rethink our Honors in Discipline program in biology, which will now include lab rotations as a required component during the freshman or sophomore years.

Although the brief nature of lab rotations does not allow us to expect publication-quality results, we have at least one

example of work done during a lab rotation published in an undergraduate research journal (Johnson *et al.*, 2010) as well as several national conference presentations. Moreover, lab rotations often result in student presentations at a variety of undergraduate research venues, such as those sponsored by the Institute for Mathematical Biology Education and Resources and the undergraduate research days hosted by the University of Tennessee, Knoxville. Indeed, such presentations are often made by freshmen and sophomores. This is possible due to the immediate incorporation of students into research at the very early stage in their careers, enabling them to obtain the background and experience necessary to participate in such conferences.

Schools that do not have a structured program similar to TEQB could easily institute a similar model through undergraduate research opportunities programs, such as the University of Michigan Undergraduate Research Opportunity Program. The director of such a program might then organize like-minded faculty members into a cohort that might run lab rotations in quantitative biology.

INTERDISCIPLINARY RESEARCH SUMMER PROGRAMS

Undergraduate research involves not only students but also their faculty mentors and lab support. Generally, undergraduate researchers join existing faculty research teams, which is successful as long as the existing teams themselves are successful already. That is, the team approach serves not only as an introduction to research, but also as a means of facilitating it long term. Indeed, with the support of our NSF Undergraduate Biology and Mathematics award, entitled “A Multi-stage Approach to Undergraduate Research in Mathematical Biology” (NSF DUE-0337406), we implemented a team-oriented interdisciplinary summer research program. This program had two overarching goals: 1) generating new teams working on mathematical biology at ETSU and 2) providing lab support and student stipends for new and existing teams in a competitive manner. The research occurs during the summer as a 9-wk-long, 40 h/wk Research Experience for Undergraduates style program available also to students outside ETSU.

Team Formation through Research Proposal

A unique aspect of our approach—one implemented directly as a means of fostering team-oriented research—is an application process that fosters the formation of teams by requiring an entire student/faculty team to apply for support via an online proposal system. To do so, the faculty members of the two departments were asked to list possible projects for this program in advance of the proposal solicitation. Several of these projects were pure biology or mathematics, but many of them were already formed as a math–biology project. We subsequently advertised the program and recruited students into taking the initiative in the application process by interacting with faculty sponsors of individual projects. They then had to write up a proposal with the help and approval of at least one mathematician and one biologist. Although this may come with a risk of losing students who start looking into summer studies late, the proposal writing has worked extremely well because the students enter summer research

having been integrated into a research team via this proposal process. Because only highly motivated students were willing to go through the process, there was relatively little attrition among those willing to complete the application process, and indeed, the students seemed to enjoy entering their summer research experience already prepared to participate and make a contribution.

Not surprisingly, the application process is extensive and is based on the preparation of a proposal similar to what would be made to a funding agency like the NSF. It was explicitly stressed that only a team effort will succeed, thus stressing that the students had to collaborate with the two faculty members in the proposal preparation. The proposal process itself was designed to foster the emergence of new mathematical biology teams. After a student expressed his/her interest, it was emphasized that a team needed to be formed around this interest or an existing team had to come up with a competitive mathematical biology project for this proposal. The main sections of the proposal, aside from the personal information, were the following:

1. Title
2. Quantitative aspects (explain how your planned work combines mathematics and biology, include intellectual merit and broader impact [max 4000 characters])
3. Student contribution to the team (explain your role in the team, list your expertise and background, how participating in the program will benefit the student [max 4000 characters])
4. Project plan (describe your planned work and how this is integrated into the whole project [max 10,000 characters])
5. Budget and justification for lab support
6. Approval of a mathematician and a biologist faculty member
7. Two letters of recommendation are also requested

During this multistage application process, students naturally develop an understanding of a team's problem and are required to define their role as an individual member of that research team. The proposal process was the equivalent of a team's collaborative development of a formal research problem, and thus, in the proposal process, the entire team had to communicate intensively and explicitly so that the student could prepare a competitive proposal. An independent panel of reviewers ranked and selected the best students as participants in the program. In addition to the quality of the proposal, we also gave extra attention to those teams that were newly formed and had applicants from different backgrounds.

Moreover, this multistage process provided unique educational opportunities in the academic year that preceded these summer research efforts. Math and biology faculty collaborated to teach a course in systems ecology that introduced many of the topics students would need in preparation for these teams. In addition, a seminar course in mathematics was populated almost exclusively by students who would become team members in summer research. The preliminary research of these students in this course allowed them to participate en masse in an undergraduate research conference at Furman University in the first year, and to participate in undergraduate research sessions in Society for Industrial and Applied Mathematics regional meetings in following years. None of

these courses or trips would have been possible without this team-oriented approach to necessitate and populate them.

Fostering interdisciplinary collaboration both at the faculty and student levels was an important secondary goal for this program. Even though we always received more quality proposals than we could support during each of the 2 yr we ran the program, the 16 students who were selected were invariably those who were most engaged in a specific team.

As a result of the application process, the arriving students were already prepared to join the teams, and the connection between the team and the student remained active (mentoring, advising, sending literature) after the application process. Most students who were participants in the first year reapplied in the second year. The research teams in this program covered a wide range of mathematical biology:

- Developmental biology team (one math and two biology faculty, two math and one biology students): Using neural networks to analyze microarray data to identify genes important for diapause of flies.
- Complexity team (one math and one biology faculty, two math and one psychology students): Using agent-based and neural network models to study emergent division of labor in wasp societies.
- Protein folding team (one math and one biology faculty, four math, one biology, and one chemical engineer students): Used graph models to describe protein structures based on their graphical invariants.
- Theoretical behavioral ecology team (one math and one biology faculty, two math and one biology students): Developed a game-theoretic model of nest parasitism that was applied to several species of birds.
- DNA structure team (one math and one biology faculty, one math student): Determined probabilities of the lengths of the longest palindromes that occur naturally in DNA structures.

An Example Project from the Complexity Team

To better illustrate this approach, we have chosen as an example the team-oriented proposal and subsequent research of the complexity team. The project that the complexity team addressed is based on the field work and a previous model of the division of labor in a wasp society produced by the biologist faculty member (Karsai and Wenzel, 2000; Karsai and Balázsi, 2002). The team developed two integrated platforms to collaborate on the project. The first platform was an agent-based simulation platform written in C++, and the second platform was a Maple-based continuous model incorporating learning by individual wasps. Each member of the team contributed and collaborated—students and faculty alike—in developing and exploring these platforms. There were frequent team meetings in the form of brainstorming sessions, in which all participants actively contributed. Those members who were proficient in coding—which included student members—developed the platforms in agreement with the goals and parameters the biologist required. The mathematician provided expertise in many areas of the modeling, as well as rigor in the model development that often does not emerge in the absence of an interdisciplinary team approach. Both the math and the psychology student team members gave feedback on the rules and assumptions of the model

and tested different ideas and algorithms. The biologist ensured that the project remained biologically relevant, checked that the assumptions of the models were biologically sound, and provided hypotheses that could be tested by the models.

The main result of the collaborative work was that, indeed, based on the biological assumptions we used, a division of labor emerges as a result of self-organizing processes. No central control or preprogrammed behavior is required to govern the regulation of the workforce in insect societies. The colonies are able to adapt to external environmental perturbations via modifying the combination of the workforce, and the prediction of the models agreed with the experimental data. One of the students stayed on the team after the summer program and turned this study into his honors thesis. He is currently in a PhD program at a top-tier university, where he is working on two interdisciplinary research teams. The results to date include nine conference presentations and one draft paper. The faculty team (I. Karsai and J. Knisley) continues to collaborate after the end of the summer program, as have many of the other teams that participated.

Outcome of the Interdisciplinary Summer Programs

With these summer programs, we were able to provide a truly interdisciplinary research experience for 16 students, and most of these students have remained in quantitative biology. Many of the students remained engaged in their teams and used the team projects in other pursuits, such as honors and eventually graduate thesis work. Moreover, individual teams did not work in isolation, but instead members of one team often played an advisory role in other teams and assisted in their projects as well.

Specifically, during the summer program, each student gives two seminars to a wide audience, including members of the other teams, other students, and faculty members who were not part of the program but were interested in the given topics, and students of other summer programs with which we interfaced. In these seminars, the students outlined the research goal of the team, but they focused on the facet of research they were specifically doing. The first seminar was given at the beginning of the summer program, and the student outlined the problem that the team would be addressing and what she/he planned to do. Then the seminar turned into a brainstorming session for providing ideas and suggestions for the student. The second seminar occurred near the end of the summer session when each student reported his/her results, and the discussion after the seminar helped the student to finish the project. At the end of the summer program, each student had to write a report, and the faculty members of the team were required to provide an evaluation of the student team members.

Each team was productive and reached the goals we aimed for. The program involved a large variety of students in majors, and we recruited more women than men for this summer program. The results of the summer program were disseminated in numerous conference presentations, in two student/faculty research publications, and three additional submissions and generated grant proposal submissions. Our team-oriented approach has also been incorporated into curriculum development, such as in our *Symbiosis* project (HHMI 52005872), which likewise features a research-style, team-oriented approach (Depelteau *et al.*, 2010). The summer pro-

gram also interfaced with or continued in other types of mentoring strategies, such as co-mentoring graduate students.

After our NSF-supported summer program ran out of support, we found alternative ways to sustain summer research in mathematical biology. The biggest challenge is to find enough support to cover all expenses. The first and more important concern is the student stipend, because this can help students focus on their academic work during the summer. We found many faculty volunteers who were leading students with minimal or no support, but the real challenges came commonly from the material support of biology research laboratories, where the projects cannot be done without materials and instrumentation. We addressed these problems via implementing summer research in our other proposals and grants (see below), and the Honors College established several programs that support materials for undergraduate research.

Summer program experiences were extended to incoming freshman students by the TEQB Summer Bridge Program, which targeted prefreshman students interested in the integration of biology and mathematics. In this program we offered students an introductory course in computational biology accompanied by a variety of nonclassroom activities aiming to encourage teamwork and learning community development. Such activities included field trips (trips to Natural Tunnel State Park and Oak Ridge National Lab were listed by students as having the most impacts), hands-on research projects, and sports events. Research projects were conducted in small groups (two to four students), and the format included several hours of supervised introduction followed by 2 d of mostly unsupervised work, during which students interacted with each other, assigned project roles to peers, and prepared a presentation. These projects were then peer-graded by all students in the program for scientific quality and presentation clarity. Extracurricular activities included the use of an obstacle course specifically designed for team-work development.

Simultaneous to this effort, D.K. obtained funding for and conducted four SUMMA NREUPs (Strengthening Underrepresented Minorities Mathematical Achievement—National Research Experience for Undergraduate Program [NREUP]; Summers 2004, 2005, 2006, and 2008). SUMMA is a program of the Mathematical Association of America (MAA) with funding provided by NSF, National Security Agency (NSA), and the Moody Foundation. SUMMA was established in 1990 to increase the representation of minorities in the fields of mathematics, science, and engineering and improve the mathematics education of minorities. In association with the program described above, the SUMMA NREUP project supported four to six underrepresented minority students per summer, the majority of whom were African American (see <http://faculty.etsu.edu/knisleyd>). The students were included in the above program socially, intellectually, and otherwise during the time the two programs overlapped, and the focus of the program was on the use of graph theory in molecular biology (SUMMA, 2010).

The students in the ETSU SUMMA programs belonged to a variety of majors—including mathematics, computer science, chemistry, and biology—with none of the disciplines comprising a majority of the majors. Unlike the students in the summer program described above, the majority of the SUMMA students were from universities other than ETSU

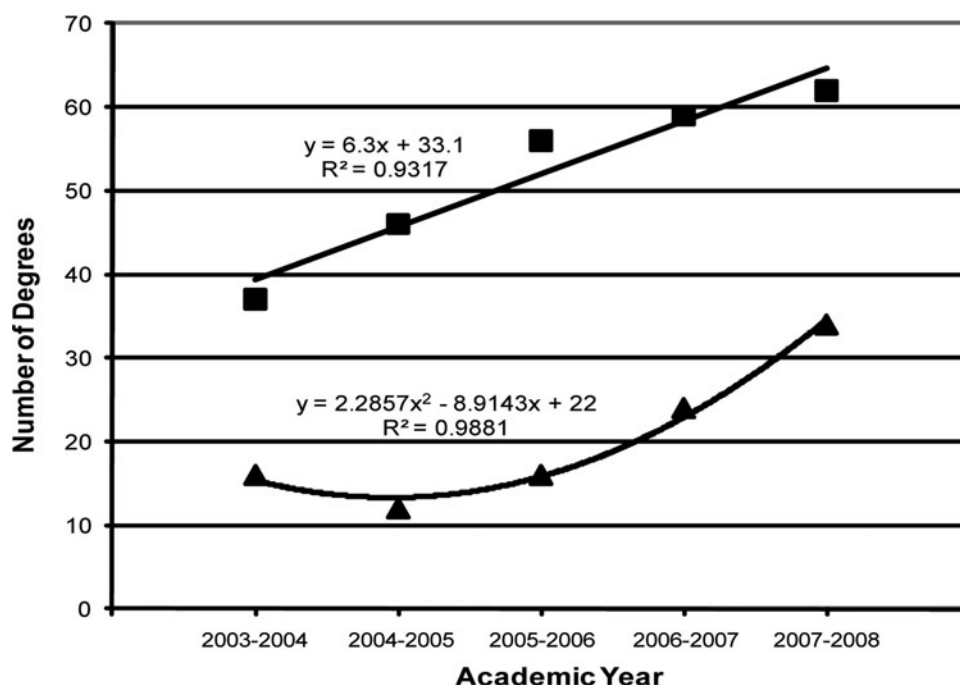


Figure 2. The effect of our team approach to STEM degree production. STEM degree production increased since the undergraduate research (first offered in summer 2003) and lab rotation (first offered in 2004) were established. Squares, biological sciences; triangles: mathematics.

and were recruited primarily from institutions that historically serve underrepresented populations. Nearly half of the students that participated in the SUMMA NREUP entered into graduate programs, and two student projects resulted in research-level publications (Knisley et al., 2008a; 2008b).

ASSESSMENT AND CONCLUSIONS

Thus, as we have now seen, there are many approaches to team-oriented research, all of which are complemented by a variety of educational opportunities. Moreover, although we have been fortunate in obtaining funding for many of these activities, the team-oriented approach was developed, in part, as a response to our lack of funding early on. That is, it is easier to recruit students into team-based efforts than it is to recruit them into individual or course-based activities. Consequently, a team-oriented approach creates the “critical mass” of students/faculty that are necessary for the development of new courses and new experiences.

The team-oriented approach has been extensively assessed. For example, as part of the TEQB program, the lab rotations are assessed annually by the TEQB project’s external reviewers. Moreover, the proposal process featured an independent review board, and the resulting faculty/student team approach to undergraduate research provided valuable feedback on the summer research programs.

For example, the NSF-STEP-funded TEQB assessments have been both formative and summative with respect to the lab rotation program. Student feedback solicited both anonymously and independently/confidentially has indicated that a team-oriented lab rotation program can be both popular and successful. The overwhelming sentiment by students and faculty alike is the desire to have a lab rotation through the sophomore year as well (after which junior/senior research

courses and opportunities can be engaged), which is a recommendation that is currently under consideration.

Summative assessment has likewise been conducted and collected. STEM degree production in the TEQB-related fields has increased significantly (Figure 2), and this has been shown to be due in part to the lab rotation program. Indeed, since lab rotations, the Institute for Quantitative Biology, and team-oriented research were established, there have been considerable increases in outcomes in both research and curriculum development (Table 3; Karsai and Knisley, 2009). Moreover, many students we supported gained diverse experience and became successful undergraduate researchers in mathematical biology.

Thus, assessment has also shown that a team-oriented approach has been of substantial benefit in facilitating undergraduate research in quantitative biology at ETSU. Moreover, the types of results we have observed should be reproducible at a variety of different institutions. Indeed, it is our hope

Table 3. Research support and mentoring in mathematical biology before and after the formation of the Institute for Quantitative Biology

Item	Before 2004	End of 2009
Interdisciplinary research group (in the College of Arts and Sciences)	1	9
Students in interdisciplinary team	0	28
Interdisciplinary courses	1 occasionally	5 regularly
External funds for interdisciplinary work	0	\$3,008,000

Both research support and mentoring in mathematical biology increased sharply due to the team effort we used at ETSU.

that this paper illustrates how a team-oriented approach can accomplish as much or more than traditional, labor-intensive “independent-study” or programmatic approaches.

ACKNOWLEDGEMENTS

This work was supported in part by the following grants: NSF DUE-0337406 (A Multi-stage Approach to Undergraduate Research in Mathematical Biology, PI Jeff Knisley); TEQB, NSF 0525447 (Talent Expansion in Quantitative Biology, PI Anant Godbole), and the MAA “Strengthening Underrepresented Minorities in Mathematical Achievement,” PI Debra Knisley, which is part of the NREUP funded jointly by the NSF’s Division of Mathematical Sciences and the NSA.

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