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Mathematics In Multi-disciplinary Research-focused Learning Communities

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1. Introduction

Undergraduate research in mathematics is booming at Truman State University. For many years, it existed quietly in the offices of the mathematics faculty disguised as a graduation capstone requirement for students. Outside the mathematics department, the rest of the campus openly celebrated the fact that Truman was heavily invested in providing open-ended research experiences for students. Truman had been making a name for itself as a powerhouse in this area by annually sending strong students with excellent work to the National Conference on Undergraduate Research (NCUR) and professional conferences, and by having many faculty serve as Counselors in the Council of Undergraduate Research (CUR). For nearly 20 years, Truman has held a conference that celebrates student research and scholarly activity, and since 1998 it has closed down campus for one day to do so. In 2006, this conference had 319 presentations by 476 students that represented the mentoring of 162 faculty members.

Until the early 2000s, mathematics student participation in undergraduate research activities on campus was marginal. We sent students to REUs, and we sent students to regional MAA meetings to give presentations on their capstone projects, but we seldom called what they were doing "research." This changed when a group of faculty from the mathematical sciences teamed up with a group of faculty from the life sciences to use undergraduate research as a vehicle for teaching and learning.

The following describes how a capstone requirement created an environment that allowed a group of mathematics and computer science faculty to work with colleagues from science to create a common, coordinated summer research experience program and academic-year follow-up activities that enhance both student and faculty scholarship at Truman. Involvement in these activities has provided students with a unique way to better understand the nature of mathematics and what it means to do research in the mathematical sciences.

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2. Undergraduate Research in the Mathematics Curriculum

Like many American mathematics programs, Truman's major degree program requires its advanced students to complete a Senior Integrating Capstone Experience before graduation. The requirement has a student work with a faculty mentor on an independent exploration of a mathematical topic that synthesizes information from multiple sources. The effort results in a locally peer-reviewed paper and a public oral presentation to peers and faculty.

The requirement began to be instituted campus-wide around 1986 as part of Truman's "Degrees with Integrity" initiative [**3**]. It was intended to increase the coherence of major programs at Truman and to allow disciplines to enhance important collegiate skills such as higher order thinking, writing, speaking, and reflection in the major. Each discipline approached the requirement differently, with some requiring their majors to take a special capstone course and others having their students do more self-directed work. While the structure of the mathematics capstone is suggestive of a research-like experience, the mathematics faculty did not view it as such. In practice, however, Truman's capstone requirement in mathematics was and is an instantiation of undergraduate research in the major curriculum.

Faculty assess the educational outcomes of the capstone through senior exit interviews. These interviews show that, although initially students find the mathematics capstone formidable and overwhelming, after a short time of reflection upon the experience once it's complete, they view it as one of the most positive experiences in the program. This attitude persists in alumni.

By early 2001, Truman's capstone requirement had allowed several mathematics faculty to cultivate skills in mentoring students in independent, research activity. In 2002, the author was working with a mathematics major on a bat echolocation question posed by a biology colleague. The student's results were interesting, and he submitted an abstract to the 2003 NCUR program to get more experience giving public presentations. The abstract was accepted along with dozens of others from Truman students, and when the author traveled to the conference with all the Truman students, he was astounded at the quality of their work. The Truman biology students were particularly impressive. Their projects were thorough and advanced, and their presentations were very professional. It was then that a group mathematics faculty reached out to the biology faculty to learn to more effectively mentor undergraduates in high-quality research.

3. An Experiment in Interdisciplinary Training

At that time, professional societies were abuzz with talk about the growing importance of the mathematical sciences to the life sciences. A month didn't go by without the MAA, the AMS, or SIAM publishing an editorial or review article on the topic, and the National Academies of Science published *Bio2010* [**1**]. While a group of Truman mathematics and computer science faculty were weighing the implications of this national buzz, we learned that some of our students were out in front of us on this; they were already actively pursuing double majors in biology and the mathematical sciences to take advantage of opportunities in, for example, bioinformatics. It didn't take much for a group of mathematicians and biologists to convince ourselves that together we needed to catch up to our students. In 2003, we submitted a proposal to a pilot NSF supplement program called "Interdisciplinary Training for Undergraduates in Biology and Mathematics" (UBM) that allowed us to establish Truman's Mathematical Biology Initiative. Through this initiative, we started to develop new courses for students and opportunities for faculty to immerse themselves in mathematical biology.

Truman's initiative's main goal was to cultivate long-term interdisciplinary collaborations between faculty in biology and faculty in the mathematical sciences through the use of high quality, faculty mentored undergraduate research experiences. These experiences would also serve as a tool for training students to work at the intersection of the life and mathematical sciences. The grant allowed us to fund two research teams consisting of a cross-disciplinary pair of faculty (one from biology, one from the mathematical sciences) and a cross-disciplinary pair of undergraduates to work over the summer. The work of each team focused on a question in mathematical biology, and the grant allowed the researchers to travel to professional conferences to present the work and learn about the growing importance of interdisciplinary collaboration between professionals in these fields. In this way, we aimed to use undergraduate research experiences to train students to interact and collaborate with experts in fields outside of their own.

During the first summer, two teams worked independently on very different projects. Students were recruited by the individual faculty mentors. Two students worked with a statistician and an ecologist on building and evaluating habitat suitability models for the Missouri Bladderpod, a federally endangered plant native to Missouri. This plant is a research focus of the ecologist, and he had built a gold-standard data set through many years of field work. The second team consisted of more students and a group of five faculty members, two from a local medical school and three from the mathematical sciences department. They worked on an image analytic approach to understanding a phenomena in anatomy and another in physiology.

Both teams made reasonable progress toward their scientific goals, with the image analysis team producing two senior capstone projects and the bladderpod team adding to an already impressive data set and doing some predictive and explanatory modeling that impressed the National Park Service. From a program perspective, we learned two important lessons. First, mentors from different disciplines must be in continual communication about their project and the students they are mentoring; opportunities and expectations for this communication must be built into the program. Second, putting students from the mathematical sciences into the field or at the laboratory bench with their biology collaborators is a priceless learning experience that helps them respect the work it takes to create a good data set.

The following semester, the Mathematical Biology Initiative ran a public biweekly seminar on the topic of mathematical biology. For each meeting, the seminar invited a research-active biology faculty member to put on a "research fashion show" to talk about his or her research program. The mathematical scientists in the audience would listen and share thoughts on mathematical or computational approaches that might assist them in their work. Each meeting had 20-25 attendees (faculty and undergraduate). The topics spanned the range of biological scales, and many mathematical and computational ideas were brought to the attention of presenters. The organizers of the seminar quickly recognized the potential to expand the Mathematical Biology Initiative and submitted a grant proposal for the 2004 UBM solicitation. The proposed program, titled "Research-focused Learning Communities in Mathematical Biology" (RLC), built upon the faculty and student interest generated by the seminar, and the knowledge we gained through the first summer of interdisciplinary research with undergraduates.

4. Research-focused Learning Community in Mathematical Biology

The new program differs from the previous in four ways. First, each year it allows Truman's mathematical biology program to support four interdisciplinary research teams of faculty and undergraduates. The NSF does not allow the grant to fund faculty or students from computer science, which is a great disappointment. Fortunately, the Truman administration recognizes the importance of computer science to our efforts and funds the participation of one faculty member and two students each year for the duration of the grant. Second, the grant supports long-term research experiences for each team. Work continues through a calendar year or more. Third, students are selected for the RLC program through a competitive application process that's widely publicized around campus. They are assigned to teams by the mentors through a consensus process. Fourth, our program mandates regular team and community meetings. During the academic year, teams are expected to attend the biweekly Mathematical Biology Seminar, and during the summer, teams participate in community events and a weekly Mathematical Biology meeting. In this way, the program creates and maintains a sense of community based on shared research interests. We further enhance the sense of community during the summer program by requiring all participating students to live in the same wing of a residence hall so they interact with one another daily.

Everyone in the RLC program participates in Truman's 10-week Summer Undergraduate Research Experience program, which is described in the next section. During this time, the students dedicate all their time and energy to research activity and participation in summer program events. Teams are often in daily contact with one another, and all teams gather for a weekly RLC meeting during which everyone articulates short-term and long-term goals for themselves, shares updates on progress toward their team goals, and asks questions or asks for assistance. These meetings create program community and identity, and they allow students to practice communicating with a multi-disciplinary audience.

We evaluate the program by looking at program products and where its student go after graduation. At last count, our students have given over 28 presentations or posters at regional, national, and international professional conferences. We have 12 manuscripts in preparation for submission to peer reviewed journals, 3 accepted in peer reviewed journals, and several others submitted. Four grants have been submitted by teams to support their work, and two of those grants have been funded. Of the 10 RLC participants who have graduated from Truman, 8 have gone on to interdisciplinary graduate programs. Insofar as the intended program outcomes include the training of students for interdisciplinary work and an elevated level of interdisciplinary faculty scholarship, that above data suggests that the program is working.

The RLC program has taught us that an extended research experience dramatically improves team productivity. Team members can spend the spring semester reading, perfecting lab and computer techniques, and planning experiments. They can also plan to spend the fall reflecting and writing about what was learned during the summer. This leaves summer as a time that can be entirely and without apology devoted to carrying out planned research activities. In addition, the extended involvement of undergraduates allows them to be peer-mentors for and help train the next cohort of students that will be involved in the team's work.

5. Talent Expansion Through Summer STEM Learning Community

At about the time the mathematical biology group received funding for its RLC program, Truman's Division of Science and Division of Mathematics and Computer Science received funding from the NSF's *Science, Technology, Engineering, and Mathematics (STEM) Talent Expansion Program* (STEP) to use high quality, faculty mentored undergraduate research experiences to improve student success in STEM courses and increase the number of students who graduate with a baccalaureate degree in a STEM area. Students from backgrounds underrepresented in STEM areas, from community colleges, and from other at-risk groups would be targeted for the program.

The STEP grant established Truman's "The Next STEP" office which coordinates grant related activities, including a bridge program for transfers students in STEM areas and some interdisciplinary curriculum development activities. Its centerpiece activity is the 10-week Summer Undergraduate Research Experience (SURE) program. Through activities intended to foster student personal, professional, and academic growth, the SURE program creates and nurtures a multi-disciplinary community of mentors and students united by their shared interest in STEM research. Prior to the STEP grant, many Truman STEM faculty and students were involved in summer research, but activity in each STEM discipline occurred in isolation from activity in the others. The new "The Next STEP" office and the SURE program brought the disciplines, including mathematics, together for mutual benefit.

To bring faculty in all STEM areas together, each summer the STEP grant provides research stipends for 20 students and their faculty mentors. Stipends are awarded to students through a competitive application process that includes an on-line application and letters of reference. As part of the application, student rank order four projects from among approximately fifty listed by Truman faculty. Student applications are ranked by an anonymous, multi-disciplinary panel of faculty, and the most meritorious students are chosen to be assigned to projects that appealed to them. The review criteria emphasizes the importance of choosing students who are in their first- or second-year, students from backgrounds that are underrepresented in STEM fields, or students who are otherwise good candidates for expanding the talent pool in STEM fields. The final cohort of participating students is selected to insure that all STEM fields are represented and that underrepresented students are included.

Undergraduates who receive a stipend live on-campus with other program participants and students in the RLC program. They attend all SURE events such as a weekend field trip to visit industry partners in St. Louis or Kansas City, weekly community lunches in the dining hall, and weekly workshops that deliver information and training to help students get the most out of their research experience and to understand the value of a STEM degree. Examples of some workshop and discussion topics are: Using LaTeX, Writing a Research Proposal, Giving an Oral Presentation, Reading the Primary Literature, Image Analysis using ImageJ, Ethics and Responsible Research Conduct, The Importance of Writing and Submitting Papers for Peer Review, Data Analysis with R, and Women and Underrepresented

Groups in STEM. Thanks to funding from the academic divisions, all STEM students involved in on-campus research over the summer are allowed to participate in SURE program activities. This has allowed these NSF programs to affect a much larger group of students than those directly funded by the programs

Participating in this program has been particularly good for mathematics students. By living and working with students from the sciences, they grow to understand both the role mathematics plays in the sciences and the merits of pursuing questions in "pure" mathematics. What's more, they can articulate these ideas to non-mathematicians. The faculty who participate in the program by attending the workshops and discussions also grow to have a better understanding of the sciences and how the academic and political cultures differ. Involvement has also mathematics faculty to make professional connections with faculty in science that are having mutual scholarly benefits.

We have a comprehensive assessment plan for the program. The program aims to increase the number of students who graduate with a baccalaureate degree in a STEM area, and because this program targets younger students, we have not yet seen a change in the numbers. Our end-of-summer evaluations are very positive, and data from our participation in the HHMI Survey of Undergraduate Research Experiences II (SURE II) [**2**] suggests our program compares well with others nationally. We also assess the growth of students through analysis of electronic journals they keep over the summer. The results of those analyses have provided us with important information about the student experience that improve mentoring.

6. Conclusion

Truman's thoughtful approach to creating multi-disciplinary research-focused learning communities has benefited mathematics faculty and students in many ways. Student enthusiasm for science and mathematics has increased, as has faculty understanding of disciplinary differences and similarities. Cross-disciplinary interaction has opened new lines of communication that are inspiring curricular reform in interdisciplinary directions. The opportunities created by these programs, and the long-term and short-term benefits to faculty and students make Truman an especially exciting place to be a teacher-scholar in mathematics.

References

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