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UBM and REU: Unique Approaches at Tennessee

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We feature two programs for research by undergraduates at the University of Tennessee, both funded by the National Science Foundation. The Undergraduate Biology and Math (UBM) program brought together math and biology undergraduates and was held from 2003-2006. The Research Experience for Undergraduates (REU) program was a summer program for math majors during 1987 to 2005. Both of these programs recently ended, and we remark on lessons learned and our different approaches. Our experiences aid us in continuing efforts in research with undergraduates and may assist the development of similar programs elsewhere.

1. UBM

As a supplement to an NSF award (DMS 0110920, Spatially-distributed population models with external forcing and spatial control), we developed a 2-year project involved 3 math and 3 biology undergraduates. The research focus was spatial aspects of ecological systems with emphasis on invasive species. This project began in the fall of 2003 and, with an extension, the program was completed in winter 2006. The faculty mentors were Jake Weltzin (a plant ecologist), John Drake (a community ecologist with a laboratory utilizing microcosms), Louis Gross (mathematical ecologist) and Suzanne Lenhart (applied mathematician). René Salinas and Andrew Whittle, post-doctoral fellows on the NSF award, were involved in mentoring and organization of activities. Our goals were:

- to provide interdisciplinary education and training for students at the intersection of math and biology,
- provide every participant with a mixture of hands-on biological field and laboratory experience and mathematical analysis,
- have students themselves develop the research questions and design experiments, with advice and support of their mentors.

Our procedures to reach these goals were to have the mixed group of students carry through the entire process of a research project by developing a research idea, planning the work required to do the research, carrying out the research, and preparing the results for dissemination. Throughout both semesters of the first year we met with the students twice a week. The sessions were a mix of brainstorming, discussing papers and lectures. We read through two books to

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provide some background: "A Primer on Ecology" (N. J. Gotelli) and "A Primer on Ecological Statistics" (A. M. Ellison and Gotelli). The students were encouraged to get to know about each others interests, to bring up potential research projects, to query faculty about these projects and to decide for themselves projects to pursue. All that we required was that the projects had to include a mixture of field/lab and mathematical components.

The first project idea seriously considered involved analysis and distribution of fish species in streams of the region. Though this project was driven in part by the strong interest of one of the participants in fish ecology, the students eventually dropped the idea due to the difficulty of collecting appropriate field data (this required electro-shocking fish at various locations, which the students decided was not feasible). Concurrently with the fish project consideration, the group had considered possible laboratory analyses of aquatic community assembly spurred by a visit to the lab of one of the faculty mentors. The students began with a pilot study of the growth of protists (*Colpidium* and *Paramecium*) using microcosms to investigate how competitive outcomes are affected by initial densities. The protists were first grown in monocultures to estimate growth rates and carrying capacities and then grown in competition. All six students learned to "count" the protists using a microscope to monitor the progress of the populations. The data collected were fit to a Lotka-Volterra model and several poster presentations were given on this work and talks were given by the students on the results of this project.

During the summer, the group met once a week and began looking for ideas for new projects. In the second year, the students designed and started on two separate plant experiments. Four students continued onto the second year and we recruited two new biology students since two biology students had graduated. Having a core of continuing students was essential. The students divided themselves into two groups, according to their interests. The projects were

- The role of trait diversity on community invasibility
- Quantifying competitive hierarchies for groups of species.

Then in some meetings, the multivariate statistics required to analyze data arising from the planned experiments was discussed. After a successful preliminary experiment with 355 *Arabidopsis* plants, the trait diversity experiment (e.g. differing competitive abilities based upon differences in traits derived from different genotypes of the same species) failed twice due to failures of equipment in the control room. The second group of students (though all students assisted with each of these two experiments) developed a new mathematical method for constructing competitive hierarchies and this was evaluated in a greenhouse experiment with two grasses and two herbaceous dicots. This resulted in a recently submitted paper by two students (Alex Perkins and Bill Holmes) and Weltzin.

The students were paid by the hour on a biweekly payroll which was raised from $10 per hour to $12 in the second year. The faculty members received from two weeks to one month of summer salary depending on their level of participation. The grant included funds for seeds and equipment for the experiments. The students all participated in determining the supplies needed, learned about procedures for equipment purchases, and established the work schedules for the experiments. While the biology students were better prepared to ask questions concerning experimental design, the math students often brought up significant factors on these matters as well.

In summary, while either having pre-defined research projects for the students or having more faculty-guided development of the projects would have increased the the amount of publishable research carried out, this would not have exposed the students to the range of difficulties in the full scientific process. The mixture of students was successful in assisting them to learn a common language from each other. While the biology students certainly developed more math appreciation, the projects were perhaps more beneficial to the math students who had not previously gotten their hands dirty with either experiments or data. The students who have graduated have moved on to graduate programs.

Jacob Kendrick (biology student) remarked on the first experiment: "Though time consuming, cultures were counted daily, the experience proved a valuable lesson in the constraints placed on experimental ecology by the time and effort necessary to complete an experiment and certainly influenced how future projects were planned."

We end this section with a quote from Bill Holmes (math student): "The two year time length and interdisciplinary nature of it have presented unique situations and opportunities. In the past, I have worked in summer research programs, and feel that I have taken more from this program than any other. I have learned a great deal about mathematics, the research process, and in general how to work with others. ... One of the truly unique aspects of this program was its interdisciplinary nature. ... The program gave me the opportunity to work with five people of various backgrounds."

2. REU

Our REU program, funded by the NSF (DMS 0243774) and the UT Science Alliance, has completed 16 years under the directorship of Suzanne Lenhart. Hem Raj Joshi was a past graduate assistant and a faculty advisor for the program in 2003. Our program was based on the theme - "one advisor with one student." Each student in our program worked with an advisor on a research problem. We believe that this "one-on-one" approach simulates most of the research experiences in mathematics and it definitely mimics the experience of working on a PhD dissertation. Although some mathematics is investigated in larger groups of researchers, usually tasks are broken down into subtasks for one or two researchers. This feature made our program distinct from most other REU programs which emphasized working in groups perhaps giving students a choice among several groups. In our case, each student was informed of their advisor and the area of the project at the time that an offer was made.

Our 8-week summer program usually had 10 to 12 students and 10 to 12 advisors. How did the program pay for the large number of research advisors involved? Our funding from the National Science Foundation was supplemented by the University's Science Alliance program, allowing us to pay all advisers at some level. We had a strong group of faculty members who wanted to be involved.

Our application process required an information form, a letter of interest, two letters of recommendation, and a transcript. Students were asked to express preferences among a list of possible research areas. Each year we received well over 100 applications and accepted 10-12 students. The student selection was done by the faculty mentors, with oversight by the director to encourage diversity. We tried to recruit from a variety of types of undergraduate institutions. Over the years, our student participants were about 50% female and 50% male; about 90% of the students went on to attend graduate school.

The main emphasis was working on research projects with each student meeting with his/her advisor at least three times a week. The researchers involved created excellent opportunities for students to work on diverse projects varying from numerical analysis to algebraic structures. The group met together on Monday, Wednesday, and Friday mornings. There were two short courses each summer - one on a "pure" math topic and one on an "applied" math topic. Each short course consisted of ten lectures. These courses gave the students a chance to interact with each other and to learn something new and sometimes unusual. Course topics were varied, including ones not typical in undergraduate math programs, such as "Circle Packing" and "Cryptography." There were no tests or grades in these courses, but the students were encouraged to work together on some problems and present solutions to the group. Each faculty advisor presented a seminar on his/her research field. Three times during the program we discussed the progress on research projects; sometimes students suggested ideas for other projects or the director saw the need for further assistance (including more help with software such as MATLAB). One group meeting was devoted to discussing graduate school opportunities, jobs, the structure of academic departments and professorial ranks, and mathematics organizations. The aim was to educate students about the spectrum of the mathematics community but not to recruit them for a particular department. Our program helped these students make a well-informed choice about their mathematical future.

In the fifth week of the program, the students gave short practice talks, reporting on their progress. The director gave an informational session a few days before this on "how to give talks." The director and the graduate student assistant attended the practice talks and gave advice and constructive criticism. The last two days were reserved for 30 minute finale talks by each student. Rather than focusing on the publication of results, we chose to make the finale talks as the high point of the program. However many publications have resulted from this research program, an estimate being that about 20 percent of the projects resulted in publications. We encouraged students to write up their results and the steps of their research journey. Our program encouraged and supported partially the REU participants to present their work at regional and national math meetings.

Each summer, two student participants worked with scientists at Oak Ridge National Laboratory. ORNL is nearby and those students went to the Laboratory on Tuesdays and Thursdays. Lenhart is a part-time employee of the laboratory and was able to coordinate this situation. This interaction with ORNL gave two students an in-depth national laboratory experience, but the others went as a group to visited ORNL once each summer and met some researchers there. We discussed the differences between working at a government laboratory and working at a college or university. This unique lab connection feature was a draw for our program because the students have the opportunity to work with researchers not directly associated with academia and to use sophisticated computer equipment. Another unique feature was the strong participation of our Math Ecology group.

Our REU students received free lodging in university apartments, a stipend of $3000 and transportation reimbursement up to $500. They also received access to university facilities such as computer labs, the library, gym and health center. Our social events included: hike, picnic, volleyball games, white water rafting, zoo trip, and several lunch outings with faculty members. The program began and ended with parties.

We completed formative evaluations at the beginning of the program and did midway and final evaluations. Below are the remarks from Rachael Miller from our REU program in 2003: "In general I think REU's offer a great opportunity to gain exposure to areas of math that are not as common at many smaller schools with limited faculty or research funds, as well as interact with other faculty. I was fortunate enough to thoroughly enjoy my research project, my interactions with coworkers and other students, and the ability to travel. One of the important things to learn is that in two months, in addition to discovering a great deal of new mathematics, it might be possible to discover areas of mathematics that are not for you, rather than waiting until graduate school or much farther down the line to come up with this conclusion. ... Of the many memorable seminars, trips, and other events, one we were quite proud of was the painting of the 'Fraternity Rock.' To say thanks to the university and our advisors, we painted "Good-bye MATH CAMP 2003" on the rock along with some key concepts of our projects. We were pretty sure that was the first time that anybody painting the rock actually knew what the Greek alphabet meant."

3. CONCLUSION

Working with researchers at the frontiers of exciting mathematics and biology, our participants had experiences which had a positive impact on their education, career decisions and aspirations. Participation in our programs helped these students make well-informed choices about their scientific future.

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