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The Long-Term Undergraduate Research (LURE) Model

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The Long-term Undergraduate Research Experience (LURE) model for the mathematical sciences represents a collaboration between the mathematics faculty at four widely different institutions: Central Michigan University (CMU) is a large public comprehensive university, Coppin State University (CSU) is a historically Black university, Olin College (OC) is a new gender-balanced engineering college, and the University of Richmond (UR) is a liberal arts college. We were recently awarded a grant through the National Science Foundation's Mentoring through Critical Transition Points (MCTP) program to pursue the LURE model. This article outlines our rationale for developing the LURE model, including our past experiences and our current thinking on best practices.

The LURE model emphasizes the early recruitment of undergraduates to mathematical research and the cultivation of interest in the mathematical sciences. It builds upon the success of the apprentice model often used in the physical and life sciences, wherein scientists routinely engage first- and second-year undergraduates in laboratory research and then continue to mentor these students until they are prepared to pursue graduate degrees. Although first- and second-year undergraduates generally have little experience or knowledge to contribute to the laboratory research, they perform routine tasks and learn how to use sophisticated equipment. Exposure to the research activities in a particular laboratory prepares them for more substantial contributions in the future. Our scientist colleagues report that their investment in these "apprentices" reaps benefits after the students devote a year or more in their laboratories. This apprentice model is successful in that it recruits early undergraduates to the sciences, retains student interest in the sciences, and prepares students for graduate study in the sciences.

Our study of the science apprenticeship model, as well as our own experiences directing undergraduate research, led us to develop the LURE model for the mathematical sciences. CMU has been a site for an NSF Research Experience for Undergraduates (REU) in mathematics for five years, and UR has enjoyed a variety of industry and government grants supporting undergraduate research in mathematics. Through our involvement at CMU and UR, we have mentored many of the common types of undergraduate research experiences, including summer programs and senior theses. One observation we have made, which appears to be a

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nationwide trend, is that mathematics students typically wait until their junior year, usually after completion of core courses such as analysis and abstract algebra, before participating in research activities. Thus, research experiences are typically not being used to attract undergraduates to mathematics, although we do believe research experiences assist in retaining those students who have already chosen a major in the mathematical sciences. A second observation is that most undergraduate mathematics research experiences are relatively short, lasting usually for one summer or at most one academic year. Students are often just reaching the point of truly understanding the problem when the experience comes to an end. Our experience indicates that many students and faculty would prefer to have more time to continue their collaboration. Specifically, faculty have noted that the "start-up" cost of involving students in short-term research experiences is high, and that students would be more likely to actually assist them in their research goals if they could keep the students involved for a longer duration.

Through the LURE model, we address the above two observations. First, we change the culture so that faculty begin to recruit early undergraduates to mathematical research experiences, thereby providing opportunities to recruit students to mathematics before losing them to other disciplines. Second, we provide for longer research relationships wherein faculty can train students to fully understand and eventually contribute to the research program, thereby avoiding the frustration that short research experiences can sometimes bring. Specifically, LURE recruits students early in their undergraduate careers and pairs them with faculty who serve as mentors throughout a two-year research experience in the mathematical sciences. Through closely supervised research and independent study activities spanning two summers (10-weeks each) and two academic years, students experience all steps in a research project, from background reading to the professional presentation of results. This allows undergraduates to be involved with mathematics research experiences that are more sophisticated than possible with traditional single-summer research experiences.

We have some evidence that this extension of the science's apprenticeship model will be successful in the mathematical sciences. Over the past four years since the inception of OC, OC faculty have experimented with involving first- and second-year students in mathematical research. Although OC's history of experience is limited, we have seen remarkable results so far. Not only have certain first-year students proven capable of contributing to professionally published papers, but these early experiences have whetted their appetite for research. The result is a culture in which first-year students clamor to be involved in faculty research programs and often continue to work with faculty for several semesters. We have seen the benefits of involving students in long-term research experiences, including facilitating peer-training opportunities, wherein "seasoned" student researchers (for example, juniors who have already spent two years working with a particular faculty member) can help bring first-year students up to speed with the basic ideas in the research program.

The LURE model includes some "best practices" that we have developed through our past experiences at our four respective institutions. Throughout the two-year program, we will focus on developing strong mentoring relationships as well as camaraderie among the students. We will pair students in groups of two or three, to combat feelings of isolation and to build group-working skills. We will also schedule

social activities, especially during the summers, to build a sense of community. For example, we plan weekly lunches, augmented by larger activities such as field trips to local parks/beaches, volleyball games, and apple/berry picking. We will improve students' oral and written communication skills through regular oral/written progress reports. The length of the research experience under the LURE model allows us to focus on developing these skills, without sacrificing a significant portion of the research time. A yearly LURE conference will bring together all LURE students and mentors from the four institutions. This conference will serve as a community-building activity and as motivation for students to develop their oral and written presentation skills. Each student will give an oral presentation on his/her work and provide an article for the LURE conference proceedings.

We will proactively recruit women and minorities, with specific aspects of the program having been developed in consultation with literature on cultivating the success of underrepresented groups. Our recruitment strategies include flyers posted around campus and mailed to incoming students, emails to special interest groups (e.g. honors programs, math clubs, science clubs), announcements in introductory mathematics classes, and personal contact. By the end of the NSF funding (four years), eighty students and twenty eight faculty will have participated in the LURE model. Each year, each institution will have two to four teams, with each team consisting of one faculty mentor and two to three students.

The LURE model provides professional development opportunities for faculty, by providing a network of colleagues for trouble-shooting questions and problems, through the optional pairing of inexperienced faculty mentors with seasoned mentors, and through group discussions at the yearly LURE conference. To kick-off the LURE program, we are developing a one-day conference wherein we share best practices and learn best practices from Joseph Gallian and Aparna Higgins, leading mentors of undergraduate research. One of our goals is to increase the number of faculty, with particular focus on women and minorities, who become mentors and role-models in undergraduate research experiences. We hope that the network and training offered by the LURE program will encourage faculty to become involved as undergraduate research mentors. This is particularly important at CSU, a historically Black college, as CSU works to establish a culture encouraging undergraduate research in mathematics.

In our model, we compensate faculty for their time (approximately $7000 per summer). We felt that this was necessary to ensure the continued participation of faculty, since being a mentor under the LURE model requires a significant time commitment. By involving early undergraduates who have less experience than junior or senior mathematics majors, it is necessary for the mentors to meet with their students more often and to do more proactive teaching. However, given the length of the mentoring relationship under the LURE model, the time invested will pay off. The mentors will eventually be able to assign more sophisticated mathematics readings and problems with the understanding that the student can master the techniques over weeks and months rather than days. In time, the students will be more likely to significantly contribute to the faculty member's research program.

By implementing the same basic model at four very different institutions, we will learn what works and what requires modification in the basic model. This will also allow us to more convincingly disseminate our model to a wide variety of institutions. At the yearly LURE conference, participating faculty will discuss

and evaluate how the model is working in the different settings. We will also analyze our findings concerning the impact of LURE on participating students through our collected data on a variety of longitudinal measures. For example, we will measure the number of students majoring in the mathematical sciences, the number of mathematics courses elected beyond institutional requirements, and the number of students pursuing a graduate degree in the mathematical sciences; collected data will be compared to previously (pre-LURE) compiled data at each school. We will hire an assessment specialist to assist us in analyzing and presenting the data. We will share our findings broadly and provide guidance on the costs and benefits of initiating a sustainable program. We expect to find concrete evidence of the benefits of involving early undergraduates in mathematical research (in part using numerical measures often considered important by college administrators), and we hope this will help other faculty succeed in securing internal (or external) funding for similar endeavors.

In summary, we have developed the LURE model based on the successful science apprenticeship model and based on our previous experiences mentoring undergraduate mathematics research projects. We will engage undergraduates in mathematical research earlier and aim to keep the students for a longer period of time than is typical in most existing programs. As we gain experience working with the LURE model and collect data on the impact of LURE on participating students, we will report our findings to the mathematics community. We hope that our findings will provide a rationale for other institutions to consider adopting this new model.

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