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Academic year undergraduate research: the CURM model

Tor A. Kwembe, Kathryn Leonard and Angel R. Pineda

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The Center for Undergraduate Research in Mathematics (CURM) provides funding and training for mathematics faculty to engage groups of students in academic year research. This paper provides an overview of the CURM model and its impact on mathematics students, faculty, and institutions across the country. We also present three case studies describing the transformational effects of CURM mini-grants at three markedly different institutions.

1. Overview of CURM

The NSF-funded Center for Undergraduate Research in Mathematics (CURM), founded in 2006 by Michael Dorff of Brigham Young University (BYU), awards mini-grants to fund academic year undergraduate research groups led by faculty at institutions nationwide. The CURM model draws on successful practices at BYU where student researchers across disciplines produce an impressive array of new results each year. The core of the CURM model is straightforward:

- Train faculty mentors to lead students in research projects.
- Provide funds for one course reassignment so faculty have time to effectively mentor students. Provide funds for supplies and travel.
- Pay students so that research becomes an alternative to other employment. Demand 10 hours per week per student on the job.
- Encourage students to work in groups.
- Celebrate student research success during a Spring Research Conference.

Faculty training. When awarding faculty mini-grants, CURM strives to balance experience, type of institution, gender, and ethnicity within each faculty cohort. A substantial number of mentors each year come from institutions where students might not otherwise have access to research.

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Each cohort begins the minigrant program at a Faculty Training Workshop held during summer at a venue where awardees share rooms, cook and eat together, and hold formal and informal discussions. Formal discussion topics cover a wide field, including how to select a good research problem, what to do when you realize your research problem is too challenging, how to handle interpersonal disputes between group members, where to publish student work, where to find additional money to fund research groups, logistics of running a research group, how to support struggling students, and how to find/select students [Leonard 2008] (see also maa.org/external_archive/columns/Resources/resources.html).

The rich content of the discussions comes in large part from the diversity of perspectives represented in each faculty cohort. Relationships built during the workshop often evolve into lasting friendships or collaborations.

Research group. Faculty must identify potential research group participants when applying for a CURM minigrant. As a result, they often reach out to students who might not otherwise know about student research opportunities. As with selecting faculty mentors, CURM strives to balance students with regard to gender, ethnicity, and economic opportunity. Additionally, CURM encourages faculty to recruit students as early in their academic progress as possible.

Students are required to work 10 hours per week for the academic year, approximately thirty weeks, and are paid $3000. At $10/hour, the CURM stipend is equivalent in pay to a typical campus job. Paying students for research affords the time for students who must work during college to participate in research. Students almost always work in small groups, enabling projects to move forward even when one group member must attend to other academic responsibilities. Often, CURM research groups evolve into self-organized learning communities where students enroll in the same courses, study together, and socialize together long after the project ends.

The precise structure of a research group varies from mentor to mentor, but a typical structure involves at least one weekly group meeting with the faculty mentor, one group meeting without the faculty mentor, and individual student meetings with the mentor. Faculty oversight often decreases as the year progresses and the students learn intellectual independence. CURM advises faculty mentors to require weekly presentations and weekly papers so that students can build their presentation and writing skills gradually over the funded period.

Students must submit a final research paper to CURM in May in order to receive their last paycheck. Ideally, these final research papers serve as a draft for a future publication.

Spring research conference. Mid-March, CURM students and faculty travel to BYU for a two-day research conference. Students present their results in 20-minute

talks and receive extensive feedback from faculty reviewers in the audience. Keynote speakers known for their ability to engage students give one-hour presentations on current mathematical topics. Half-hour "What is…" presentations introduce students to concepts like cryptography, knot theory, or operations research. Panelists describe graduate school applications and industry employment opportunities. Students interact with each other through ice-breaker activities, hikes, and a pizza party.

For CURM students at smaller, more isolated schools, the Spring Research Conference offers a series of firsts: the first visit to a research university, the first mathematical conference, the first research presentation, and the first conversations with other student researchers. Even for more experienced students, the CURM conference is often their first conference aimed entirely at students.

Outcomes, 2006–2011. During the first grant period (2006-2011), CURM funded 64 faculty mentors and 195 research students from 54 distinct institutions. Among faculty, 41% were female and 19% were from ethnic/racial groups traditionally underrepresented in mathematics. Among students, 54% were female and 29% were from traditionally underrepresented groups. CURM students generated 60 research papers, 158 conference presentations, and 29 awards. Graduate school attendance rate among CURM graduates was 63% as compared to the national average among math majors of 18% [AMS 2009]. Several CURM faculty alumni have successfully applied for larger NSF grants to support student research through programs such as REU, UBM, MCTP and CAREER. Others have succeeded with private foundations such as the Keck Foundation.

Subtler impacts also surfaced. Based on a survey administered to students before and after their CURM experience, CURM students' perception of interest in studying mathematics rose from just under 60% to just over 80%, and perception of interest in graduate school rose from just under 50% to 80%.

CURM's transformational power is perhaps best captured through anecdotes from participants:

- *CURM has opened many doors for my future. It encouraged me to apply for [be accepted to, and attend] a summer* 2008 *REU … If it weren't for CURM, I wouldn't be where I am today. I wouldn't know what it meant to do research, and I wouldn't be applying for graduate school.*

- *Two of my students were funded by the CURM grant for doing undergraduate research. Being from a minority institution these students were not exposed to this kind of work/project before. This work made them more disciplined, organized, and independent researchers. Also, participating in the CURM research conference in March of* 2009 *enhanced their communication skills significantly* (*note that English is not native language for either of these students*) *and thus, helped to improve their confidence levels.*

• *For several years the math department... has wanted to start encouraging interested students to do undergraduate research. However, they never got past wanting the research to happen, since faculty didn't have the time, energy or ideas to start undergrad research projects, and students didn't know to ask about the opportunity of doing research in mathematics. Because of the CURM grant, I was able to work with a large number of students* (7 *total, while only* 2 *were supported by CURM). All it took was this one year of the CURM grant to fan the fire, and our department has begun to foster an environment that encourages undergraduate research. This coming year there will be* 4 *professors working with students or groups of students on research projects.*

• *Another important impact that I believe the CURM experience had... is at the institutional level. We are in the process of revising our general education requirements and there is interest of somehow including a component or option related to research and scholarly activity. Recently, more external funding such as the CURM funding has been coming in... This has greatly helped us gain the support of the administration for the recognition of the educational value of undergraduate research.*

• *Before joining the CURM team in* 2007, *I had directed undergraduate research projects, so considered myself an experienced faculty in this matter. But through your CURM program, I realized that there is so much more to learn!... A very beneficial part I consider from the CURM program is the opportunity to collaborate/communicate with other faculty mentors in the program. Most of us are from undergraduate universities, at the similar stages of career, and facing the similar challenges... The network formed for this group kept active throughout the year and it was a very useful resource.*

In the next sections, we present case studies of the CURM model at three institutions: a large public university (close to 40,000 students), a small public university (around 3500 students), and a historically black university.

2. Case study: California State University, Fullerton, a large public university

Context. We begin by providing a quick snapshot of California State University, Fullerton (CSUF) as a whole (see fullerton.edu/analyticalstudies):

- Serves Orange County, located 25 miles from downtown Los Angeles
- Second largest campus in the California State University (CSU) system
- Over 37,000 students in its bachelor's and master's programs
- Among students who are US citizens or permanent residents: 57.0% women, 43.0% men

- In the same group, 37.2% self-identify as Hispanic, 31.9% white, 23.7% Asian and Pacific Islander, 4.1% multi-race, 2.8% African American, and 0.3% Native American
- Hispanic Serving Institution that is first in California and fifth in the nation in awarding baccalaureate degrees to Hispanic students [Cooper 2011]

This larger picture is reflected in the mathematics department. In Fall 2011, out of a total of 280 declared math majors, 128 (79 female) were Hispanic, African American or Native American, with the overwhelming majority being Hispanic (121; 71 female). The diversity in the mathematics department is one of its strengths.

The teaching load in the mathematics department is typically between 11-12 contact hours (3-4 courses) per semester, which makes it difficult to maintain a student-centered research program without assigned time for research with students, especially in a department that also has research expectations. The socio-economic situation of the student population often requires them to work many hours outside of their coursework. The demographics of the students and the high teaching load for faculty create conditions where a program like CURM is able to have a significant impact.

Prior to funding through CURM, most of the student-faculty research projects were carried out by faculty in addition to their teaching duties and without any training on effective research mentoring. In very few cases, faculty had external grants from NSF and the National Institutes of Health (NIH) which included funding for undergraduate students, but those grants are rare even now. NSF and NIH grants also did not provide any training for faculty in best practices for mentoring undergraduates in research.

The CURM research stipend for students, as well as training and reassigned time for faculty, directly addressed the challenges for mentoring undergraduates at an institution like CSUF.

CURM grants at CSUF. Three separate student-faculty collaborations have been supported at CSUF through CURM mini-grants:

- Gulhan Alpargu (CURM 2009-10) mentored a project in statistics titled "Microarray Gene Expression Analysis" with two students (Kirsten Cunanan and Suzette Puente).
- Scott Annin (2009-10) mentored a project in pure mathematics titled "On kth Roots in the Symmetric Inverse Monoid" with two students (Troy Cannon and Carlos Hernandez).
- Angel Pineda (2010-11) mentored a project in applied mathematics titled "Statistical Modeling of the Fat Fraction in Magnetic Resonance Imaging

(MRI)" working with four students (Kevin Park, Anne Calder, Eden Ellis and Li-Hsuan Huang).

The CURM projects at CSUF from Fall 2009 to Spring 2011 were instrumental in raising the level of interest in student-faculty research collaborations in the department. Faculty leading the projects improved their mentoring skills. Students presented their work at national meetings, published their results, and most attended graduate school. In addition, the CURM grants increased interest throughout the department, from both students and faculty, in undergraduate research. Consequently, there is now an undergraduate research course offered in the department which provides assigned time for faculty to mentor students. During Spring 2012, there were 19 student-faculty research projects (involving 9 faculty members) which generated the equivalent of three 3-unit courses for faculty. There is also additional assigned time being provided by the administration. We do not have reliable records of student-faculty research activity before the CURM grants, but anecdotally the change is dramatic.

The awareness that there is external funding available for mentoring students has also increased the efforts from the faculty to find such funding for students. Currently, mathematics students are funded by LSAMP (lsamp.fullerton.edu) and the Minority Access to Research Careers (MARC) program at CSUF (marc.fullerton.edu). There has also been increased submission of external grant proposals for additional funds to mentor students.

The CURM mini-grants provided not only the support for three research projects, they also created a cultural shift within the department by increasing awareness of the possibilities available locally and nationally to support student-faculty research. CURM has served as a catalyst to materialize our potential for developing an excellent undergraduate research program.

In the next section, we describe in detail one of the projects.

CURM 2010-11: Statistical modeling of the fat fraction in MRI. The first component of the CURM project was the Faculty Training Workshop held from June 24 to June 27, 2010 in Draper, Utah. That workshop was critical in creating a support structure among the mentors of the CURM research projects for that year. During the workshop we developed materials for introducing our students to research and learned about sources of information regarding mentoring of students [Leonard 2008] (see also maa.org/external_archive/columns/Resources/resources.html). The diversity in terms of experience, type of institution and type of mathematics studied made for an extremely informative exchange of ideas. We also developed friendships which helped us create a mentor network to support each other. We describe one such network at the end of the section.

In my case (Pineda), I originally planned to have three CURM students, but when a fourth student wanted to join the group, we combined funds from the Louis Stokes Alliance for Minority Participation program (LSAMP, CSUF) and the CURM mini-grant to provide support for all four students. The flexibility provided by having two funding sources played an important role in creating opportunities for the fourth student.

The four students divided themselves to work into two teams of two working on complementary projects involving statistical modeling in MRI, with one group focusing on the numerical simulations and the other on analytical derivations. The students met without me once a week and we all met once a week to discuss progress. Because the students were paid, they maintained a time log of the work they had done each week. A critical component for the success of the project was having reasonable expectations. The summer workshop and discussions with other mentors were extremely helpful for a realistic understanding what a team of undergraduates can do. The students worked hard and discovered new and interesting results, eventually identifying a situation where the current method for estimating the fat content of tissue fails and deriving the probability density function for a new random variable to quantify fat content.

The CURM team gave several presentations, including a poster at the Undergraduate Poster Session at the Joint Mathematics Meetings (JMM) in New Orleans, LA, a talk at the Pacific Coast Undergraduate Math Conference (PCUMC) in Los Angeles, CA, and talks at the CURM Conference, Provo, UT. They also published a paper in the undergraduate research journal of our college [Calder et al. 2011] and a paper in a peer-reviewed journal [Calder et al. 2012].

All four students who participated in this project decided to continue their studies. Li-Hsuan Huang and Kevin Park both attended California State University, Northridge as part of the LSAMP Bridge to the Doctorate. They are currently applying to PhD programs in applied mathematics and statistics. Anne Calder is now a master's student in applied mathematics at CSUF. Eden Ellis is currently applying to PhD programs in statistics. The experience and success provided by the CURM project played a role in these students deciding they would like to continue their studies.

The summer workshop preceding the CURM project facilitated the collaboration of three CURM groups working in southern California. Kathryn Leonard at CI, Herbert Medina at Loyola Marymount University (LMU) and Angel Pineda at CSUF created SoCal CURM, a regional version of CURM, where faculty and students travel to each other's universities to share their progress. These external but local presentations of intermediate results were critical for students to develop their communication skills and to create a local network of students with similar interests. The meetings also gave faculty an opportunity to work through various

challenges together as they arose. SoCal CURM continued for a second year, but is currently on sabbatical-related hiatus.

3. Case study: California State University Channel Islands, a small public university

We begin with a quick snapshot of CSU Channel Islands (CI):

- Only four-year public university in Ventura County, a highly rural area near Los Angeles
- Accepted first students in 2001
- Demographics similar to CSUF, also a Hispanic Serving Institution
- Enrolls ∼3,500 full-time-equivalent students
- Employs 85 tenure-track faculty

Most of the math majors at CI transfer from local community colleges. Understandably, we have some difficulty acculturating students to the mathematics profession. Faculty members are stretched by the standard campus service responsibilities spread over such a small number of individuals. Upon my (Leonard's) arrival at CI, no mathematics faculty were engaged in student research during the academic year, in large part because of the time demands of mentoring. I wanted to involve students in my research, knowing it might be the only way to keep my scholarship alive, but had no experience or exposure to undergraduate research and no departmental models to draw from. CURM's funding and training program was precisely what I needed. I applied for and was awarded a CURM mini-grant during the first two years of CURM's existence.

The first year, I soaked in wisdom from the Faculty Training Workshop. I carefully analyzed my group structure and my research problem and planned the first few weeks' activities. Our research project involved modeling textures in digital images that can be viewed as continuous deformations of periodic patterns. The semester began, my three students started work, and immediately disaster loomed. My problem was far too challenging and the group dynamics spiralled downward. Drawing largely on resources and relationships from the Faculty Training Workshop, I salvaged the problem and patched relationships between group members. Without CURM, I might not have overcome the challenges of that first year. I detailed my experiences and lessons learned that first year in [Leonard 2008] to help others avoid my rookie mistakes.

The second year, CURM funded two new students for my research group while two students from the previous year continued without funding. The year progressed smoothly: students successfully identified relationships between wavelet coefficients of periodic functions and the coefficients after a deformation of the

function, presented their work in multiple venues including the Undergraduate Poster Session at JMM 2009, and submitted a paper for publication.

Of the five students funded through CURM, two women (one Caucasian, one Filipina) have master's degrees in mathematics, one (Latino) is in a master's program in astronomy at CSU Northridge through the Bridges to the Doctorate program, and one (male Caucasian, first-generation college student) is in a PhD program in mathematics at Univ. of Nebraska. The fifth student (Latina) married and drifted away before graduating. My research group has grown each year since the first CURM award so that I have now mentored over 20 students. Among those who have graduated, all but two have continued on to graduate study in mathematics, statistics, computer science, or physics. The other two now work as mathematicians in industry.

CURM contributed to my professional development as well. The two CURM grants awarded early in my tenure process provided a foundation for two successful NSF grants involving student research. I continued attending the Faculty Training Workshops and Spring Research Conferences after my funded years, and am now a co-director of CURM.

Meanwhile, CURM ideas trickled into my institution. Inspired by the CURM academic year research model, CI's Dean of Faculty implemented a new course, UNIV 498, for faculty from any discipline to mentor senior-level research students for one semester per year. The UNIV 498 program led to a successful grant from the Keck Foundation to fund UNIV $x98$ courses, $x = 1, 2, 3, 4$, engaging students in interdisciplinary research at the freshman, sophomore, junior and senior level. CI now has a Student Research Steering Committee that offers travel funding for students presenting research at conferences, raises awareness about campus research opportunities, and strategizes about the future of student research at CI. Several campus programs offer research stipends that pay students to do research, including some funded through the Department of Education HSI-STEM grant. In addition, CI hosts an annual research conference funded by SAGE Publications where students showcase their research accomplishments. None of these campus efforts existed before my CURM mini-grant.

CURM has altered the department as well. Every tenure track mathematics faculty member has now mentored at least one academic year student research project. Increasing numbers of our students are attending the Joint Mathematics Meetings and local MAA meetings. Transfer students are learning about research from fellow students and seeking opportunities. This year, my research group of eight students includes two transfer students. Slowly but surely, we are becoming a department where students expect research to be part of their education. CURM provided the necessary push.

4. Case study: Jackson State University, a public, historically black university

We begin with a quick snapshot of Jackson State University (JSU) as a whole:

- Located in Jackson, Mississipi, a highly urban environment
- Founded in 1877
- Over 8,900 students in its bachelor's, master's, and doctoral programs
- Designated a research-intensive institution by the Carnegie Mellon Foundation

The Department of Mathematics at JSU offers a program of study in mathematics leading to two undergraduate degree tracks, the Bachelor of Science in mathematics and Bachelor of Science in secondary mathematics education. A majority of the students completing the Bachelor of Science degree in mathematics first seek employment with the federal government or in industry, then later pursue advanced studies in their areas of employment. Today, a degree in mathematics with additional course work in a related field such as computer science, engineering, statistics, or actuarial science is a more appropriate educational preparation for most industries. These industries expect employees to have interdisciplinary skills allowing them to team up with engineers, scientists, and other professionals [BLS 2013]. In addition, they are expected to explore quantitative data, to explain mathematical theories and solutions to people who do not have extensive knowledge of mathematics, and to devise new solutions to problems encountered by scientists or engineers. Because course work for the typical undergraduate degree in mathematics is not sufficient to meet these minimum skill requirements for employment, the JSU Department of Mathematics sought to address the deficiency with undergraduate research experience in mathematics.

We first chose to collaborate with the Department of Biology to train students in exploring data, explaining abstract mathematical theories, and deriving new theories [Robeva et al. 2010]. The vision was that JSU students would take part in collaborative research work during the academic year for a minimum of two years under the supervision of faculty teams from the biology and mathematics departments. As implemented, a mathematics faculty member usually initiates a research project in consultation with a biology faculty member whose research interests align with the objectives of the project. The two faculty mentors design a project and choose a team of undergraduate mathematics and biology majors to participate in the research. Implementation began with a successful National Science Foundation grant (0531927) for an Interdisciplinary Training of Undergraduates for the Biological and Mathematical Sciences (UBM) program.

Following the success of UBM, PI Tor A. Kwembe decided to expand undergraduate research in the mathematics department beyond mathematical biology

and to make it permanent. He applied for and was awarded a CURM grant for the 2010-2011 academic year to support five undergraduate mathematics majors to conduct research in applied mathematics. Currently, all five students are in good academic standing. Two will graduate in December 2012, one in May 2013 and the other two in May 2014.

Unlike in the previous two case studies, the UBM program at JSU had already established a firm foundation for undergraduate research. Nonetheless, receiving a CURM award shifted the paradigm at JSU. The CURM model of awarding mini-grants to faculty from different universities led JSU to establish a Center for Undergraduate Research (CUR) that awards mini-grants of $7,500 to twenty faculty members drawn from the five academic colleges. Each awardee conducts a yearlong research project with five undergraduate students. Participating researchers are encouraged to design research projects that are interdisciplinary in nature. Thus, interdisciplinary undergraduate research at JSU is institutionalized with the creation of CURM-inspired CUR. The Department of Mathematics has already benefited: two of the recipients of the first cohort and one of the second cohort of CUR mini-grants were awarded to mathematics faculty.

Samples of completed projects to date are:

- Effects of water depth and turbidity on spectral signature of submerged aquatic vegetation
- Numerical analysis of distal vasculature pressured fluid velocity and stresses on the walls of cylindrical shaped aneurysms
- Vegetation indices for remote sensing of canopy-forming submerged vegetation
- Detection of submerged plants using closed range hyperspectral remote sensing
- A mathematical model of the effects of aquatic contaminants on freshwater mollusks
- Modeling probability density functions for detecting quantum dot crystalline nano-particles by transmission electron microscopy (TEM).

5. Conclusion

The simplicity and effectiveness of the CURM model to inspire and sustain active undergraduate research programs is unmistakable. Repeatedly, a single CURM award has led to departmental or institutional transformation. By providing faculty and students with the support they need to succeed in undergraduate research, CURM funding demonstrates how undergraduate research bolsters student and faculty achievement. The manageable expense and high returns of academic year

research groups appeal to department chairs and administrators as a way to institutionalize a high-impact practice. For more information about CURM activities and opportunities, please see http://curm.byu.edu.

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