

2014

ISU REU: diverse, research-intensive, team-based

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a journal of mathematics

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(Communicated by Darren A. Narayan)

This article describes the Iowa State University (ISU) mathematics REU. The emphasis is on how certain choices made have shaped the ISU REU. The ISU REU draws a diverse group of students from a broad spectrum of colleges and universities nationwide. It is research-intense, with no course or workshop component, and results are disseminated through publications and presentations at conferences. Students in the REU work in teams with graduate students and faculty.

1. Introduction

The Iowa State University (ISU) Mathematics Department frequently involves students, both undergraduate and graduate, in a variety of research projects during both the summer and the academic year. This article focuses on the summer REU program at ISU, here called the ISU REU, directed by Justin Peters and Leslie Hogben, and usually managed by Hogben. In addition to Hogben and Peters, Wolfgang Kliemann and Sung-Yell Song regularly mentor REU groups; a total of 14 current ISU Mathematics faculty have served as mentors, as have another 7 former or visiting faculty. This program has operated seven of the past ten summers, and we will again offer the ISU REU in the summer of 2013. More information can be found on our website at orion.math.iastate.edu/reu.

The diversity of undergraduate research experiences — summer or academic year, all-research or combination of workshop/background class and research, research project teams or individual research projects, nationwide or local — serves students well, but each program must make choices. In this article the focus is on how certain choices made at ISU for our summer undergraduate research program, namely to

MSC2010: primary 00A99; secondary 01A61, 01A73.

Keywords: REU, undergraduate research, Iowa State, diverse, team.

The ISU Math REU is supported by the National Science Foundation through grants DMS 0750986, DMS 0502354, DMS 0353880, through other grants, and by the Iowa State University Department of Mathematics. The opinions expressed are those of the author, and not of Iowa State University or the National Science Foundation.

be a diverse national, research-intense, team-based REU, have shaped the ISU REU (Sections 2, 3, and 4, respectively). The most recent ISU REU (2011) is discussed in Section 5, and Section 6 expresses the author's concerns about the future of the national REU program; the remainder of this introduction discusses funding sources.

The ISU REU has had three major funding sources: (1) two NSF REU site grants (covering summer 2004, 2005, 2006, and 2009, 2011, 2013); (2) the NSF-funded Alliance grant (covering summers 2003, 2004, 2005, 2009, 2010, 2011); and (3) the ISU Mathematics Department (funding students in 2003, funding graduate research assistants during the other six summers, and having faculty donate time all seven summers of the program). In addition to students being funded by these three main sources, a few students have been funded by faculty grants or ISU programs, and several ISU students have been accepted as volunteers in the ISU REU (sometimes with their expenses paid by ISU Mathematics Department). The funding source affects the pool of eligible students. For example, the 2003 REU, in which many of the students were supported by the ISU Mathematics Department, had 7 of 14 students from ISU and 4 others from central Iowa, and Alliance funding was restricted to students at certain schools.

While NSF REU site grants are well known, and it is not uncommon for colleges or universities to support their own students in summer research, some description of the Alliance is needed here. The NSF-funded Alliance for the Production of African American PhDs in the Mathematical Sciences was a partnership between ISU, the University of Iowa, the University of Northern Iowa, and four historically black colleges and universities (HBCUs). It supported Alliance scholars at the partner HBCUs both financially and with mentoring during the academic year, and involved them in REUs at the three Iowa regents universities during the summer. The ISU REU has integrated all students in research projects regardless of funding source, and has used an all-research model. UI integrated Alliance-funded students with students from their NSF VIGRE REU, and both UI and UNI used a workshop and research model. All the Alliance students in REUs would get together at either UI or ISU at the beginning of the summer, and at the other institution at the end of the summer, where they would present their research.

Between 2006 and 2009 this Alliance merged with other programs that had successfully mentored under-represented minority students to pursue graduate degrees in the mathematical sciences and became the National Alliance for Doctoral Studies in the Mathematical Sciences. This change substantially expanded the activities of the Alliance, but the three Iowa regents universities continued to operate the (Iowa) Alliance REU in much the same manner. However, three of the changes in the Alliance and in the (Iowa) Alliance REU had major positive impacts on the ISU REU: (1) The expansion of the Alliance greatly expanded the pool of

students eligible to be supported by Alliance funding. (2) The symposium at the end of the summer was expanded to include all mathematics and statistics students in the REUs at ISU, UI, and UNI. (3) At ISU and UI, all mathematical sciences REU students are now housed together regardless of funding source.

2. Working with students from diverse backgrounds

The ISU REU has involved 106 students over seven summers, with 9–21 students per summer.¹ Of these students, 26% are under-represented minorities as defined by the NSF (predominantly African Americans and Latinos/as, in roughly equal numbers), and 40% are women. Half of our students come from nondoctoral colleges and universities, and more than 3/4 attend(ed) a college or university that is *not* among the top 25 national universities or top 25 liberal arts colleges as ranked by *US News & World Report*. While all REUs are selective, the ISU REU is reaching a relatively broad spectrum of students.

We are working to diversify the pool of graduate student and faculty mentors: 32% of the graduate RAs are women and 11% are under-represented minorities; the corresponding percentages for faculty are 25% and 4%.²

More than half of the ISU REU students (and more than half of the under-represented minority students) who had graduated at the time we collected our most recent data have enrolled in graduate school.³

ISU REU students have won major national fellowships, such as NSF Graduate Research Fellowships and National Defense Science and Engineering Fellowships. The success of our students in publishing and presenting their research is discussed in Sections 3 and 5.

Changes in the Alliance program (discussed in Section 1), and changes at ISU have had a significant positive impact on the ISU REU in recent years. Although we have always believed in integrating all ISU REU students in research projects regardless of funding source, this integration was only partially successful prior to 2009, leading some project groups to split into subgroups and in some cases into different projects because of substantial differences in student background. One source of difficulty was that the number of places available at ISU, UI, and UNI for Alliance REU students sometimes exceeded the number of qualified, interested

¹Two of the seven summer programs included students doing research in statistics as part of the living group, but their data is not included here because Statistics is a separate department at ISU and their research supervision model was quite different from ours (and varied over time).

²A faculty mentor is counted according to the number of summer programs in which s/he is a mentor, but is not counted extra if s/he mentors multiple projects in a single summer.

³This is a combination of relatively complete data for NSF REU site grant-funded students in the years 2004–2006, and one year after data combined with anecdotal data for the other years and for students from other funding sources.

students at the four partner HBCUs. The ISU REU struggled during these years to recruit Alliance students with the background to benefit from our all-research program. The broadening of the pool of Alliance-eligible students⁴ has facilitated the recruitment of a diverse group of students with the necessary background for an all-research REU. Another factor that improved the pool of applicants is several new diversity initiatives undertaken by the ISU Mathematics Department starting in 2008. In particular, a partnership with the University of Puerto Rico, Rio Piedras campus has been helpful in recruiting students. Since 2009 the research groups have worked more smoothly and none has split (except in a planned manner, such as dividing a group of 6 into two groups of 3 with related projects). The expansion of the Alliance symposium to include all mathematics and statistics REU students at ISU, UI, and UNI, and the common housing of ISU REU students have helped the ISU REU to become more cohesive.

All of the standard measures of REU success (students enrolling in graduate school, students winning fellowships and awards, students publishing research, etc.) have increased since 2009. And perhaps more importantly, since 2009 our under-represented students (and our Alliance-funded students) have by any of these measures been just as successful as our majority students and our NSF REU site grant-funded students.

The diversity of students' cultural backgrounds has enriched the REU. For example, in 2009 ISU REU students organized a weekly Spanish class that was well attended by students, RAs and faculty. Dinners with ethnic dishes have also been organized.

3. Research and publications

The ISU REU program has had research projects in a wide range of areas, depending on faculty involved and their research interests. This flexibility has allowed the program to evolve over time. Nonetheless, there are several areas (corresponding to the interests of long-term faculty mentors) that have been offered repeatedly: these include combinatorial matrix theory, dynamical systems, and algebraic graph theory.

Iowa State University is a public land-grant university with more than 30,000 students, is a member of the American Association of Universities (an association of 62 leading research universities), and is classified by the Carnegie Commission as a research university with very high research activity (RU/VH). As such, research is the primary focus for most tenured and tenure-track faculty, especially during the summer, and we volunteer our time to do research. Many of us particularly

⁴Although any student nominated by an Alliance mentor is eligible, almost all Alliance-funded students continue to be under-represented minorities; other Alliance-funded students have faced health or financial crises.

enjoy doing research with bright enthusiastic young people, such as REU students or graduate students, but research remains a major goal.

We publish results in a wide variety of journals, ranging from standard research journals to undergraduate journals. As all but one ISU REU paper have faculty and graduate students as coauthors, and we want the researchers in the area to be aware of the results, *Involve*, with its articles being reviewed on MathSciNet and joint student-faculty authorship encouraged, is an excellent journal in which to publish REU research results. A list of ISU REU research publications can be found on our website at orion.math.iastate.edu/reu/REUpubs.html.

Over the course of seven ISU REU programs, there have been 43 projects; 19 papers, involving students in 20 of those projects, have appeared or been accepted.⁵ Of the 106 REU students, 50 are coauthors of ISU REU research papers. Overall, 47% of ISU REU students are coauthors on published papers. Since 2009, there have been 14 research projects and 9 papers; 58% of the students are coauthors (and two papers are still under review).

4. Research teams and vertical integration

Throughout the ten-year life of this REU, research groups have been used to introduce undergraduates to research. While this is not unusual in REUs (in some cases out of economic necessity), the research group approach informs much of what we do with students at ISU, both undergraduate and graduate. Prior to starting the ISU REU, several faculty in the department, including the author, had used research groups of graduate students, postdocs, and faculty, both for their own students and to introduce new students to a research area.

For the ISU REU, research groups are not just the most practical way to offer our program, but we have found that they also the most effective. In many cases the students learn from each other. In the first few years we sometimes divided a group and gave students individual projects, but have not done so since 2007.

While all of our REU students are bright and enthusiastic, we engage a broad spectrum of students with a diverse range of backgrounds in research. Our REU students have typically completed junior level mathematical coursework,⁶ although in some cases we take exceptional students who have completed only their sophomore mathematics courses.

The (paid) graduate student research assistants (RAs) play a critical role in the ISU REU. It would not be possible to offer the ISU REU without graduate RAs.

⁵In a few cases results from two summers were combined in one paper or a single project produced two papers.

⁶The student's mathematical age is more relevant here than the year of college the student has completed, as many of our REU students are accelerated, having completed junior level courses after two years of college.

As none of the faculty are paid any salary to serve as research mentors in the ISU REU⁷ and most are on nine-month contracts without summer support, such a faculty volunteer needs the flexibility to travel to research conferences during the eight-week REU; the graduate RA supervises the undergraduates in the absence of the faculty member. Faculty members focus their efforts on research (and in some cases on mentoring the students for graduate school and mathematical careers), but the graduate RAs are involved in all aspects of the REU. They are actively engaged in research with the students and faculty, are available most of each work day to answer student questions, provide support for \LaTeX , assist with mathematical software, work with the students on the preparation of final papers, presentations, and posters, and are wonderful mentors who are trusted by the students to provide the “inside story” about life in graduate school.

Postdoctoral associates have served as faculty mentors in this REU, and for the purposes of this article their data have been combined with faculty.

We have also used research groups (both academic year and summer) to create a supportive environment for faculty at undergraduate colleges to continue involvement in research, and several such faculty are coauthors on ISU REU publications. Such faculty also contribute substantially to mentoring students.

Our experience with research groups and the REU led us to develop an Early Graduate Research (EGR) course, which is offered in the spring semester. ISU’s EGR course is a model that can be replicated at research universities for graduate students (but not for undergraduates due to minimum enrollments), and possibly by undergraduate colleges that have lower undergraduate course enrollment requirements.

5. The 2011 ISU REU

The combination of these changes and our growing experience led to a highly successful 2011 REU.

One student won an NSF Graduate Research Fellowship and another won a National Defense Science and Engineering Graduate Fellowship. At least ten of fifteen students who graduated in 2012 enrolled in graduate school in an NSF discipline, most in doctoral programs in the mathematical sciences. Schools they are attending include Harvard, Cornell, SUNY Stonybrook, Georgia Tech, Arizona State and Iowa State.

Four of the five research projects have published (or had accepted) papers reporting their results, and the fifth group has its paper under review — we are aiming for 100% publication from this REU.

⁷In a few of the REU summer programs, one faculty member was paid a small (e.g., two-week) salary to manage the program; there is no funding in the current NSF REU-site grant for this.



Figure 1. The 2011 ISU REU in front of Carver Hall.

Fifteen of the eighteen students attended the 2011 SACNAS National Conference in San Jose and presented 5 posters. Fourteen students attended the 2012 Joint Mathematics Meetings in Boston and presented 6 posters.⁸ At each of these conferences, ISU REU students won poster presentation awards.

6. The future of REUs

Involving undergraduates in research in the mathematical sciences, and specifically summer REU programs, has proved highly successful nationally in enhancing student interest in graduate school in the mathematical sciences. REUs are playing an important role in expanding the mathematical workforce and strengthening the next generation of mathematical scientists, and federal support, especially the NSF REU program, has played an essential role in this.

The author was disturbed by statements at the Trends in Undergraduate Research in Mathematical Sciences (TURMS) conference that the NSF is considering changing the funding model for REUs, expecting REU programs to be redesigned to continue without federal funding. It should be pointed out that the ISU Mathematics Department already provides a substantial contribution to the direct funding needed to operate the ISU REU, in the form of most of the graduate student research assistantships. Furthermore, if the value of the faculty time that is volunteered is included, the ISU Mathematics Department is providing more than one third of the entire cost of the current ISU REU that benefits students nationally.

The highly successful ISU REU, which has contributed significantly to both broadening the mathematical workforce and producing new mathematics, cannot continue in its present form without outside funding. Of course alternatives are possible — as noted earlier, we do research with students in a variety of settings — but an entirely locally funded alternative would understandably be for ISU students

⁸Not all students who attended presented a poster, and some presented other research (the number of posters given is for ISU REU research only).

only, and would therefore be substantially different from the ISU REU described in this article.

National impact requires national funding.

Received: 2013-01-05

Accepted: 2013-10-11

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See inside back cover or msp.org/involve for submission instructions. The subscription price for 2014 is US \$120/year for the electronic version, and \$165/year (+\$35, if shipping outside the US) for print and electronic. Subscriptions, requests for back issues from the last three years and changes of subscribers address should be sent to MSP.

Involve (ISSN 1944-4184 electronic, 1944-4176 printed) at Mathematical Sciences Publishers, 798 Evans Hall #3840, c/o University of California, Berkeley, CA 94720-3840, is published continuously online. Periodical rate postage paid at Berkeley, CA 94704, and additional mailing offices.

Involve peer review and production are managed by EditFLOW[®] from Mathematical Sciences Publishers.

PUBLISHED BY



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involve

2014

vol. 7

no. 3

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