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and promoting success

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This article summarizes the authors' presentations on the panel "Working with Students from Underrepresented Groups" as part of the MAA's Trends in Undergraduate Research in Mathematics Conference held in Chicago, in October 2012. We highlight effective aspects of our own successful programs that emphasize working with students from underrepresented groups. We discuss specific issues of program design that one might beneficially consider when planning to work with students from underrepresented groups and provide examples of ways in which the authors have addressed these concerns.

1. Research experiences for undergraduates and the STEM crisis

Much has been written and presented about the "STEM crisis" in the United States — the increasingly large gap between the number of highly educated science, technology, engineering and mathematics professionals needed to sustain our workforce and the number current educational practices will produce. For instance, mathematical workforce and relevant demographic trends are discussed in [Cortez et al. 2007]; a brief update is provided in [Dye and Russell 2014]. The concern is not new: for decades, calls to address this slow-moving crisis have made clear that developing talent within all segments of our population constitutes our best hope of competing economically.[1]

Two other arguments for diversifying our STEM student and professional populations are relevant. One is the fairness aspect: each individual should have the opportunity to realize his/her potential, with no limits imposed by race or ethnicity, gender, disability status, socioeconomic status, or family educational background.

[1]For example, Widnall [1988] cites studies from the 1970s and 1980s in analyzing gender differences in experiences and perceptions of graduate school and PhD attainment in STEM fields; Jackson [2002] refers to the decades-long growth of the gap between STEM professional production and needs.

Another broadens the economic argument beyond the mere quantity of STEM professionals to the value of bringing diverse perspectives to bear on complex problems.

> *There are large and complex problems to solve. Many of these vital, exciting, and challenging problems are characterized by increasing complexity, ambiguity, uncertainty, and rapidly changing conditions. Solutions to these problems require the best minds and facilities to work together* [CEOSE 2004, p. 1].

Similarly, the National Science Foundation's Mathematical and Physical Sciences Broadening Participation Working Group refers to research indicating that diversity is a "powerful contributor to the attainment of effective solutions." They write "we see improving our nation's economic outlook by providing research teams with the distinct competitive advantage of a diverse workforce as an equally compelling reason to demand improvements in broadening participation" [DeSimone et al. 2010].

Research Experiences for Undergraduates (REUs) can play a significant role in enhancing diversity in the United States' STEM workforce by seeking out talented students from groups traditionally underrepresented in STEM fields and providing the benefits known to accrue from REU participation. Yet a recurring conversation among REU-engaged faculty centers on the dearth of competitive applications by students from underrepresented groups to many REUs. Advice regarding recruiting such students has remained fairly consistent in recent years [Dye and Russell 2014; Cortez et al. 2007; Vélez 2011] and has been effectively practiced by multiple REUs. However, reaching a target student with information about an REU is not sufficient if a student decides that REU is not for her, or even more damaging, that REUs in general are not for him. The concomitant challenge lies in designing an REU that both attracts and supports students from underrepresented groups. To be clear, by "students from underrepresented groups" (S-URGs), we will mean not only underrepresented minorities[2] and women, but also first-generation college students, community college students and transfers, and low-income students.

What are the considerations relevant to designing such an REU? One guide for a wider range of programs offers eight design principles gleaned from examining programs that successfully broadened participation by S-URGs [BEST 2004]:

- Institutional leadership
- Targeted recruitment
- Engaged faculty

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[2]As defined by the federal government: African-Americans, Hispanics, Native Americans, and Pacific Islanders.

- Personal attention

- Peer support

- Enriched research experience

- Bridging to the next level

- Continuous evaluation

We propose a series of questions loosely corresponding to these principles that REU planners may consider when designing an REU to attract and support S-URGs. We then highlight aspects of two programs explicitly designed to broaden participation while intentionally constructing heterogeneous research groups. We offer these not as one-size-fits-all solutions but as our attempts, within the contexts present, to provide pathways to success in the mathematical sciences for S-URGs.

2. REU design: questions to consider

We offer here many questions that REU planners might productively consider in designing an REU to attract and support S-URGs. These lists are not exhaustive: other questions common to all REUs, for example, about finding good research topics, may be found elsewhere. While our first set of questions concerns goals and philosophy, some later questions (e.g., about forming heterogeneous groups) reflect the goals and philosophies of the authors.

- Why are the *faculty planners* hosting or considering hosting an REU?
    - What do they wish to accomplish through this REU?
    - What is the philosophy behind these goals?

- What is the *institutional environment* for the REU?
    - Do the relevant administrators value the goals of the faculty planners?
    - What type of support (staff, financial, logistical) is available?
    - Are physical spaces — for working, for living — conducive to the goals?
    - Will faculty engagement be valued in tenure and promotion decisions?

- In addition to the faculty planners, what *faculty* will be engaged in the work of the REU? (From this point on, we use "faculty" to include REU planners/ directors as well as research mentors.)
    - Do all faculty share the goals and philosophy of the planners?
    - Do the faculty value working with undergraduates highly?
    - Do the faculty view broadening participation in the mathematical sciences as an important undertaking?
    - Are the faculty engaged in working with S-URGs?
    - Are the faculty engaged in or willing to engage themselves in learning about

underrepresentation in the mathematical sciences: its history, ongoing barriers to participation, individual and cultural challenges, etc.?

- How will *students* be recruited and selected for the REU?
  - How will recruiting materials and processes attract the types of students desired?
  - How will the application process identify mathematical potential? Sufficient mathematical background for the research projects? Ability to work well with others? Motivation and work ethic? Openness to the possibility of pursuing a graduate degree in the mathematical sciences?
  - How will the faculty determine which students are likely to benefit to the greatest extent possible from their participation in the REU?
  - How will the selection and notification process ensure heterogeneous groups?

- What will the *activities* of the REU be?
  - What tone should be set during pre-REU communications? How will this be accomplished?
  - What activities will ensure that all students feel equally welcome and supported by faculty and peers?
  - How will the faculty provide each student sufficient personal attention for that student's mathematical and personal growth?
  - How will the mathematical activities be structured so as to ensure that all students have an enriched research experience?
  - What professional skills will students need to develop? How will this be accomplished?
  - Will REU activities help students manage the frustration inherent in mathematical research? Will they help students build confidence in their abilities?

- What sort of *follow-up* will there be after the on-site REU?
  - How will the REU be evaluated? How will lessons learned from the evaluation be incorporated to improve the REU?
  - How will student be supported through the process of disseminating their results?
  - How will students be supported as they consider their next REU, their post-graduation plans, etc.?

3. REU design: our approaches

The CI and PURE REUs: ***an overview.*** The CSU Channel Islands REU began in 2010. It has supported 14-15 students in three research groups each summer.[3]

While welcoming all student applicants, it particularly seeks S-URGs, with a special emphasis on students who are native Spanish speakers or first-generation college students. At least one faculty mentor each summer is Spanish-English bilingual; at least one student is from a partner university in Mexico: these two features and several other aspects address the goal of creating an especially welcoming program for native Spanish speakers while enhancing the international perspectives and cross-cultural competency of the entire REU group. Students spend the bulk of their time working on research; skills workshops, distinguished visitors and colloquia, meals, and social outings are also included in the activities.

The Pacific Undergraduate Research Experience in Mathematics (PURE Math) is a combined summer program for undergraduates in mathematics.[4] It began in 2011 and was developed to bring the summer research experience to the people of the U.S. Pacific Islands. It is a collaborative project between the University of Hawai'i at Hilo and Sam Houston State University and is housed on the campus of the University of Hawai'i at Hilo. Through the experience of mathematics research (an 8-week Residents Program) and advanced mathematical training (a concurrent 5-week Interns Program), participants receive valuable mentoring towards

(1) the preparation for upper-level theoretical coursework in mathematics,

(2) the development of the necessary framework for continued academic success in science, technology, engineering and mathematics (STEM) disciplines,

(3) the consideration for further training in STEM graduate schools.

PURE Math and the CI REU share a primary goal for our student participants: for the students to conduct original mathematical research leading to conference presentations and publications. In so doing we wish to raise their levels of mathematical maturity and confidence while fostering an enthusiasm for mathematics. We intend to create and maintain research communities of mathematicians. We seek to improve the participants' abilities to communicate mathematics visually, orally, and in written form. We incorporate S-URGs and non-S-URGs into a heterogeneous group with shared intellectual goals. We want students to leave the program feeling excited and prepared to perform graduate-level mathematics in an academic or industrial setting.

Participants.

Faculty. All faculty engaged with our REUs consider working with undergraduates to be an essential component of their professional lives, are research active with components of their research conducive to undergraduate research, and are

committed to broadening participation in the mathematical sciences. We mix experienced research mentors with early career mathematicians and include copious pre-REU planning and conversations with ongoing mid-REU meetings to engage in mutual professional development around the topics of undergraduate research and working with underserved populations. Mentor expectations are made explicit before mentors commit to the REUs: expectations include far more in-person work with individual students and research groups than seems to be the norm at most REUs.

Students. Students are selected for the CI REU by determining who ranks high on the first two criteria below, then considering the extent to which those students meet the remaining criteria:

- demonstrates mathematical talent and/or potential
- demonstrates mastery of sufficient mathematical background for selected projects
- attends an institution with limited opportunity for undergraduate research (typically a non-PhD-granting institution)
- is a member of a group underrepresented in mathematics
- is a first-generation college student
- either has considered a mathematical or scientific career, or should be encouraged to do so

(Not all criteria have to be satisfied.) Research mentors and project directors work together in an effort to create a heterogeneous community as well as heterogeneous research groups. As our REU emphasizes collaboration and a supportive-to-all atmosphere, faculty also seek indications that students are eager to contribute to this atmosphere in their essay responses and letters of recommendation.

A similar process is involved in selecting students for PURE Math. Particular attention is paid to the level of mathematical maturity so as to place students in the appropriate program. Building and maintaining an idyllic and genuinely collaborative community of young researchers that have access to appropriate levels of support is critical to the success of each summer. It is crucial that participants share a common experience in their logistical and academic environment, that there is a clear and common set of reasonably high expectations, and that there is diversity and balance among the group in terms of ability, experience and background. For these reasons, the selection process often involves directly contacting the candidate and the faculty who have written letters of recommendation to discuss the candidates' applications in greater depth.

Atmosphere and activities. As Ricardo Cortez observes [2007], "It is important to create the 'right' atmosphere right away".

Setting the tone: pre-REU. We send messages in the pre-REU stage through the following mechanisms.

- Webpages and recruiting materials are crafted to give students a sense of the programs and the atmospheres they seek to create.
  - All CI materials are presented in both English and Spanish; at least one faculty mentor is Spanish-English bilingual; a webpage entitled "What's research?" (see faculty.csuci.edu/cynthia.wyels/REU/) mentions the frustration (and fun) inherent in mathematical research and emphasizes the community and collaborative aspects of research in our REU; expectations of and benefits for students are spelled out. Goals listed on the webpage include "get participants excited about doing mathematical research", "create a learning community", and "help participants develop the confidence to succeed in ongoing mathematical studies".
  - The PURE Math webpage provides information regarding the upcoming summer (see www2.hawaii.edu/ pure/PURE_Math/Welcome.html), and the previous years' projects and reports are available for both programs as well. Photos and video montages are also available on the website. Students are directed to the application form available through mathprograms.org.

- Predecision communications with students are critical to helping program directors, research mentors, and students make good choices. Both PURE Math and the CI REU provide students with explicit expectations. These include working hard on every task, participating fully in all program activities, listening to peers and faculty, sharing ideas, providing helpful suggestions, asking questions, giving constructive criticism when possible, and having fun "stretching their brains in the company of like-minded people". Students are reminded that their efforts will be the determining factor in their outcomes. Similarly, PURE Math and the CI REU ask students to sign a contract to accept their offer of admittance: a sample pledge is "to approach the mathematical learning and all people involved in the program in a spirit of openness and collaboration".

- Prearrival communication continues to set the tone for students who will be participating. Both community building and mathematical formation takes place here: mentors provide articles along with tailored reading guides, and students are asked to use social media to introduce themselves to the group. Even logistical information can reinforce expectations about open-mindeness regarding other cultures: for example, PURE Math includes information on Native Hawai'ian culture to help students interact respectfully during their stay.

Establishing the desired environment: the first week. During the first week of each REU, several activities are carefully chosen to promote social cohesion, identity exploration, and team building. All such activities include debriefing and often

further conversations initiated by students. Team building activities are used to help students develop effective collaboration skills and to help them understand the benefits of peer support. Discussions tie these activities to various ways in which mathematical research is undertaken, including the necessity of stepping away from others for private work at times. During identity exploration activities, students are led to self-assess who they are and who they are becoming as people, learners, and mathematicians. For example, one identity exploration (which doubles as an exercise in writing with precision) consists of providing students a list of 15 to 20 "common values" and asking them to write about the three they value most. Experience shows that this exercise also turns into group bonding: in spite of their diverse backgrounds, they discover they share similar values, with family repeatedly being highly valued among students. The goals are for them to better understand themselves and use that insight both to learn and do mathematics more effectively, and to better understand and work with others. After exploring their own cultural/familial backgrounds and individual identities, they're asked to identify strengths they can build on as mathematics students and researchers; at the same time, they consider potential hurdles and strategies to overcome them. Through these types of activities, we make clear that we expect diversity to enhance the work of the REUs. Heterogeneity (overall, and within each research group) offers each person the opportunity to enhance his/her "intercultural competence, cognitive complexity, ability to work in diverse groups, and capacity to take seriously the perspectives of others".[5]

Building competence and confidence: weeks 2–8. Effective student research requires a structured but flexible setting that allows faculty mentors to meet students at their current levels and draw them up to a place where they can engage productively with challenging problems. Initially, faculty mentors are heavily engaged with the students' mathematical learning, helping them understand the readings sent pre-REU and the possible research topics. Faculty may direct students to create and work out examples, they may present material, and they provide students extensive opportunities to ask questions. The goal of the mathematical activities during the first week is for each research group to understand their REU topic and several relevant problems, and to be able to present these coherently to the whole REU. As our REUs progress, faculty intentionally help students make the transition from classroom (directed) mathematics to independent research. They talk about the differences and what research "is", they model the thinking necessary, they give the students larger open-ended tasks and questions, and lead the students to develop their own avenues of investigation. Faculty continually nudge students forward on

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[5]From the "Inclusion" core principle of AAC&U's "Making Excellence Inclusive" initiative, as cited in [O'Neill 2009].

this path, while being available to support as appropriate. Throughout, REU faculty take joint responsibility for monitoring students' progress, while staying attuned to group and individual dynamics.

REU activities common to many REUs include invited speakers, group meals, ethics components, skills development, student presentations, and social outings. We advocate these activities, while considering how they can best further the goals of our REUs. In seeking speakers, we invite accomplished mathematicians from academia and industry who are also dynamic speakers; we seek the same sort of diversity of background in our speakers as we do in our students. We ask speakers to share their pathways — especially hurdles and hard lessons learned, in addition to their mathematics. The more students are aware of different pathways taken — leaving school, pursuing different degrees and careers, and hurdles (dropping out of school, failing quals, being told "you're not good enough", dealing with a sense of not belonging) — the more they recognize that there are multiple paths to success. Exposing students to successful researchers and scientists who have taken very different and often difficult paths in the younger stages of their lives allows students to see their own potential to succeed. They are able to relate to someone who has achieved tremendous success, thereby permitting themselves to take on the same challenges and face the same fears, but with a higher degree of confidence due to an "existence proof" that it can be done. Social outings also build confidence: they include trips in which some of the S-URGs become cultural experts for the rest of the group; the same is true of the menus at some group meals. We take advantage of the locations of our REUs whenever possible to support subgroups of our S-URGs who may often feel out-of-place in majority-culture and language institutions.

As our REUs intentionally admit students at critical transition points in their mathematical education, we carefully plan a series of workshops[6] for students to develop professional skills. These are hands-on workshops; follow-up is done within research groups and between individual students and any faculty. Peer support is modeled and encouraged at all times, especially during students' weekly presentations of their work-to-date; these practice presentations also help students develop their presentation skills and confidence speaking before groups. The faculty also model the goal of ongoing learning through our informal interactions, planned meetings, and reliance on one another to support all our students.

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[6]Topics for workshops include: reading mathematical literature; proof techniques (illustrations chosen from research topics or background for research areas); using MathSciNet; abstracts triage; mathematical software; LaTeX; preparing visuals for presentations; giving oral presentations; preparing posters; presenting posters; upcoming conference options (includes deadlines, funding, etc.); graduate school: what is it, how to prepare, apply, choose; careers in mathematics: how to learn more and seek positions; writing abstracts; writing mathematics; math chats (discussing research informally, e.g., at conferences and in interviews).

Onward and upward: post-REU. Our REUs structure our time together to ensure that students leave the summer program ready to give a 10–15 minute conference presentation and a poster presentation of their work. During the REU, faculty help students identify conferences appropriate to their goals at which to present,[7] and provide guidance in applying for travel funding. Students also write up their results, going through several drafts with faculty and peer feedback. When appropriate, faculty mentors oversee submission to journals. Faculty continue mentoring students post-REU both in person at conferences and through e-mail and social media. In addition to writing letters of recommendation for students' next research experience and/or graduate admissions, faculty contact individual students with opportunities, respond to questions, and celebrate students' successes.

Student outcomes. As our programs are relatively young, participants are still undergraduates or just beginning postgraduate lives. Yet the outcomes summarized below are promising.

PURE Math. 2011: 5 of the 12 participants in the Interns Program have graduated. Of these 5, 3 are going on to graduate programs (in math education, mathematics and physics) all with full funding. Of the 7 who are still undergraduates, 3 will graduate in 2013 and are applying to graduate programs. All 3 have spent their subsequent summers at other REU programs.

2012: There were 12 participants in the Residents Program and 12 in the Interns Program; all are still undergraduates at this time. 6 will be graduating in 2013; all 6 are applying to graduate programs.

CI REU. 2010: 12 of the 14 participants have graduated. Of these 12, 9 applied to graduate programs; all were accepted with full funding.

2011: 10 of the 15 participants have graduated. Of these 12, 7 applied to graduate programs; all were accepted with full funding. 2 of the 4 graduating in 2013 participated in other REUs during Summer 2012; these 2 are applying to graduate school for Fall 2013 admission.

2012: All of the 15 participants are undergraduates at this time. Of the 9 graduating in 2013, at least 7 are applying to graduate programs.

4. Final considerations

Designing a new REU, garnering the necessary institutional support, and acquiring external funding can be daunting. Multiple-research-group, externally funded

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[7]SACNAS, the National Alliance's Field of Dreams Conference, and the Nebraska Conference for Undergraduate Women in Mathematics are all excellent venues for S-URGs and others; the Joint Mathematics Meetings also provides many opportunities for REU students. Regional MAA meetings provide student-friendly and more affordable options.

summer REUs are far from the only avenue for mentoring undergraduate research. The Center for Undergraduate Research in Mathematics (curm.byu.edu) not only offers funding for academic-year research groups but also provides mentoring and advice to help faculty grow in this undertaking. The National REU Program (see maa.org/nreup) is geared toward one-faculty, one-research-group REUs with minority students from the faculty member's institution. Individual institutions may provide teaching credit or internal grants for engaging undergraduates in research. Energetic faculty may simply invite a few students to engage in research for the pure joy and learning involved! These and other methods to facilitate undergraduate research can benefit from consciously designing the effort to attract and support S-URGs.

In the end, the benefits of broadening participation are themselves broad. To quote from [Hartline and Poston 2009], for students, "especially when the students are visibly different from the faculty and the majority of their peers, caring and resourceful mentors can help illuminate the possible pathways, develop the mentee's talents, and encourage them to transition successfully into the next career phase". For faculty, "insights gained from students with different perspectives can take research projects in unanticipated but exciting and worthwhile new directions". We attest from personal experience that working with talented S-URGs who did not initially view themselves as potential mathematicians is professionally and personally fulfilling. And finally, the mathematical community and society at large benefit from capturing individuals from all segments of our population, bringing their numbers and diverse perspectives to bear on the complex problems yet to solve.

Acknowledgements

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