NSF REU Site: Chemistry / Chemical Engineering: The Bonds Between Us - A Three Year Retrospective

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Abstract – A little over three years ago, two brand new assistant professors successfully earned funding from the National Science Foundation (NSF) for a Research Experiences for Undergraduates (REU) site at Mississippi State University. In the time that the "Chemistry / Chemical Engineering: The Bonds Between Us" program ran, much was learned about how to organize for a ten week intensive research program, how to ensure each student had a meaningful, positive experience, how to promote camaraderie among participants, and how to streamline participant logistics. In this manuscript and corresponding presentation, a description of the program and its goals will be discussed. This contribution will benefit anyone considering developing an REU program. It will provide guidance on how to structure student projects so that student learning and productivity is maximized. Further, organized professional development activities will be outlined in addition to a summary of structured social activities that build trust, teamwork, and camaraderie. Qualitative evaluation of activities is included so that others can improve upon the techniques used at Mississippi State University.

Keywords: Research Experience for Undergraduates, Research Program, Professional Development, Projects.

INTRODUCTION & BACKGROUND

The National Science Foundation (NSF) has an ongoing effort known as a Research Experiences for Undergraduates (REU) program [1]. The goal of this program is to support active research participation by undergraduate students with the long-term goal of encouraging more students to pursue advanced degrees and to increase participation of groups traditionally underrepresented in science and engineering. One key attribute of such a program is that the REU projects must involve students in meaningful ways – i.e. the undergraduates may not be simply lab technicians. It is viewed favorably if the REU Sites include professional development training including ethics. Also, involving participants from diverse schools across the country (especially those from primarily undergraduate institutions) as well as inclusion of an international component is also viewed as favorable because it broadens REU Participant perspectives and increases the breadth of their training. The research theme of REU Sites is open to any research area that NSF currently funds. Of course, themed sites with an interdisciplinary or multi-department research component are good.

Purpose and Goal of REU Programs

REU site programs may run during the school year, but the most common form is a summer internship. A ten-week summer experience that enables an undergraduate student to emerge himself or herself in research can be a life-changing experience. For the students, it really is a no-risk chance to see if they love research. The students are paid a stipend along with other support which may include housing, food, trips, and miscellaneous. Students are typically paired with a faculty advisor and possibly a graduate student mentor. These mentors help guide the undergraduate student through their first independent research experience. Exit evaluations and discussions with participants often indicate that they are surprised when their projects do not work perfectly in line with the objectives they were assigned at the beginning of the summer (unlike the "cookbook" undergraduate lab classes they may have previously experienced). A previous REU participant summarized this feeling in his / her exit evaluation

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as, “It's called re-search - things fail, and you are supposed to try again. Otherwise it would just be called search.” The purpose of REU programs is to provide a meaningful, hands-on experience that hopefully excites students into pursuing advanced degrees in their field.

Attributes & Outcomes of “The Bonds Between Us” Program

The Bonds Between Us Program strove to combine the research strengths of the chemistry and chemical engineering disciplines in a synergistic relationship [2]. Participants gained experience, techniques, and perspectives in the chemical sciences that illustrated how chemists and chemical engineers approach similar research challenges from different perspectives. Research themes featured were Biotechnology & Bioanalytical Applications, Nanomaterials & Structural Studies, Integrated Environmental Research, and Synthesis & Separation Processes. Participants benefited from close mentoring relationships with graduate students and faculty. Professional development and research skills training was interspersed with laboratory research, site visits of chemical plants and national research labs, social activities, interactive workshops in diversity and research ethics, and an end-summer symposium. At the conclusion of the summer, they presented at a campus-wide symposium with the option of submitting an abstract to present at regional meetings, such as those of the American Chemical Society (ACS) and the American Institute of Chemical Engineers (AIChE).

The program was designed with the following attributes and outcomes in mind:

- State-of-the-art research experiences that motivate students to pursue graduate degrees in chemistry, chemical engineering, or related field.
    - Broad participation of underrepresented groups in chemistry & chemical engineering
    - Increased appreciation and understanding of complementary discipline
- Sense of community among REU students, faculty, and graduate student mentors
- Strengthened/increased collaboration between chemistry and chemical engineering disciplines
- Enhanced educational and mentoring experience for graduate students

Each component of the program is discussed in detail in the following sections. Evaluations and assessment is visited in its own section followed by comprehensive conclusions regarding “Chemistry / Chemical Engineering: The Bonds Between Us” summer research program which ran during the summers of 2005, 2006, and 2007.

ORGANIZING & RUNNING A 10-WEEK RESEARCH PROGRAM

Organizing for a 10-week research program is quite involved. It usually needs to start in December of the previous year in order to get webpage updated and advertising materials designed and printed. We found it was important to advertise and proactively circulate your materials throughout the early spring up to the application deadline. Once applications were received, the logistics of fairly reviewing upwards of 100 applications was difficult, but the development of a rubric and a selection committee helps this greatly. Once invitations are extended to participants and accepted, logistics and communication with those participants is a time consuming area with potential for streamlining. This section also discusses student selection of projects and providing program closure. However, the specifics of enabling a meaningful research experience are discussed in the next major section.

Website

The development of an informative, well-organized website is extremely important. NSF has a directory linking to all active REU sites and it is important to make sure your website is updated with them [3]. Many students shop for REUs via NSF’s directory and their impression of the program can be based entirely on what they see online. Important information to include is descriptions of potential projects, logistic information including stipends, housing, and activities. Links to departments, the university, campus activities, and community activities can also be useful. Lastly, the development of an online application is extremely useful for encouraging numerous applications from a diverse set of students as well as minimizing the extraneous paperwork that can potentially engulf a director of an REU program.

Advertising

The value of professional looking advertising materials cannot be underestimated. Included is a copy of the ledger-sized flyer with tear off info cards that we used in 2007 (figure 1). These were sent to every chemistry department in community colleges and universities in Mississippi, Louisiana, Tennessee, and Alabama. Further, these flyers were sent to every chemical engineering department across the country and to personal contacts of the PIs. An arrangement with University of Puerto Rico, Mayaguez yielded significant visibility on their campus and numerous applications.

Advertising via email and the web is particularly valuable. Inclusion in NSFs directory as well as on Mike Cutlip's listing of undergraduate research opportunities for chemical engineers is beneficial [3,4]. Emails to personal contacts yield a large number of high quality applications. These contacts tend to personally recommend to the student the REU program and further, the quality of student referred to The Bonds was good or excellent.

Fielding & Reviewing Applications

Fully electronic submission of application materials can help with organization. For example, The Bonds website compiled all data into a database [2]. It was easy to pull information from this database into Excel and to compile applications. The students were asked to provide background info on their school, major, and GPA into a fill-able online form. Next, they were asked to write a personal statement, provide contact information for two recommenders, and then to postal mail an official transcript. The website automatically generated the request to the recommenders to submit their recommendations online. Reminders for late recommendations had to be generated manually – an area for improvement. The website stored all information together according to the student's name.

Support staff helped with compiling all information into a single file, which was circulated around a committee of three Chemistry or Chemical Engineering professors and one support staffer. In order to evaluate applications from so many qualified and talented undergraduate students, a quantifiable rubric was developed. It is shown in figure 2 and included three main sections: assessment of personal statement, coursework & GPA, and assessment of recommendations. Students whose package inspired any committee member due to enthusiasm, special situation, etc. were flagged and re-examined in a meeting. Offers were made paying careful attention that the offers made reflected the demographics (women, minority, disability, regional) of the applicant pool. If an offer was declined, an additional offer was made to an alternate candidate. Further, due to the large applicant pool, it was widely advertised across campus that anyone could sponsor an additional student off of their own independent projects. An expense summary was circulated where the faculty member would cover stipend, tuition, travel, and housing, and the REU program (via returned overhead) would cover programmatic expenses for the student. This strategy yielded an additional 11 students

Chemistry: Chemical Engineering – The Bonds Between Us

A National Science Foundation sponsored Research Experiences for Undergraduates Site

2007 REU Applicant Evaluation Criteria

First Name:_____ Last Name:_____

Disqualifiers

Graduating Senior:_____ Not a U.S. Citizen:_____

Personal Statement (40 points / 10 points each) **Total:**

Quality of writing:_____

Enthusiasm:_____

Research / Educational Experiences:_____

Career goals:_____
(10 for graduate degree, 0 for M.D.)

From primarily UG Institution / Minority Serving Institution (+10):_____

Coursework Completed (30 points / 10 points each) **Total:**

For the following: A=10 pts, B= 8 pts, C = 6 pts, D = 4 pts
Completed Organic Chemistry (CH) :_____
Completed Mass & Energy Balances (ChE):_____
Completed Laboratory Course (CH / ChE):_____

Overall GPA:_____
> 3.75 = 10 pts
3.5 to 3.75 = 8 points
3.25 to 3.5 = 6 points
3.0 to 3.25 = 4 points
2.75 to 3.0 = 2 points
< 2.75 = 0 points

References (30 points / 15 points each) **Total:**

Reference #1
Comments on work ethic, responsibility, laboratory skills (7points):_____
Overall strength of recommendation (8 points):_____

Reference #2:
Comments on work ethic, responsibility, laboratory skills (7points):_____
Overall strength of recommendation (8 points):_____

Overall Total:_____

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for 2007 (9 NSF sponsored and 11 independently sponsored students).

Logistics & Planning

Coordination of program schedule, research course, trips to industrial plant and national lab, welcoming and closing activities, social events, and other required careful communication and planning. Communication with the student participants was important throughout the spring leading up to the start of the program. Many are packing for an entire summer and so information on clothing worn in labs, temperatures in Mississippi, and the nature of activities was important to include. Faculty needed to plan for lab supplies as well as to coordinate with their students and so it was important to circulate a calendar of events to them well in advance. Coordinating professional development workshops, and student development activities with the instructor of the research course was also important. It was also important to invite and coordinate administrator's keynote addresses at key events such as the welcoming receptions and closing symposia.

The student participants were assigned office space together in a central room between the two lab buildings. This helped facilitate communication beyond emails once the students began working on their independent projects. In 2007, the students developed their own group on Facebook and communicating activities through that venue proved to be very effective. The key lesson learned in this category is that one cannot communicate with the various individuals involved in such a program too frequently.

Student Selection of Projects

Participants need the opportunity to work on a project that really excites them. However, pairing participants with faculty mentors and projects can be difficult. There is a significant advantage to have the Participants paired to a project before they arrive on campus; faculty can order supplies well in advance and participants can be given advanced reading material. However, this strategy does not work as well for first time undergraduate research participants (a key population an REU program targets). This is because participants are usually asked to make a selection based on a paragraph or two description of the project. For someone who has never set foot in a research lab, an abstract reads very differently than it does for an experienced researcher. For this reason, The Bonds developed a guided tour of all of the research labs offering projects and free time for the participants to visit with faculty and graduate student mentors about the project. This occurred on the second day of the program and students were asked to submit their first, second, and third choice for a project by the end of the day. The program director then matched as many first choice participant selections as possible. Approximately 80% of students were paired with their first choice with the remaining getting their second choice. While some of the students were unsure of this on day 1, by day 3, they were very happy and excited to get into the lab and start their projects. Exit evaluations indicated high student satisfaction with their projects, mentors, and overall research experience (please see [5]).

Closure

At the end of the program, the students need closure on their experience. The Bonds accomplished this with a closing poster symposia (progress presentations were done about week 6 of the program) and an awards banquet. This has been typically conducted in coordination with the other NSF REU programs on campus. The participants designed 3 foot by 4 foot posters describing their research problem, their experiments, results, analysis, and conclusions. The poster symposium was particularly successful because it entailed active involvement of all participants at all times. Faculty and administrators from across campus could come and talk with the participants in depth about their project. The participants also experienced and learned both major forms of professional presentation skills with this approach. Friends and family who had come for the closing banquet also attended and frequently commented on how professional their child / friend looked with their poster.

The closing banquet was also conducted in coordination with other REU programs and is a chance for the participants to say farewell to each other and their mentors. Certificates of completion are awarded to all participants along with a parting REU Bonds mug as a souvenir. A keynote address by the associate provost on considering a career in graduate school was included in 2007. As with most graduations, the mentors take as much from this as do the students. However, this banquet is also a time for the students to lead a fun farewell to each other, so consider allowing the students to run portions of the program.

ENABLING MEANINGFUL RESEARCH EXPERIENCES

The primary goal of a summer research experience is to offer an informative, positive immersion in research so that participants can make an informed decision as to whether they would like to pursue an advanced degree in chemistry or chemical engineering or pursue a career in research. Therefore, it is necessary to have well-defined projects that enable successively more independence as the participant's competency grows. It is important that the project enable true research and that the participant does not simply act as a lab technician for a graduate student's project.

Structure of Projects

An ideal REU project has a solid foundation from the mentor's ongoing research efforts that is within the expertise of any graduate student mentors. The project should have a preliminary literature survey conducted and organized for the student such that the student can build upon this body of literature. Per NSFs requirements, the project needs to contain an independent problem solving component and this necessitates that the student have clear, attainable objectives with immediate access to necessary research tools. The scope should be sufficiently narrow such that controls and dependencies are apparent and thus yield meaningful outcomes.

Providing the student a project description along with descriptive objectives and estimates of the timeline for each objective is particularly useful. At the beginning of the summer, students think they have all the time in the world to complete the project, but by about week 6, they are frantically trying to finish up experiments. By providing smaller objectives and shorter milestones, inexperienced students do much better at managing their time. Structuring training as an apprentice progressing to a journeyman, objectives that include becoming proficient on a piece of equipment or preparing a sample with certain properties are useful.

For example, one project might involve functionalizing a surface with a special polymer. The lab skills to accomplish this task independently must be developed and depending on the complexity of the procedure, it may take a couple of weeks for the student to consistently and reproducibly accomplish this task. Next, the student should be directly responsible for characterization of that surface with only one or two instrumental tools. This is because it requires time and study for a student to learn and understand how a piece of equipment works, the principles behind the measurement technique and the limitations of that as it relates to their sample. One technique that is particularly educational is to develop a detailed experimental plan for the participant on the first instrument, but then ask the student to develop their own experimental plan for the second instrument. Data analysis should be structured as ongoing so that the student doesn't errantly run numerous experiments incorrectly or without producing meaningful results.

Research Outputs

The research objectives are most effective when they are directly tied to research outputs. For a new undergraduate researcher, it can be beneficial to clearly outline exactly what an output looks like. Pulling up a file with data from a similar experiment and showing plots, etc., then asking them to reproduce a similar plot with their data is good. When research is going smoothly, these smaller outputs build together into a cohesive puzzle. During the 2006 and 2007 summer Bonds programs, we had the participants do a 10 to 12 minute oral presentation on their research project and preliminary data at approximately week 6. This enabled the students to pull all the foundation information together on their project, and organize it such that they could explain it to their peers and their mentors in a formal setting. The proficiency of the students in the lab increased after this milestone making its educational impact all the more valuable. Further, the students were able to build from this presentation to do their final posters and final papers. The quality of the final student posters was greater in 2006 and 2007 than in the first year of the REU program. Participants were provided mailing tubes for their posters so that they could take them home.

Presenting at Conferences

NSF strongly encourages programs to facilitate involvement of participants in regional or national student conferences. Since participants were provided their posters, they were encouraged to seek opportunities to present their projects at conferences when opportunities arose. The American Chemical Society helped sponsor students to attend regional conferences to present their research via a fellowship program. Also, some schools co-sponsored American Institute of Chemical Engineers student officers to attend the national conference and The Bonds REU

program supplemented their expenses. ASEE regional conferences are also an excellent place to encourage participants to present because travel and expenses are much reduced. Online Celebration of Undergraduate Research sponsored by NSF's Division of Chemistry REU Leadership Group, partnering with the Colorado State University Libraries has featured student projects from 2005 to 2007 [http://reu.library.colostate.edu/]. REU budgets are extremely tight, so facilitating opportunities for students in this area is always a challenge.

PROFESSIONAL DEVELOPMENT

In addition to the research experience within the laboratory, the participants also received guidance on professional development including formal instruction and mentoring of research skills, hands-on observation of chemistry and chemical engineering in industry as well as at a national research laboratory, and interactive workshops on diversity, ethics, and a panel on attending graduate school.

Advanced Research Skills Course

The program has been scheduled to coincide with the 10 week summer term at Mississippi State University. As an unique and beneficial perk of the program, REU Participants enrolled in a three credit hour course, CH 4613 Advanced Research Skills, which they could transfer to back to their home institution. This course was taught by Dr. Alicia Beatty, an assistant professor in Chemistry with extensive experience mentoring undergraduates in research. Topics covered in this course included: Safety, Research and the laboratory, How to maintain a lab notebook; Literature searches and article applicability to your research; Dissection of a research article; Effective scientific presentations; Preparing an abstract of your research project, and Preparing a scientific poster. At approximately week 6 of the program, all participants were mentored through preparing a 10–12 minute oral PowerPoint presentation of their research. Two afternoons were dedicated to participant presentations for the entire Bonds community (faculty, graduate students, and peers). For the final week of the program, students prepared a 3X4 foot poster on their finished research project. This was presented during the Closing Poster Symposia and the entire Bonds research community and the greater MSU community was invited. The students demonstrated how much they had learned over the summer during these professional discussions with experts in their fields.

Trips to a Local Chemical Plant and to a National Research Facility

In order to add depth to the participants understanding of the impact of chemistry and chemical engineering research within the larger world, on-site visits to a local chemical plant and to a national research laboratory were conducted. Eka Chemicals, Inc. in Columbus, MS sponsored visits for students to learn process chemistry and large-scale equipment function for a sodium chlorate and hydrogen peroxide production facility [6]. The second trip was to the US Army Corps of Engineers' Engineer Research and Development Center (a.k.a. Waterways Experiment Station) in Vicksburg, MS [7]. The tour of ERDC provided a diverse view of the many different areas of research including how numerous disciplines cooperated so closely in research that was directly applicable to current disasters (Katrina) or ecosystem needs (chemically controlling invasive species). During these tours, chemical processing, research, development and analytical facilities were featured. These experiences provided the students an appreciation for the applications of research.

Workshops on Diversity, Ethics, and Graduate School

Three 2 to 3-hour workshops were held during the summer program and were conducted in cooperation with the other REUs on campus. The first workshop was conducted by the REU PI, Dr. Gloria Thomas; it focused on diversity and included an interactive game encouraging thought regarding responses based on categorization of types of people. A Naval Reserve officer and recognized ethics trainer for the National Society of Professional Engineers helped conduct the Ethics Workshop. For the Graduate School workshop, the Dean of the Graduate School conducted the session, which focused on addressing student's questions about applying and successfully attaining an advanced degree. Current graduate students in chemistry, chemical engineering, and other applicable areas (for the coinciding REU programs) were also invited to attend and answer questions in a panel structure. Student assessments were conducted after each workshop in order to provide data for formative improvement of the workshops from year to year [5].

PARTICIPANT CAMARADERIE

The tone of the program is determined early in the program. A climate that supports close participant camaraderie will do more for facilitating a positive experience for students than anything else. This climate is created by how the facilitators cast opening activities in the start of the program. Student groups that form a strong friendship early sustain this throughout the summer and are more likely to encourage each other through any challenges with their research project. Because the participants are also having fun, their capacity for learning is better and their enthusiasm builds throughout the summer.

Planned Social Activities

For The Bonds program, a day was spent experiencing the surrounding community via a guided tour from the local Chamber of Commerce. While this was not mandatory, a majority of the participants moved into their dorm with enough time to go on this tour. The following day was the official start of the program and included a tour of campus and completion of all necessary paperwork for ID cards, dispersal of their first stipend check, and a Meet and Greet Bowling Social. The second day was a formal welcoming ceremony followed by lab tours, one-on-one visits with mentors and project selections. The participants then began their projects with their mentors and at the end of the first week were brought back together for a planned pool party social. In one week, it was amazing how close and tight friends they seemed. REU Participants also participated in the Big Dawg Adventure Challenge Course, a team building exercise run by MSU's Department of Recreational Sports. This team strategy and trust workshop consisting of physically and mentally challenging ropes course requires a combination of teamwork and individual commitment [8]. Additional planned social activities throughout the summer included a Fourth of July picnic, dinners after workshops, and an end of summer pool party.

Unplanned Social Activities

In past years, the participants have self-organized road trips to Memphis, New Orleans, or the Gulf Coast because local participants have wanted to show off their homes and national/international participants have been avid tourists of the southeast region. Also, by including graduate student mentors in first week social activities, the participants tied into the local social community very quickly. They had events planned nearly every day each weekend. Collectively, the social networking among REU participants was a very important component to the tone, enthusiasm and success of The Bonds program.

SUMMARY & CONCLUSIONS

This paper discussed organization and execution of a National Science Foundation Research Experiences for Undergraduates site at Mississippi State University. REU program goals are to support active research participation by undergraduate students with the long-term impact of encouraging more students to pursue advanced degrees and to increase participation of groups traditionally underrepresented in science and engineering. In the time that the "Chemistry / Chemical Engineering: The Bonds Between Us" program ran, much was learned about how to organize for a ten week intensive research program, how to ensure each student had a meaningful, positive experience, how to promote camaraderie among participants, and how to streamline participant logistics. These lessons were summarized in this paper. Further, this contribution discussed the strategies that the Bonds program utilized to accomplish these goals and provided guidance on structuring student projects to maximize student learning and productivity. Organized professional development activities were outlined in addition to a discussion of structured social activities to build trust, teamwork, and camaraderie. A ten-week summer experience can enable an undergraduate student to emerge himself or herself in research can be a life-changing experience. It is an initiation of life-long learning that is unparalleled. By building upon the lessons learned in The Bonds REU, hopefully more programs can grow to encourage student participation in research.

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