AC 2008-2040: INCORPORATING K-12 OUTREACH INTO AN REU PROGRAM FOR FEMALES

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Integrated research, education, and outreach experiences for undergraduates at Worcester Polytechnic Institute

Abstract

Research Experience for Undergraduates (REU) programs, such as those supported by the National Science Foundation (NSF), provide an excellent tool to help recruit and retain females and underrepresented minorities in engineering, which is crucial to our nation’s economic survival. Integrated research, education, and outreach experiences were offered for 8-9 females and underrepresented minorities per year in a Bioengineering REU at Worcester Polytechnic Institute, over a three-year period. The goals of our program were to provide inquiry-based research and training opportunities for female undergraduates, particularly those from underrepresented minority groups, along with the opportunity to participate in an outreach program that benefits the undergraduates as well as middle-school interns. The REU students’ interaction with middle-school students was facilitated by the creation of a two-week (half-day) mentored internship program, called the Bio-Discovery Program. Experience as mentors provides a form of civic engagement that helps the REU students realize their ability to influence the next generation of engineers and scientists. For the middle-school students, participation increases their interest in science and their retention in essential math and science courses that will allow them to pursue engineering as an academic discipline.

A multifaceted evaluation of our program, conducted primarily by an external consultant, included surveys of faculty advisors, open-ended questionnaires for faculty and student participants, focus groups with REU students, and evaluation of final research presentations. Parents of middle-school students were surveyed to assess the effectiveness of the mentoring program. Ongoing assessment includes collecting longitudinal data on sustained interest in research (for example, graduate school application) by the REU alumni, but this data is not yet available. We were able to recruit a diverse group of female students and give them exposure to biomedical engineering research. For 52% of program participants, this was their first research experience of any kind. We had a positive impact on influencing the career path of the REU participants, according to their self-reported plans. The mentoring program has been very successful, as indicated by the number of return attendees and alumni of the Bio-Discovery program, who recommend their younger sisters or friends to the program. According to our assessment data, the Bio-Discovery Program has been the most rewarding part of the program for several of the REU participants, even though it also presented a challenge, as it limits the amount of time REU students can dedicate exclusively to their research projects. With our recommendations for improvement, this program can be adopted by other faculty who wish to incorporate middle-school outreach into an REU program.

Introduction

Motivation for Developing the REU Program

Although more B.S. degrees are awarded to females in U.S. institutions than males when considering all disciplines together, females still account for considerably less than half of the B.S. recipients in engineering. The percentages are lower when considering advanced degrees,
such that only 15.8% of Ph.D. recipients in engineering in 2000 were female. This was an increase from the 9.0% in 1991, but certainly further work is necessary to address this imbalance and the attrition of females from higher education\textsuperscript{1,2}.

Although more than 25% of schoolchildren in this country are of minority populations, the pattern of under representation in pursuing engineering B.S. degrees persists for African Americans, Hispanics, and Native Americans\textsuperscript{3}. The picture is even grimmer when considering degrees beyond the B.S. level with only 5.9% of Ph.D.s being awarded to underrepresented minorities\textsuperscript{1,2}.

We felt that bioengineering would be an avenue through which we could increase the interest and participation of females and minority students in engineering. The very nature of bioengineering research, as well as the inherently interdisciplinary outlook of bioengineers, provides a unique opportunity for a meaningful integration of research activities with hands-on and vivid educational experiences for students at various educational levels. Bioengineering research demonstrates to students how engineers, as much as doctors, can have direct effects on peoples’ lives. It can represent a life-changing opportunity for students to explore problems directly related to the mystery of life, the surprisingly similar features in the biological background of living organisms, and in some aspects, the human condition itself.

As a discipline, bioengineering attracts a more diverse pool of students than has been historically observed in engineering as a whole. The number of females entering engineering disciplines in bioengineering is higher and continues to grow at a faster rate than other engineering disciplines.

Once students are participating in a research opportunity, it is natural for them to want to share their knowledge and enthusiasm with even younger students. We focused the outreach portions of our work on middle-school students because attitudes towards engineering are formed at an early age. For females, the following critical points are noted: 1) girls’ self-esteem begins to decline during the middle-school years, and affects their academic performance and their choice of classes in school; 2) there is a circular relationship between girls’ affection for science, their self-esteem, and their career plans; and 3) without pursuing science and math courses in middle-school, girls will be left behind in high school and unable to pursue college degrees in engineering. Currently, in virtually every science subject (biology, chemistry, computer science, environmental science, and physics), boys achieve higher Advanced Placement scores\textsuperscript{4}.

The goal of the REU program is not to institute curriculum changes at the K-12 level. Our objective is to increase the awareness and interest of students on the nature of the engineering discipline and the opportunities it provides. We will encourage these young individuals to keep taking math and science courses so that engineering will be a possible choice for them in high school, college, and beyond. In addition, the undergraduate students will have an opportunity to make a difference in influencing the educational and career plans of the younger students, which we believe will make them more likely to engage in such types of pipeline and outreach activities in their future careers as professional engineers.
Methods

Nature of REU Activities

Undergraduate students (8-9/year) participated in the REU program for 10 weeks during the summer (Figure 1). Each student was paired with a faculty mentor and given a specific research project to work on, and almost always had a graduate student working with them in the laboratory, although not necessarily working on the same research project. Orientation and training (chemical safety, pathogens safety, waste disposal, computer use, etc.) were provided during the first few days. Seminars were scheduled every week for students to learn about topics including career choices, balancing work and family issues, graduate school applications, funding for graduate school, ethics in bioengineering research, use of statistics, writing, and oral presentations. During a two-week period within the REU program, the undergraduate students became mentors to middle-school girls for the Bio-Discovery Program. Some training was provided on how students learn and how to present material to this age group. This training was provided by numerous individuals, including Prof. DiBiasio, who is an expert in experience-based learning and in engineering pedagogy, and staff members from the Office of Counseling and Development and the Office of Women’s Programs at WPI. The main goals of the training were to provide a frame of reference to allow the undergraduates to think about how they learn, and thus how others may have different learning styles. In addition, we tried to take them back to their own middle-school years so that they could remember some of the insecurities middle-school students might have about their academic performance, especially in science and math. We also wanted them to appreciate how significant an influence they would have on the middle-school students, so they would carefully consider the impact of their actions toward and interactions with the interns.

The undergraduates did all of the planning of the Bio-Discovery activities, mainly during the week before the program. On the last day of the Bio-Discovery program, parents and friends were invited to view the joint poster presentations made by the interns and mentors. The REU students spent the remainder of the summer working on their independent research projects, which concluded with a day of final oral presentations. Some students presented their work at national meetings (e.g., Biomedical Engineering Society; BMES and American Chemical Society; ACS) in the academic year following the REU program.
Sample Project Description

Undergraduate researchers have completed a number of very interesting and successful projects during the three year program. We highlight just one project here to illustrate some of the activities that the students were involved in. Kerrie Holguin was an REU student who worked with Prof. Camesano during summer 2007. Her project was related to the role of cranberry juice and its constituents on the adhesion of the bacterium *Escherichia coli*. A graduate student, Paola Pinzon-Arango, was already working on this topic for her M.S. thesis, and became a mentor to Kerrie for the summer. At this time, Paola knew that cranberry or compounds isolated from cranberries (called proanthocyanidins) affected the attachment of *E. coli* bacteria to uroepithelial cells. We also hypothesized that these compounds would affect the formation of biofilms, but this had not been previously tested. Therefore, the goal of Kerrie’s summer project was to determine how biofilm formation was affected by exposing *E. coli* to different concentrations of either cranberry juice or the isolated proanthocyanidins. The biofilm assay was new for our lab, so Kerrie and Paola had to work together to design an experiment based on their reading of the literature.

The experiments showed that cranberry or proanthocyanidins could inhibit the formation of biofilms of *E. coli* on PVC plates. However, the behavior of the juice vs. the behavior of the isolated proanthocyanidins was not identical. This was somewhat surprising since previous research had indicated that the proanthocyanidins were the sole compounds in cranberry responsible for the anti-adhesive effects on bacteria. The students hypothesized that other compounds in cranberry helped “protect” the proanthocyanidins from degradation, since they are
highly unstable, making them more effective in the juice environment than in isolated form. More experiments would be needed to understand this better, which Paola completed during the school year after Kerrie’s project had ended.

The project was successful because the research task was fairly well defined and could be completed in 10 weeks. Also, the professor, graduate student, and undergraduate student were able to work very well together as a team. The relationship between the graduate and undergraduate student was especially critical to the success of the project. This is something for REU directors to consider when assigning particular undergraduates to research projects, in that a good graduate mentor can make a huge difference in the success of the project. Kerrie will be presenting this work at the American Chemical Society National Meeting in April, 2008. We are working on a joint publication to submit later this year.

Results

REU Participant Recruitment and Acceptance Data

The program has attracted a large pool of highly qualified applicants (more than 100 applicants each year on average, greater than 78% of whom were women) from institutions throughout the United States. Of the 25 students who participated in the program over the past three summers, 100% were women, and 24% were self-identified as underrepresented minority students (Table 1). We observed over the course of the three years that interest and general awareness of REU opportunities is growing due to a number of colleges and universities promoting these programs. Therefore, the numbers of applicants increased every year, even without taking additional measures to market and advertise the program. NSF funding to continue the REU program is pending at this time. However, if our program is funded again, the main difference we will make in recruiting is to take advantage of our institution’s participation in the Louis Stokes Alliances for Minority Participation (LSAMP) program in order to more directly recruit minority student participants.

Table 1. Demographic data of REU students 2005-2007.

<table>
<thead>
<tr>
<th>Program Year</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Students</td>
<td>8</td>
<td>8</td>
<td>9</td>
<td>25</td>
</tr>
<tr>
<td>Women</td>
<td>100% (8/8)</td>
<td>100% (8/8)</td>
<td>100% (9/9)</td>
<td>100% (25/25)</td>
</tr>
<tr>
<td>Underrepresented Minority*</td>
<td>25% (2/8)</td>
<td>12% (1/8)</td>
<td>33% (3/9)</td>
<td>24% (6/25)</td>
</tr>
<tr>
<td>Hispanic</td>
<td>25% (2/8)</td>
<td>12% (1/8)</td>
<td>22% (2/9)</td>
<td></td>
</tr>
<tr>
<td>Pacific Islander</td>
<td>0% (0/8)</td>
<td>0% (0/8)</td>
<td>11% (1/9)</td>
<td></td>
</tr>
<tr>
<td>Native American</td>
<td>0% (0/8)</td>
<td>0% (0/8)</td>
<td>11% (1/9)</td>
<td></td>
</tr>
<tr>
<td>Participants from Outside Host Institution (non-WPI)</td>
<td>87% (7/8)</td>
<td>87% (7/8)</td>
<td>78% (7/9)</td>
<td>84% (21/25)</td>
</tr>
</tbody>
</table>

*Students may have checked more than one box, or may have been of mixed race or ethnicity but only checked one box.

In addition to promoting diversity among the program participants, our goal was to ensure that students who would not otherwise have opportunities to participate in bioengineering research
were selected for this REU program. The majority of the students who participated in the program came from outside of the host institution (84%). These institutions (and the number of undergraduates from that institution) included: Brandeis University (1), Carnegie Mellon University (1), Clemson University (1), Cornell University (1), North Carolina State University (1), Northeastern University (1), Pennsylvania State University (2), Princeton University (1), Rensselaer Polytechnic Institute (2), Rose-Hulman Institute of Technology (1), Smith College (1), SUNY – Stony Brook (1), University of Delaware (1), University of Denver (1), University of Massachusetts – Amherst (1), University of Minnesota (1), University of Nebraska – Lincoln (1), University of Texas – Austin (2), and WPI (4). Italics indicate institutions that have a department of bioengineering or biomedical engineering that offers Ph.D. programs, which was determined by gathering information from the institutions’ academic web sites. Of the 19 institutions, only 58% offer Ph.D. programs specifically in bioengineering or biomedical engineering. Therefore, the Bioengineering REU at WPI allowed many participating students research opportunities that were unlikely to be available at their home institutions.

Furthermore, the opportunity to contribute to academic research may have benefitted most of the REU participants. While some students came from “very high research level” institutions (according to the Carnegie Classification), 36% of participants attended undergraduate schools that were not classified as having very high research activity, and 8% were from schools that do not qualify as Doctoral/Research Institutions.

For more than half of the students in our program, this was their first research experience of any kind (52%). Only 3 participants (12%) had previously been involved in research in biomedical engineering, and all of these students completed the work at their home institution. Two participants had previously participated in NSF REU programs (8%), but neither was in engineering (1 hydrology, 1 neurobiology). Therefore, we satisfied our goal of providing research opportunities to students who previously did not have exposure to biomedical engineering research.

Assessment of the REU Program and Recommendations

The three-year program was evaluated with assistance from an external consulting agency, Peterfreund Associates. The evaluation was used formatively to increase the quality of the program year-to-year, and summatively to assess how well the objectives were met. The summary below incorporates data from 2005-2007.

Technical Content: Most undergraduates felt they understood the technical content of their projects very well; one student said it took her longer as she had just finished her 1st year and only had one semester of chemistry, but felt she understood it well regardless. In the first year of our program, most faculty mentors did not send the undergraduates reading material before the start of the REU program. During the exit interviews that year, many of the students indicated that they did not feel prepared and were somewhat afraid to ask questions at the beginning of the project. Therefore, the faculty mentors were asked to send reading material to students ahead of the REU program in years 2 and 3. This complaint (about feeling unprepared) was almost eliminated after the first year, although one student felt that she was given too many articles to read and was therefore overwhelmed at how to begin. The technical quality of student work has
been high and improved each year of the program. For example, five presentations at national scientific meetings resulted from the student work in years 1 and 2 combined\textsuperscript{5-9}, while in year three, \(7/9\) participants (78\%) presented their work at a national scientific meeting\textsuperscript{10-15}. Overall, one paper was published that includes an REU student as a co-author\textsuperscript{16}, with another submitted\textsuperscript{17}, and several more are in preparation.

**Impact on Career:** The REU program positively impacted the career plans of over half of the students, as the students reported at the end of the program. For example, in 2007, \(3/9\) participants (33\%) reported that they enjoyed the research, which reinforced their desire to continue in research and pursue academic careers. Two participants (22\%) said it was a great experience as it helped them to determine that they might prefer to pursue an industrial career in research. Our program has had a number of young participants (rising sophomores and juniors at the time of their participation), therefore we do not yet have enough longitudinal data to assess if the REU program has changed their long-term career path. Within the next two years, we will re-survey the original participants to determine how many have continued in Ph.D. programs and in research careers.

**Bio-Discovery Program:** The involvement of middle-school students (33 students over the three-year program) within an REU program is the most unique feature of our program. The Bio-Discovery Program can be difficult to integrate with the research part of the program, but it has been an overwhelmingly positive experience for all participants. The middle-school students (which we call “interns” to distinguish them from the undergraduate students), mentors, and parents all reported being pleased with the Bio-Discovery Program, with the parents and middle-school interns having the most positive experience. For the undergraduate mentors, some of them were unprepared to spend the amount of time needed to plan activities for their interns, and some found it difficult to balance the outreach activities with their own research. Most felt that the outreach program adversely impacted the time available to complete their research, although none of the faculty saw this as a drawback. Despite the extra work, several undergraduates felt that the middle-school outreach was the most positive aspect of the entire REU program. When asked what worked especially well, the undergraduates noted that presentations that included props or a hands-on component were most enjoyable (the interns loved seeing fake skin, etc.). Those students who worked in a group of several mentors/interns together felt that the team environment worked well because the students learned from each other, the interns helped each other, and the mentors worked together to design and present activities. This structure seemed to be especially helpful for very introverted interns. The one-to-one setup of the intern and mentor together in the lab worked well for experimental projects that can be simplified for the middle-school student. It was also helpful when the mentor assigned the intern some independent tasks to pursue. Activities that were practiced beforehand were more successful than those completed for the first time with the interns, but time for practice was very limited for the undergraduates due to the work necessary for their research projects. Asking the interns to keep a lab notebook was helpful in getting them to think like a scientist/engineer, and this also gave them something to take home and share with their families. In general, mentors paired with younger students (up to 7\textsuperscript{th} grade) reported a better experience than those paired with students entering 8\textsuperscript{th} or 9\textsuperscript{th} grade. This may be because the older students are at a technically more advanced level, and therefore the mentors need to prepare more in depth and challenging material for this group.
Anecdotally, parents of the interns mentioned that their daughters increased their knowledge and interest in engineering as a result of the program and gained confidence in their ability to perform an experiment. Some parents also reported that their child responded much better to their mentor than to the science curriculum presented by their middle-school teachers. When asked to elaborate, parents explained that the undergraduate student’s enthusiasm for the research and ability to explain the relevance of the work to society (i.e. working to prevent infections or manage heart disease) captured students’ interest in biomedical engineering.

**Recommendations Based on Program Assessment**

For future programs, faculty will be asked to provide a very brief (1 page maximum) abstract of the project listing specific objectives for the REU student, along with a short collection of articles from the literature to send to the students in advance of the program. The opportunity to publish and present will be discussed with the REU participants from the beginning of the program, as this may encourage more students to bring their work to a complete stage.

For others wishing to adopt a similar program, we suggest to restructure the Bio-Discovery Program so that it is less disruptive to the research activities of the REU students and even more rewarding to both the REU and middle-school students. For example, the Bio-Discovery Program may be offered earlier in the REU program (rather than near the end when REU students are concluding their research and preparing final presentations), the preparation time for REU students may be reduced by utilizing successful activities developed during the first three years of the program, and we also plan to partner with other K-12 summer outreach programs at WPI to provide additional mentorship training to REU students. This additional training may include how to respond to conflicts and issues that arise when working with this young population, as well as age-appropriate curricula and activities for middle-school students.

**Overall Conclusions**

An NSF-funded REU program for females and underrepresented minorities was developed and executed for three years. The recruiting of REU participants has been aided by the fact that NSF extensively advertises REU programs and many institutions distribute information on REU programs to their students. In the future, we would like to increase the percentage of students from underrepresented minority groups who participate, potentially by partnering with an existing Louis Stokes Alliance for Minority Participation program at WPI. The execution of the technical components of the research projects has generally been successful, and many students were able to present their work at national meetings. This aspect might be enhanced by a more direct communication between undergraduates and the faculty mentors at the beginning of the program, and by discussing publication and presentation of research results as an explicit incentive for completing their research projects. The middle-school outreach portion presents the greatest opportunity for feeling a sense of accomplishment, but is also the most difficult part to integrate with the research program. In future years, we would consider changing the timing or logistics of the Bio-Discovery Program to make it interfere less with the research projects the undergraduates are trying to complete. We may also limit the program to younger girls (5th – 7th graders), since it may take less time to prepare activities appropriate for that age group, compared to girls entering high school. Also, although some training was provided, some of the
mentors did not feel well prepared to mentor the middle-school students, so we will incorporate additional mentorship training in future programs to prepare REU students for the experience. In summary, we have used an iterative process to develop an innovative model of inquiry-based research and outreach educational experience for females and underrepresented minorities, and provide recommendations to facilitate adoption of this program at a larger scale by other institutions.

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Bibliography