Evaluation of a Research Experiences for Undergraduates Program in ChE INDICATES BENEFIT FROM A COLLABORATIVE MODEL

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Undergraduate research programs in engineering provide a wide range of benefits to participating students, including increases in students' skills and confidence with research and laboratory techniques, improved understanding of the scientific and research process, and clarification and refinement of students' educational goals.[1-4] Research experiences for undergraduates (REU) programs in particular have been shown to provide meaningful and rigorous experiences to students from under-represented groups as well as students who have had little prior experience with research.[3-5]

Benefits of undergraduate research programs extend beyond direct gains during structured research experiences.[6-8] For example, Zydney and colleagues found that undergraduate students who engaged in research were more likely to pursue graduate education than students who had not participated in research. Undergraduate students with research experience also indicated greater development of key research-based skills, including the ability to understand scientific findings, to communicate the results of research effectively, and to understand and analyze research literature accurately.[8,9] Similarly, Lopatto found that participation in research enhances students' overall undergraduate educational experience.[12] Such findings align with research by Seymour and colleagues supporting student gains in areas such as personal or professional skills, clarification and confirmation of career or educational plans, and enhanced preparation for careers or graduate education.[4]

Previous research has also supported the effectiveness of collaborative learning methods in facilitating gains in student learning among students in engineering as well as other areas of STEM.[10-12] Innovative interdisciplinary work is oftentimes most effectively conducted in teams as part of collaborative research and endeavors.[13,14] Many innovative projects, both

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in industry and academia, are initiated by a joint idea that is pursued by two or more groups with different training and expertise. This type of environment perhaps represents the best place for an undergraduate student to learn about the excitement and potential, as well as the challenges, of multidisciplinary research. As such, in the implementation of this REU program, we sought to determine how a collaborative research environment in a structured research experience impacts undergraduate student outcomes.

This paper presents the results of a three-year evaluation of an undergraduate research program in chemical engineering. We first summarize gains and benefits obtained by students participating in the REU program. We then describe the program's emphasis on collaboration among undergraduate students from different universities, including a host and guest model, and discuss implications of this collaborative learning environment for undergraduate research programs.

THE CURRENT STUDY

Chemical engineers are increasingly involved in developing novel materials as well as in working on biological processes.[15] In particular, research by chemical engineers in molecular biology, protein expression and purification, and synthetic biology has increased dramatically in recent years.[15,16] As such, a chemical engineering department is well-suited to host an undergraduate program focused on multidisciplinary research in the areas of biomolecular materials and processes.

The current study presents a 3-year evaluation of an REU program hosted by a chemical engineering department at a large, research-intensive university located in the mid-Atlantic United States. Students completed research projects at the interface of biology and materials, with projects centered on biomimetics, bioinspiration, bioderivation, and biosourcing. The intensive 10-week program occurred during three consecutive summers consistent with the structure of National Science Foundation (NSF)-funded REU programs. The REU had the following primary objectives: to enhance the diversity of students involved in chemical engineering research; to provide broad overview of and preparation for career opportunities; to foster the development of a wide range of analytical skills transferable to laboratory and simulation-based research; to foster the development and enhancement of student collaborative, writing, and presentation skills; and to evaluate the impact of collaboration on student outcomes.[1,2]

Throughout the research experience, students participated in technical activities designed to introduce them to important skills for performing scientific research and to state-of-the-art analytical equipment and techniques that enable cutting-edge research at the interface of materials and biology. The technical program included a variety of workshops focused on topics including oral and written communication, graduate school, and careers in research. Specifically, these workshops included: an ethics in scientific research discussion, a workshop on writing a one-page research summary, a graduate school panel discussion, a presentation on the assertion-evidence approach to scientific presentations, a workshop on materials characterization techniques, and a careers-in-research panel discussion. Workshops occurred, on average, bi-weekly throughout the program and typically lasted from 1 to 2 hours. In addition, social activities provided opportunities for REU participants to interact with participants from other REU programs, faculty, and graduate student mentors outside of the laboratory.

A unique feature of the implementation of the REU program was the pairing of REU participants with undergraduate students from the host institution. The collaborative student teams interacted in the organized technical and social activities as well as in the laboratory. Students who were paired worked jointly on the same research project but assumed individual contributions toward the completion of that research project. For example, two students in year one of the program worked on a project that aimed to examine the response of cells to the nanoscale structure of the cell microenvironment. The team was composed of one undergraduate student from the host institution and one undergraduate student from another institution. One student focused on synthesis and characterization of biomaterials while the other student examined the response of cells to the biomaterials. Through the collaboration, the students were able to learn about both materials and biology aspects of the project.

As a result of the focus on collaboration, a central aim of the evaluation for the program was to determine the impact of this collaboration on the development of students' research skills and perceptions of the research process.[1] Implications for incorporating collaborative elements into undergraduate students' research experiences based on these findings are discussed.

METHOD

Participants

A total of 64 students participated in the REU across the three years of the program. During each year of the REU program, the proportion of participating students who were female or from underrepresented groups well exceeded the proportion of such students at the bachelor's degree level in engineering overall.[17] Students were primarily first-year, second-year, and third-year students (93%) and chemical engineering majors (83%). Of the students, 30 participated from outside institutions and were funded by the NSF through the REU program.

Assessment methodology and measures

A mixed methods approach to the evaluation of student learning gains in the REU program was undertaken. This approach utilized quantitative analyses based on pre- and post-survey measures of students' research experience and skills, openness to collaboration during research, and likelihood of

TABLE 1
Assessment Measures, Mechanisms, and Procedures

Measure	Outcomes Measured	Time of Administration	Procedures
Pre-survey	Initial experience with research-based skills and procedures	Week 1	Administered via online survey software
Student interviews	Motivations for REU participation; Description of REU experiences; Description of research mentor experiences; Description of student pairing experiences; Impact of REU program;Suggestions for REU program improvement	Week 8	Administered in person
Post-survey	Experience with research-based skills and procedures; Career and graduate school plans; Openness to research collaboration; Ratings of REU experiences; Satisfaction with REU	Week 10	Administered via online survey software

TABLE 2
Description of Pre- and Post-Survey Measures

Measure	Number of Items	Scale Type	Scale Anchors/Response Type
URSSA	37	6-Point Likert	Not at all confident – Very confident
EWRAS	4	5-Point Likert	Not experienced – Very experienced
Openness to collaborating	1	5-Point Likert	Not open – Very open
Likelihood of grad school	1	5-Point Likert	Very unlikely –Very likely

pursuing graduate education (see Appendix, <https://sites.google.com/view/djakefollmer/reu-materials>). It further leveraged in-depth interviews of students for qualitative analysis of participants' experiences in the REU program. Assessment measures, mechanisms, and procedures used in the evaluation of the REU are summarized in Table 1.

Table 2 describes the measures administered in the pre- and post-surveys. Two measures of research-based experience and skills were administered: the Experiences with Research Activities Scale (EWRAS) and the Undergraduate Research Student Self-Assessment (URSSA). The EWRAS, developed by the authors, was administered as a brief measure of broad experience with research and was designed for the evaluation of this REU program.[1,2] The URSSA is an NSF-funded survey instrument designed to measure student learning gains from research experiences.[18] Evidence supporting the validity of score interpretations based on the measures as well as the reliability of scores has been obtained and supported in previous studies.[1-2, 18-19]

In addition to these measures, the post-survey also included ratings of key REU program elements and satisfaction with the program as well as items measuring the completion of the following research-based activities: presenting a talk or poster to other students or faculty, presenting a talk or poster at a professional research conference, and writing or co-writing a paper to be published in an academic or undergraduate research journal. Implied consent was obtained prior to administration of the pre- and post-surveys; informed consent was obtained prior to each interview.

Student interviews were also conducted to provide an in-depth assessment of specific elements of the REU program. Interviews were conducted with all participating students across the three years of the REU program by the first author and lasted approximately 30 minutes. Interviews were coded utilizing a general inductive qualitative approach based on the derivation of coding themes created from analysis of student interviews during year one of the program.[1,20,21] Codes were refined in an iterative process in subsequent years of the program as additional quotes and examples of the codes emerged. Interviews were analyzed using NVivo 10.[20] Qualitative analysis of student interviews yielded themes based on: students' motivations for participating in the program; students' experiences with research mentors; students' perceived gains from participation in the program; students' beliefs about the impact of the REU program on their career- and education-related goals; students' appraisal of the effectiveness of the workshops and technical activities; and students' suggestions for improvement to the program.

RESULTS

Survey analyses

Descriptive statistics for pre- and post-survey measures across all three years of the program are reported in Table 3, next page. Scores on the measures of research experience demonstrated adequate reliability (α=0.80-0.95) as evidenced by Cronbach's alpha values equal to or higher than 0.80 for both pre- and post-survey administrations. Analyses were conducted to examine whether scores on the survey measures differed based on gender or underrepresented

minority status. Multivariate analysis of variance (MANOVA) indicated that scores on the EWRAS and URSSA did not differ significantly based on student gender, λ=0.99, F(2, 41)=0.05, p>.05, ηp^2=0.01, or underrepresented minority status, λ=0.99, F(2, 41)=0.20, p>.05, ηp^2=0.01, suggesting that student gains made during the REU program were similar across sample subgroups. Scores on the post-survey administrations of the EWRAS and URSSA were moderately correlated with each other, r=0.40, p<.01, indicating a significant relationship between students' broad and specific research skill development at program completion.

TABLE 3
Descriptive Statistics for Pre-Survey and Post-Survey Measures

Measure	Mean	Median	Standard Deviation	Range	Minimum-Maximum
Pre-Survey					
URSSA	163.22	161.00	23.99	113.00	105.00-218.00
EWRAS	11.29	12.00	4.21	15.00	4.00-19.00
Openness to collaborating	4.46	5.00	0.61	3.00	2.00-5.00
Likelihood of grad school	3.79	4.00	0.99	4.00	1.00-5.00
Post-Survey					
URSSA	177.08	177.50	23.54	100.00	121.00-221.00
EWRAS	16.21	16.00	2.59	10.00	10.00-20.00
Openness to collaborating	4.46	5.00	0.65	2.00	3.00-5.00
Likelihood of grad school	3.81	4.00	0.96	4.00	1.00-5.00

Note. URSSA=Undergraduate Research Student Self-Assessment; EWRAS=Experiences with Research Activities Scale. Minimum-Maximum=minimum and maximum scores obtained for each of the measures. α=Reliability coefficient as estimated by Cronbach's alpha. N/C=Not calculable because there was one score per measure.

Students' scores on the EWRAS and URSSA were then entered into repeated measures analyses of variance (RM ANOVAs) to evaluate gains in students' research-based experiences and skills. The analysis supported significant increases in students' reported research experience as measured by the EWRAS, F(1, 45)=43.14, p<.001, ηp^2=0.49. Paired responses indicated that students' mean EWRAS scores increased from 11.67 (SD=4.00) to 16.13(SD=2.59). The analysis also indicated significant increases in students' reported research-based skills as measured by the URSSA, F(1, 45)=11.43, p<.01, ηp^2=0.20. Students' mean URSSA scores increased from 162.47 (SD=21.82) to 176.30 (SD=23.33), suggesting that students' reported research experience increased significantly from pre- to post-survey.

TABLE 4
Ratings of REU Program Elements

Rating	Mean	Mode	Standard Deviation
Relationship with mentor	3.23	3.00	0.84
Relationship with research group	3.45	4.00	0.78
Time spent doing research	2.96	3.00	0.86
Time spent with mentor	2.72	3.00	1.04
Advice given by mentor	2.98	3.00	1.09
Research experience overall	3.17	3.00	0.73

Student ratings of key REU program elements are presented in Table 4. Positive ratings (*i.e.*, values that exceeded 3.00) were obtained for the following areas: working relationship with research mentors, working relationship with research group members, and the research experience overall. In addition, students reported being satisfied overall with the REU program (M=4.34, Mo=4.00, SD=0.56). Somewhat lower ratings (*i.e.*, values lower than 3.00) were obtained for the item measuring the amount of time spent with their research mentors.

Students also indicated engagement in key research activities. Approximately 75% of students anticipated presenting a talk or poster to other faculty or students, while approximately 27% anticipated presentation of a talk or poster at a professional research conference. A total of 42% of participating students indicated plans for co-writing a paper to be published in either an academic or undergraduate research journal; of these, 33% indicated plans specifically to co-write a paper to be published in an academic journal. Finally, approximately 52% of students indicated plans of pursuing some level of graduate education. Remaining students indicated either planned pursuance of a career in industry or that they were uncertain of their plans post-graduation.

Student interviews

Although other questions were explored in the interview data, because the primary foci of the study were to examine the impact of student collaboration on gains in research skills and the effectiveness of the workshops and technical activities, the summary here focuses on these REU elements. Across the interviews, students who were paired in collaboration during the REU indicated substantial benefit of working collaboratively while engaging in research, as indicated in the following quote: "It's been positive. I think it's always good

to get more minds on the same problems and get some different insights. [...] And then, you know, learning some new things with her as well. So it's been good to have, like I said, another person, a different perspective."

In addition, undergraduate students from outside institutions who collaborated with students from the host institution during the research program perceived a benefit in acclimating to the university and the research setting. For example, one student commented "…he's helped me out a lot as far as where things are like laboratories, offices, buildings, how to get, where to get." Other students described the benefit of working in pairs as an enhancement of the overall research experience: "I'd say it's definitely enhanced it. Just working with someone who has a different background because he's been learning different things; he came in with a different background. But we've been able to communicate effectively, learn to an extent what each other is doing. I think it's been useful." Overall, benefits of student pairing indicated by the interviews included an improved ability to acclimate to the research and university setting, the ability to utilize fellow undergraduate students as a resource during project completion, an overall enhancement of the research experience, and the ability to draw on diverse backgrounds and experiences when completing research project requirements and navigating time- and work-management-related issues.

Students indicated similar benefit of the workshops and technical activities. For example, one student commented in reference to the workshops as a whole that "...those were definitely helpful. I mean, just in general they did well in providing us with different activities that we could go to, to get different aspects of the program." Other students suggested benefits of specific workshops: "I definitely learned a lot, specifically with the—we had a seminar [about] scientific presentations and how to make those, and how you can go beyond just PowerPoint. I think that was by far the most beneficial for me...." Student interviews overall supported the importance and effectiveness of these workshops in providing opportunities for exposure to and training on diverse and relevant topics.

Longitudinal assessment of the REU: preliminary findings

To assess the long-term effects of the REU program, we employed longitudinal assessment of students' reported research experience and engagement in research activities at 6-month, 1-year, and 2-year follow-up intervals. Longitudinal assessment of the program is ongoing; thus far, data based on follow-up assessment of years 1 and 2 of the program have been collected. Participants were administered the Undergraduate Research Student Self-Assessment (URSSA) and six items assessing engagement in research activities (see Appendix <https://sites.google.com/view/djakefollmer/reu-materials>). The administration of these items thus allowed for the assessment of research-based skill development and engagement in research activities over time.

Overall, students completing the 6-month follow-up post-survey demonstrated higher confidence with research-based skills and activities as measured by the URSSA compared with the initial post-survey assessment. The mean URSSA composite score for the follow-up post-survey at 6 months was 189.00, whereas the mean obtained on the immediate post-survey at REU program completion was 171.21. In general, REU participants indicated attendance at research conferences as well as involvement with presenting research, either to other faculty or students or at research conferences.

Students completing the 1-year follow-up post-survey also demonstrated higher confidence with research- or scientific-based skills and activities as measured by the EWRAS and URSSA. The mean URSSA composite score for the 1-year, follow-up post-survey was 179.88, reflecting a higher obtained score than at initial post-survey assessment of the program. Findings from the longitudinal assessment have thus far indicated stability of reported research experience relative to post-survey assessments and have also demonstrated that the gains over pre-survey assessments of students' research experience are maintained into the future.

Out of 23 program participants (from both the host institution and other institutions) that have received their undergraduate degrees to date, 12 participants are pursing graduate degrees at top institutions, while 11 participants are pursuing a career in industry. Companies where students have found employment represent diverse sectors of industry including advanced materials, biotechnology, and consulting. Several students have won national awards and student participants have also contributed to a number of conference presentations and publications.

DISCUSSION

The cumulative evaluation of the 3-year project was generally quite positive. The data overall support that students have greater perceptions of their research skills as a result of participating in the program. Furthermore, students rated a number of key REU program elements positively—including their working relationship with research mentors, working relationship with research group members, and the research experience overall—and indicated engagement in a number of research activities.

Surveys and in-depth interviews revealed that REU participants would like more mentorship and time with their research mentors. To address this need, a future goal of the program will be to incorporate graduate students as research mentors in the REU program. To this end, we will provide training opportunities for graduate student mentors at the outset of the program that aim to foster mentoring skills and equip graduate student mentors with the ability to effectively guide student research. This aim intends to maximize undergraduate

students' time spent with research mentors while providing graduate students with the opportunity for training in effective mentoring—an opportunity not often available during the course of graduate students' training. Additional structured social activities will also be included to build student-mentor relationships.

The pairing of visiting students with local students from the host institution also was found to have multiple benefits. Students who were paired on collaborative projects during the REU indicated benefit in acclimating to the university and the research setting, facilitating problem solving and idea generation during research, and enhancing the overall research experience during the program. In addition, in post-surveys undergraduate students rated themselves as very open to collaboration with other students, providing further support for the benefit of collaboration amongst undergraduate students in research settings. As such, it may be valuable to include a collaborative research component within undergraduate research experiences at other institutions as a means of fostering student integration into the research group and program and enhancing student gains in research-based skills. Collaborative research experiences also have the potential to provide students with important teamwork-related skills, including communication and conflict management, that are becoming increasingly important for success in multidisciplinary workplaces. Given the success of this aspect of the REU, we will continue this practice and work with other REUs on campus to explore the possibility of implementing such a model on a larger scale. In future research a more detailed quantitative evaluation will be conducted on the effect of different collaboration models within structured undergraduate research programs.

One of the limitations of the evaluation is the primary emphasis on student perception data, focusing on student interviews and surveys. A direct measure of student learning through the research experience would likely provide interesting insights. However, the development of such an instrument that would be appropriate for all students, regardless of specific project assignments, would be extremely challenging. One additional challenge that may be encountered for long-term longitudinal surveys (out to 2 years post-completion of the REU program) is low student response rate after the students leave the program. Efforts will be made to maintain communication and interactions with students' post-completion of the program to encourage completion of longitudinal surveys. Through these surveys, future assessments will aim to provide a continued examination of students' outcomes and more in-depth information regarding the long-term impacts of collaboration within a structured undergraduate research program.

ACKNOWLEDGMENTS

This work was supported by a grant from the NSF (EEC-1359365).

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