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Preliminary Evaluation of a Research Experience for Undergraduates (REU) Program: A Methodology for Examining Student Outcomes

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Abstract

The current study presented an initial evaluation, following Year 1, of a National Science Foundation (NSF) sponsored Research Experience for Undergraduates (REU) program in chemical engineering conducted at a large Mid-Atlantic research university. A methodology for evaluating student outcomes from undergraduate research experiences was also proposed. Evaluation of the REU program relied upon an extensive assessment methodology, utilizing pre- and post-survey measures of research and scientific-based experiences and skills as well as in-depth student and faculty mentor interviews of REU experiences, gains, and perceived benefits. Participants (n = 21; 25% female; 42% underrepresented minority status) evidenced significant gains in broad research experience and specific research-based skills and experiences after completing the REU program. Specific production metrics, ratings of research experiences, as well as initial graduate school plans and outcomes, were also obtained. Results indicated involvement in presentations and publications as well as moderate to high ratings of core REU experiences.

A key finding from the study is the clarifying role the REU program played in facilitating students' graduate school plans; results support REU programs as a refining experience rather than a prompting experience for graduate school outcomes. Qualitative analysis of student interview data revealed a perceived significant benefit of working collaboratively with other students while engaged in the research experience and an increased and improved understanding of the nature of research. Qualitative analysis of faculty mentor interview data corroborated the perceived benefits of student pairing and research collaboration, and also noted the ability of student pairing to facilitate student work and time management. Despite high ratings of core REU program elements, students expressed a desire for more time working with and under the advisement of faculty mentors. Across students and faculty mentors, suggestion was made for the inclusion of additional social and related events and programs to further facilitate research collaboration and integration during the program. Limitations, recommendations for improvement of the REU program and for future evaluation of the REU, and implications for institutions interested in implementing REU programs are discussed.

Background

Intensive programs providing experiences for undergraduate students to engage in research have demonstrated a number of benefits, including increases in students' research-based experience, facility in conducting individual research projects, ability to collaborate effectively in research-based settings, and ability to communicate and present research and research-based findings [1, 3, 8]. Programs emphasizing research experiences for undergraduate students have a rich history, with funded research experience for undergraduate (REU) programs arising more than twenty-five years ago [1]. A goal of such programs is to retain and strengthen the presence of students engaged

in science, technology, engineering, and mathematics (STEM) fields as well as to increase the number of students engaged in such research from underrepresented groups [1, 2]. Beyond these goals, REU programs aim to serve the more fundamental function of facilitating the development of research and research-based skills among undergraduate students [6, 11].

The primary goal of the current study was to examine student outcomes from a National Science Foundation (NSF) sponsored REU program focused on the integration of biology and materials in chemical engineering. A distinguishing feature of the REU program centered on the use of student pairing as a mechanism for fostering research collaboration and integration into the research community at the REU site. Selected NSF-funded REU students were paired with undergraduate students selected for participation at the Penn State for the duration of the REU program. As a result, another goal of the current study was to examine the impact of the pairing and collaboration on student outcomes. Secondary to these goals, the current study aimed to provide a comprehensive and empirically sound methodology for examining student outcomes stemming from REU experiences. Related to this goal, the evaluation of the REU program utilized pre- and post-surveys as well as both student and faculty interviews. Taken together, the emphasis placed on student pairing as well as the collection of qualitative data from faculty mentors, complementing data obtained from student participant interviews, served as novel features of the overarching assessment methodology.

In an extensive review of the literature, Seymour and colleagues reviewed published studies and conference proceedings examining the impact of undergraduate research experiences on student outcomes [4]. Based on their review, they clustered the most commonly indicated benefits to students of such programs. These included: increased interest in specific areas of research and study among participating students; increased recruitment of underrepresented groups in research-based experiences; gains in research and research-based skills; clarification, refinement, and confirmation of educational- and/or career-related goals; increases in the understanding of the research process; and increases in both self-confidence of ability and self-esteem [4]. Seymour and colleagues also delineated a typology among the fifty-four articles reviewed, noting that, while many evaluations of undergraduate research programs made stated claims of benefits, relatively few stated benefits that were both hypothesized and well supported by their evaluation methodology [4]. For example, many studies did not adequately describe evaluation methods utilized on which the stated claims were based. Other studies described increases in areas such as critical thinking; however the descriptions of such constructs, the authors assert, were often vague [4].

In their own research, Seymour and colleagues conducted interviews of students participating in undergraduate research experiences, drawing, in part, on their review of the possible benefits derived from the literature. Student responses to the research experiences were largely positive; 91% of students indicated that they experienced gains from completing the research experience [4]. They also identified a number of benefits to students, including personal and professional gains, gains in communications skills, gains in various research skills (e.g., laboratory/field skills, work organization skills, etc.), clarification or confirmation of educational and career plans and goals, and improved career or graduate school preparation [4]. These identified benefits aligned largely with those identified in their review of the literature.

In another evaluation of undergraduate research experiences, Zydney and colleagues examined the impact of undergraduate student research by way of a comparison group with undergraduate students who had not participated in a research experience during their college tenures [11]. Students who participated in research described the experience as very important to their undergraduate educational experiences; students engaged in research experiences for longer periods of time also indicated a greater perceived benefit of engaging in research than students who engaged in such research for shorter periods of time. In addition to these findings, students who engaged in research were more likely to pursue graduate education than students who had not engaged in a research experience during their undergraduate careers [11]. Undergraduate students with research experience also indicated greater development of key research-based skills, including the ability to understand scientific findings, communicate the results of research effectively, and understand and analyze research literature accurately [7, 11].

In an evaluation of an electrical engineering REU, Bielefeldt examined student gains in personal, knowledge, and research-based skill areas. Student knowledge and skills, mapped onto the Accreditation Board for Engineering and Technology (ABET) learning outcomes, showed significant improvement and gain in several areas, including knowledge of research and graduate student funding, knowledge of experimental design, and knowledge of research methods [1]. The greatest gains in skill development occurred generally among those students who had little prior experience with research. As Bielefeldt indicates, REU programs may be well-placed to target and recruit such students. A significant gain in the likelihood of pursuing a master's degree was also noted for students completing the REU [1].

In a survey of undergraduate students who engaged in a summer research experience, Lopatto found that students participating in such research experiences reported gains in several areas, including those related to an understanding of the research process, scientific problems, and laboratory techniques [4]. Participation in a research experience was found to enhance students' overall undergraduate educational experience. The majority of students participating in the research experience reported plans for pursuing graduate study; those students who did not report postgraduate plans reported significantly fewer gains in research-based skill development [4]. It is important to note, however, that most students reporting postgraduate plans *continued to plan* for graduate education after completing the REU experience. Thus, establishing a causal link between participation in such research experiences and later pursuance of graduate school is difficult to evidence. Seymour and colleagues summarize this point succinctly as follows, "…both in the literature, and in this study, it is important to distinguish between claims that undergraduate experiences can prompt undergraduates to *choose* a graduate school career path, and more qualified claims that the experience can *clarify*, *refine*, and *reinforce* such a choice" (p. 522) [7].

Evaluations of the impact of undergraduate research experiences have extended to the examination of faculty perspectives of the relative benefits of undergraduate research [5, 10]. In a study examining faculty perceptions regarding undergraduate research experiences, faculty identified engagement in undergraduate research as having significant educational benefits to students [10]. Those faculty mentors who supervised undergraduate research for longer periods of time perceived a greater improvement in research-based skills, findings that are consistent with those obtained from research examining the benefits of research experiences among

undergraduate students [10, 11]. Benefits were also indicated for graduate students who worked with undergraduate students engaged in research in terms of development of mentoring and teaching experience [11].

Based on the review of the literature, an additional goal of the paper was to delineate an empirically sound methodology for examining and evaluating student outcomes of undergraduate research-based experiences. Outcomes of interest centered on: broad experiential development with research and research activities; specific research-based skill and experiential development; graduate school and career plans and outcomes; production metrics including publications and conference presentations; openness to collaborating with students and faculty in research after completion of the REU experience; impact of student pairings on research collaboration; and overall ratings of and satisfaction with REU experiences. Student outcomes were evaluated using an extensive assessment methodology, including quantitative and qualitative measures, that utilized pre- and post-surveys of student participants, interviews of student participants, and interviews of faculty mentors.

Based on the outcomes of interest and the evaluation methodology employed, the following research questions guided the current study: 1) what gains in broad experience with research will be evidenced as a result of participation in the REU?; 2) what gains in specific research-based skills and experiences (e.g., laboratory and measurement procedures, understanding of research methodology and processes, communication of research and scientific results, etc.) will be evidenced as a result of participation in the REU?; 3) is there evidence of clarification and refinement of graduate school- and career-related plans and outcomes?; 4) is there evidence of engagement with production metrics (i.e., talks and presentations given at events, conference presentations, publications) as a result of participation in the REU program?; 5) what is the impact and potential benefit of student pairings in facilitating research collaboration; and 6) is there evidence of overall satisfaction with and high ratings of core REU experiences?

Description of Chemical Engineering REU Program

The NSF-funded research experience for undergraduates (REU) program was housed at The Pennsylvania State University and occurred during Year 1 in the summer of 2014. The REU program centered on the integration of biology and materials with a focus on allowing undergraduate students to engage in research in the area of biomolecular materials [12]. As delineated in the NSF proposal, the term biomolecular materials was utilized to refer to research that encompassed: “materials that mimicked biological structures (biomimetics), materials and processes that are inspired by biological systems (bioinspiration), synthetic materials that incorporate one or more biological components (bioderivation), and materials produced using biological systems (biosourcing)” (p. 1) [12].

Emphasized heavily in the REU structure was a focus on collaboration between student participants and established research groups conducting research bridging materials and biology. This emphasis included research collaboration between REU student participants and existing undergraduate students. Such collaboration rested on the use of student pairing to facilitate the attainment of student outcomes; REU student participants were paired with undergraduate students at Penn State to facilitate integration into the research community at the REU site [12].

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 [12].

The broad research activity and projects offered during the REU centered on the following research areas: polymer membranes for protein incorporation; DNA guided catalysis; membrane ultrafiltration for biomolecule purification; expressing and characterizing cellulose degrading enzymes; integrating nanoparticles in lipid membranes; developing materials to guide cell phenotype; developing fully human antibodies; and computational enzyme design [12]. Students engaged in these areas by faculty mentor assignment. In some instances, student research activities were split across two research projects.

Students participating in the REU were provided orientation sessions that served the functions of acclimating them to the research and laboratory environments, providing training on laboratory procedures (e.g., maintaining a high quality laboratory notebook), and providing training on safety and safety-related procedures in the laboratory setting. Students were also given an orientation to university-related services, including important university locations as well as library services and citation indexes. Students also participated in weekly technical activities and sessions that provided training and information on a broad range of topic areas related to conducting and engaging in research. Examples include a session on ethics in scientific research, training on effective oral and written communication and presentation of research and scientific findings, and a panel discussion focused on careers in research [12]. Students were also provided with the opportunities to tour various laboratories and research centers at Penn State (e.g., Materials Characterization Laboratory; Microscopy and Cytometry Facility; Nanofabrication Facility).

In addition to the focus on student pairing and collaboration with research, a series of social events and activities were embedded in the program to further facilitate successful integration of student participants into the research and university community. These activities included sponsored trips to surrounding parks and sporting and related events as well as more structured joint-REU networking events that embedded sponsored events across undergraduate research programs held at Penn State. The overarching focus of such events was to foster a sense of community as well as to facilitate the integration of REU participants into the research laboratory and community.

Student Participants

Demographic and related information of students who applied to the REU program is included in Table 1. In general, the percentage of applicants who were female and from underrepresented groups was similar to the typical representation of such students at the bachelor's degree level in engineering overall [13].

Table 1. Demographic Information of Applicants to the Chemical Engineering REU Program

Year	Number of Applicants	% Female	% URM	% CE/E/S Major	Average Cumulative GPA	% Fr/So/Ju/Se
2014	70	36	20*	91/7/2	3.44**	10/41/49/0

URM = Under-Represented Minority; CE = Chemical Engineering; E = Engineering, Other; S = Science; Fr = Freshmen; So = Sophomore; Ju = Junior; Se = Senior

* 5 students (7%) did not report ethnicity information

** 4 students (6%) did not report cumulative GPA

Demographic and related information of students who participated in the REU program across all funding sources is included in Table 2. A total of 21 students participated in the chemical engineering REU program; the students were funded either by the NSF or by fellowship and related university funding. The percentage of students participating in the REU program overall who were female exceeded the typical representation of female students at the bachelor's degree level in engineering [13]. The percentage of students from underrepresented groups well exceeded the typical representation of students at the bachelor's degree level in engineering overall [13]. Five of the 21 students had had prior experience with a research experience for undergraduate programs.

Table 2. Demographic Information of Participants in the Chemical Engineering REU Program

Year	Number of Participants	% Female	% URM	% CE/E/S Major	Average Cumulative GPA	% Fr/So/Ju/Se
2014	21	25	42	89/0/11	3.75	0/56/44/0

URM = Under-Represented Minority; CE = Chemical Engineering; E = Engineering, Other; S = Science; Fr = Freshmen; So = Sophomore; Ju = Junior; Se = Senior

Finally, demographic and related information of students who participated in the REU program and were funded by the NSF is included in Table 3. Of the 21 total students, 10 students were funded by the NSF. The percentage of students participating in the REU program who were female and were from underrepresented groups well exceeded the typical representation of such students at the undergraduate level in engineering [13]. One student exited the REU midway through the program as a result of illness, resulting in 9 total participants funded by the NSF completing the REU program.

Table 3. Demographic Information of Participants in the Chemical Engineering REU Program

Year	Number of Participants	% Female	% URM	% CE/E/S Major	Average Cumulative GPA	% Fr/So/Ju/Se
2014	10	40	60	90/0/10	3.81	0/50/50/0

URM = Under-Represented Minority; CE = Chemical Engineering; E = Engineering, Other; S = Science; Fr = Freshmen; So = Sophomore; Ju = Junior; Se = Senior

Assessment Methodology and Measures

Evaluation of the REU program relied upon an extensive assessment methodology drawing on the use of pre- and post-surveys as well as in-depth student and faculty interviews. Pre- and post-survey measures as well as student and faculty interview protocol items are available upon request from the first author. Assessment measures, mechanisms, and administration procedures

are summarized in Table 4. Evaluation of the REU program was conducted by the first and second authors as part of a teaching and learning center distinct from but working in collaboration with the primary and co-primary investigators of the REU. Approval from the Institutional Review Board was obtained prior to data collection; implied and informed consent were obtained prior to data collection for all measures.

Table 4. Assessment Measures, Mechanisms, and Administration Procedures

Measure	Outcome(s) Measured	Time of Administration	Procedures
Pre-survey	Prior experience with REU programs or research experiences; Motivations and goals for REU participation; Initial experience with research/research activities; Initial experience with specific research procedures	Week 1 (of 10) of REU	Administered via online survey software (i.e., Qualtrics Survey Software)
Post-survey	Broad experience with research/research activities; Specific research-based experience; Initial career and graduate school plans and outcomes; Openness to research collaboration; Ratings of REU experiences; Satisfaction with REU	Week 10 (of 10) of REU	Administered via online survey software (i.e., Qualtrics Survey Software)
Interviews with student participants	Motivations for REU participation; Description of REU experiences and perceived gains; Description of faculty mentor experiences; Student pairing experiences; Impact of REU on career and/or graduate education plans; Suggestions for REU program improvement	Week 8 (of 10) of REU	Administered in person
Interviews with mentoring faculty	Changes in REU students' skill levels; Experiences and challenges in working with students; Benefits obtained from REU collaboration; Suggestions for REU improvement	After completion of REU	Administered in person and over the phone

The pre-survey was administered during week 1 of the REU program. Table 5 lists descriptions of pre-survey measures, scales, anchors, and reliability indices using Cronbach's alpha. The pre-survey contained two measures designed to assess experience with research, research-related activities, and skills related to lab work and presentation and communication of scientific research. The pre-survey also contained two open-ended items gauging motivation and interest in the REU as well as goals for participating in the REU program.

The first of the two experience-based measures, the Undergraduate Research Student Self-Assessment (URSSA), is an NSF-funded survey instrument designed to measure student learning gains from research experiences [9]. The URSSA is free for use in assessing student outcomes from research experiences [9]. Slight modifications to the instrument were made for administration and assessment of the REU primarily centering on language, tense, and scale. The assessment of gains focuses on areas such as skills related to lab work and communication, conceptual

knowledge and linkages, and an increased understanding of the intellectual and practical work of science [9].

The second measure, the Experience with Research Activities Scale (EWRAS), is a brief, 4-item scale that was designed to measure broad experiential development and gain with overall experience with research, experience working in a research lab, experience collaborating with faculty while engaged in research, and experience working with students while engaged with research.

Table 5. Pre-Survey Measures Descriptions

Measure	# of Items	Scale Type	Scale Anchors/Response Type	α
URSSA	37	6-Point Likert	Not at all confident – Very confident	.96
EWRAS	4	5-Point Likert	Not experienced – Considerably experienced	.78
Motivation/Interest Item	1	Open-ended	Not applicable; Open response	N/A
Goals Item	1	Open-ended	Not applicable; Open response	N/A

N/A = Not applicable.

The post-survey was administered during week 10 of the REU program. Table 6 lists descriptions of post-survey measures, scales, anchors, and reliability indices using Cronbach's alpha. It included the same experience-based measures – the URSSA and the EWRAS – contained in the pre-survey. The use of these measures in the post-survey allowed for comparison of responses among REU participants as well as an analysis of post-REU gains in both broad and specific research experiential development. The post-survey also contained items measuring the openness of participants to collaborating with other students while engaged in research and the likelihood of participants pursuing a graduate degree.

In addition to these measures, the post-survey contained ratings of core REU experiences that asked participants to rate their experiences in accordance with their working relationship with their research mentor, their working relationship with their research group members, the amount of time spent doing meaningful research, the amount of time spent with their research mentor, the advice given by their research mentor regarding graduate school and careers, and the research experience overall.

Production metrics were measured by having participants indicate which of the following activities they completed or will have completed as a result of their participation in the REU: presenting a talk or poster to other students or faculty, presenting a talk or poster at a professional conference, writing or co-writing a paper to be published in an academic journal, writing or co-writing a paper to be published in an undergraduate research journal, and winning an award or scholarship based on research completed during the REU program. Finally, participants responded to an overall evaluative item asking them to rate their overall satisfaction with the REU. Following completion of this item, participants were administered an open-ended item gauging recommendations for improvement of the REU.

Table 6. Post-Survey Measures Descriptions

Measure	# of Items	Scale Type	Scale Anchors/Response Type	α
URSSA	37	6-Point Likert	(Not applicable) No gain – Great gain	.93
EWRAS	4	5-Point Likert	Not experienced – Considerably experienced	.81
Ratings of core REU experiences	6	5-Point Likert	Poor – Excellent	.70
Openness	1	5-Point Likert	Not open – Very open	N/C
Likelihood	1	5-Point Likert	Very unlikely – Very likely	N/C
Satisfaction	1	5-Point Likert	Very dissatisfied – Very satisfied	N/C

N/C = Not calculable.

In-depth student interviews took place during week 8 of the REU. The interviews served the function of providing a more in-depth assessment of the experiences of REU participants. The interviews focused on the following elements of participant experiences: motivations for participating in the REU, research and related project-based experiences, experiences working with faculty mentors, perceived gains from participation in the REU, perceived benefits of student pairing experiences, impact of the REU on conceptualizations of and plans for research, impact of the REU on career or educational goals, and suggestions and recommendations for improvement of the REU.

Faculty interviews took place following completion of the REU (i.e., one to two weeks after completion of the REU). The interviews with faculty allowed for in-depth assessment of: the procedures utilized for introducing and orienting students to research projects, perceived changes in students' skill levels, experiences and challenges in working with students during the REU program, benefits (including potential faculty collaboration and data obtained) derived from mentoring an REU student, and suggestions and recommendations for improvement of the REU.

Results

Pre-Survey Data

The measures utilized in the pre-survey, consisting of the Undergraduate Research Student Self-Assessment (URSSA; α = .96) and the Experience with Research Activities Scale (EWRAS; α = .78), demonstrated adequate reliability. Both measures were administered electronically utilizing online survey software (i.e., Qualtrics Survey Software) and were administered in accordance with appropriate administration procedures. Eight questions, comprising an item block, of the URSSA were not endorsed by one participant; as a result, the composite score for this participant was not calculated and was removed from the analyses. Descriptive statistics for the composite scores of the measures are presented in Table 7. Data were obtained from 19 REU participants (90.48% response and completion rate).

Table 7. Descriptive Statistics for Pre-Survey Measures

Measure	Mean	Median	SD	Minimum	Maximum
URSSA	165.86	162.00	25.07	131.00	218.00
EWRAS	11.47	11.00	4.23	4.00	9.00

As a means of ensuring the measures administered performed similarly for all individuals, analyses of differences in responses by gender (male $n = 14$; female $n = 5$) and by underrepresented minority status (URM; male $n = 7$; female $n = 1$) were conducted. It was expected that no significant differences in responses would be obtained. In line with these expectations, no significant differences were obtained in URSSA scores ($t = 0.70$; $p = .49$) or EWRAS scores ($t = -0.01$; $p = .99$) by gender. Also, no significant differences were obtained in URSSA scores ($t = -1.51$; $p = .18$) or EWRAS scores ($t = -0.41$; $p = .69$) by underrepresented minority (URM) status. Participants were also administered two items asking them to rate their openness to collaborating with other students with research activities and the likelihood of their pursuing graduate school. No significant differences were noted in responses to these two items by gender ($t = -1.87$; $p = .08$; $t = 0.26$; $p = .80$) or URM status ($t = -0.54$; $p = .60$; $t = -0.54$; $p = .61$).

A correlational analysis was conducted between the URSSA and the EWRAS. The correlation coefficient obtained ($r = .23$, $p = .35$) indicated a moderate positive relationship between the measures, suggesting that the scales measured somewhat related but unique elements of experiences with research and research-related activities. This finding, together with the finding of strong reliability coefficients for both measures, supports the EWRAS as a measure of broad experiences with research activities and the URSSA as a measure of specific scientific- and research-based experiences.

Overall, the results of the pre-survey analyses indicate good measurement properties of the instruments used. The results also indicate that there were no significant differences among scores obtained from the measures by gender or URM status. This indicates that the items were not being differentially responded to or rated based upon gender or by individuals of differing ethnicities; in other words, the measures performed similarly for all individuals. The measures also appeared to have provided unique information about participant experiences with research and related activities.

An analysis of the salient themes among qualitative responses for motivation and interests in participating in the program indicated: 1) the ability to gain introduction to and experience with research; 2) the ability to work with faculty and mentors in conducting quality research; 3) the ability to meet and engage with other students and to learn from other students' experiences; and 4) using the REU program as a mechanism for determining the desire for and appropriateness of graduate school. An analysis of the salient themes among qualitative responses for goals in participating in the program indicated: 1) building and developing skill and facility with research; 2) building and developing skill in a research laboratory; 3) using the REU program to inform decisions about future education- and work-related goals (i.e., graduate school, research goals, career goals); and 4) being able to produce or co-produce a research product (i.e., poster, research paper) to be submitted for publication or presentation.

Post-Survey Data

The post-survey utilized the Undergraduate Research Student Self-Assessment (URSSA; $\alpha = .93$) and the Experience with Research Activities Scale (EWRAS; $\alpha = .81$) that were incorporated in the pre-survey. Both measures again demonstrated adequate reliability.

Descriptive statistics for the composite scores of the measures are presented in Table 8. Data were obtained from 14 REU participants (70.00% response and completion rate).

Table 8. Descriptive Statistics for Post-Survey Measures

Measure	Mean	Median	SD	Minimum	Maximum
URSSA	171.21	169.00	23.23	121.00	211.00
EWRAS	16.57	17.00	2.31	12.00	20.00

Analyses of differences in responses by gender (male n = 10; female n = 4) and by underrepresented minority status (URM; male n = 7; female n = 1) were again conducted as a means of ensuring the measures performed similarly. As expected, no significant differences were obtained in URSSA scores (t = -0.15; p = .89) or EWRAS scores (t = -0.18; p = .86) by gender. No significant differences were obtained in URSSA scores (t = 0.97; p = .38) or EWRAS scores (t = 0.73; p = .51) by underrepresented minority (URM) status. Participants were also administered two items asking them to rate their openness to collaborating with other students with research activities and the likelihood of their pursuing graduate school. As with the pre-survey, no significant differences were noted in responses to these two items by gender (t = 0.50; p = .63; t = -0.74; p = .47) or URM status (t = -0.38; p = .72; t = -0.34; p = .75). In addition to the items included in the pre-survey, the post-survey contained items asking participants to rate their specific research experiences as well as an overall satisfaction item. No significant differences were obtained in ratings or in overall satisfaction by gender (t = 0.46; p = .66; t = 0.39; p = .71) or URM status (t = 0.43; p = .69; t = 0.85; p = .44).

As with the pre-survey analysis, a correlational analysis was conducted between the URSSA and the EWRAS. The correlation coefficient obtained (r = .39, p = .17) indicated a moderate, positive relationship between the responses on the URSSA and the EWRAS, providing additional support for the two instruments measuring unique aspects of participant experiences with research.

Item responses to the URSSA were analyzed descriptively as a means of indicating specific areas for which participants rated either good or great gain in research experiences. Table 9 includes items of the URSSA for which participants rated either good (5) or great (6) gain, with item descriptions, based on mean and mode responses. Participants indicated considerable gains in areas centered on understanding research and research methodology, the communication of research and scientific findings, and working both independently and in collaboration with others while engaged in research.

Table 9. Mean and Mode Responses for URSSA Items Indicating Good or Great Gain

Item	Mean	Mode	SD
Figuring out the next step in a research project	5.07	5.00	0.73
Comfort in discussing scientific concepts with others	5.29	5.00	0.61
Comfort in working collaboratively with others	5.07	5.00	0.92
Ability to work independently	5.21	6.00	0.89
Understanding what everyday research is like	5.14	6.00	1.03
Preparing a scientific poster	5.00	6.00	1.36

Engaging in real-world science research	5.21	6.00	1.05
Feeling like a scientist	5.14	6.00	1.10

Ratings of specific REU experiences were obtained from participants through six items assessing participant ratings of the following areas: working relationship with research mentor, working relationship with research group members, amount of time spent doing meaningful research, amount of time spent with research mentor, advice given by research mentor regarding graduate school and careers, and the research experience overall. The items demonstrated adequate reliability ($\alpha = .70$) and were measured on a 4-point Likert scale ranging from 'Poor' to 'Very good'. Mean and mode responses for each item are displayed in Table 10.

Table 10. Mean and Mode Responses for Ratings of Research Experiences

Item	Mean	Mode	SD
Relationship with mentor	3.07	3	0.92
Relationship with research group	2.93	3	0.92
Time spent doing research	2.80	3	0.80
Time spent with mentor	2.60	2	1.02
Advice given by mentor	3.21	4	1.25
Research experience overall	2.93	3	0.83

Participants rated their working relationship with their faculty mentor, their working relationship with their research group members, the amount of time spent doing meaningful research, and the advice given by their mentors regarding careers or graduate school as being good (*Mo* = 3.00, good). For advice given by their faculty mentor, participants rated the experience as being very good (*Mo* = 4.00). The research experience overall was rated as being good (*Mo* = 3.00). The ratings area that received the lowest rating by participants was the amount of time spent with their faculty mentor; this area was rated as fair (*Mo* = 2.00). This finding suggests a desire among REU participants to have had the opportunity for more time working with and under the advisement of their faculty mentors.

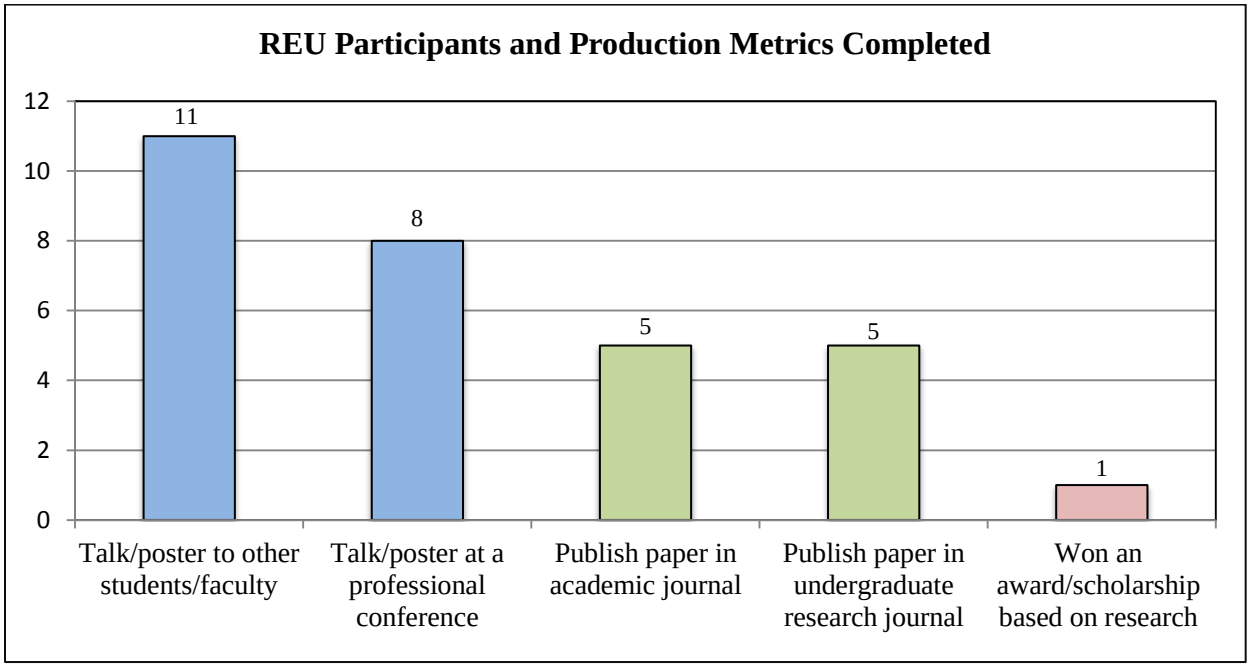
Participants' rating of openness to collaborating with other students while engaged with research following the completion of the REU was measured with a 5-point Likert scale item ranging from 'Not open' to 'Very open'. The mean response for openness to collaboration with students was 4.14 while the mode response was 4.00 ('Open'). Initial indication of graduate school outcomes was also obtained. As indicated, participants were asked to rate their likelihood of pursuing a graduate degree. The item was administered with a 5-point Likert scale (i.e., 'Very unlikely' to 'Very likely'). The mean response for the participants was 4.00, while the mode response was also 4.00 ('Likely').

Participants' overall satisfaction with the REU was gauged with a 5-point Likert scale item ranging from 'Very dissatisfied' to 'Very satisfied'. The mean response for the overall satisfaction item was 4.38, while the mode response was 4.00 ('Satisfied'). This suggests that, overall, REU participants indicated satisfaction in having completed the REU experience.

Specific production metrics were assessed by surveying participants for completion or anticipated completion of the following activities: presenting a talk or poster to other students or

faculty, presenting a talk or poster at a professional conference, writing or co-writing a paper to be published in an academic journal, writing or co-writing a paper to be published in an undergraduate research journal, and winning an award or scholarship based on research. Figure 1 depicts the number of students engaged in these activities.

Figure 1. Number of REU Participants and Production Metrics Completed



As can be seen from Figure 1, of the REU participants, 11 indicated completion or anticipated completion of a talk or poster presentation to other students or faculty. Eight students indicated completion or anticipated completion of a talk or poster presentation at a professional conference. In terms of publications, 5 participants indicated publication in an academic journal, while 5 participants indicated publication in an undergraduate research journal. One student indicated the attainment of an award or scholarship based, in part, on research conducting during the REU.

Comparisons of Pre- and Post-Survey Data and Post-Survey Gains

Post-survey gains were assessed through analyses of differences between pre- and post-survey ratings of both broad (EWRAS) and specific (URSSA) scientific- and research-based experiences. Post-survey ratings of broad experiences with research (i.e., experience with research, experience working in a research lab, experience collaborating with faculty while engaged in research, experience collaborating with students while engaged in research) were significantly higher than pre-survey ratings of research experiences ($t = 4.13$, $p < .01$). Descriptively, the mean composite score increased from 11.47 for the pre-survey to 16.57 for the post-survey (relative to a maximum total score of 20.00) This indicates significant gains in broad research experience as a result of participation in the REU. For follow-up, item-level difference analyses, the Wilcoxon signed-rank test was used as the item-level analysis appropriate given the potential for item distribution non-normality. The most significant gains were evidenced in

experience with research ($Z = 2.87$, $p = .004$), experience working in a research laboratory ($Z = 2.57$, $p = .01$), and experience collaborating with faculty while engaged in research ($Z = 2.55$, $p = .01$).

Analyses of differences between pre- and post-survey ratings with respect to specific scientific- and research-based experiences did not reveal a significant increase in the composite score for the URSSA ($t = 1.30$, $p = .22$). Descriptively, the mean composite score increased from 158.35 for the pre-survey to 168.15 for the post-survey (relative to a maximum total score of 185.00). The analyses revealed gains in several key areas of research skill, development, and communication as evidenced by reported gain along several URSSA items. These areas included significant gains in: figuring out the next step in a research project ($Z = 2.70$, $p = .01$); formulating a research question that could be answered with data ($Z = 2.02$, $p = .04$); identifying limitations of research methods and designs ($Z = 2.55$, $p = .01$); understanding the theory and concepts guiding my research project ($Z = 2.34$, $p = .02$); comfort in discussing scientific concepts with others ($Z = 2.15$, $p = .03$); and understanding what everyday research work is like ($Z = 2.46$, $p = .01$). As noted previously, obtained gains were found to be equitable across groups of student participants.

Descriptive analyses were also conducted examining differences in post-survey gain scores in broad experiential development by prior experience with undergraduate research experiences. Post-survey gain scores were calculated by subtracting the composite pre-survey score on the EWRAS from the composite post-survey EWRAS score; gain scores were then utilized as the dependent variable of focus to evaluate differences based on prior experience with undergraduate research and research programs. Students who had not engaged in prior research experiences at the undergraduate level obtained a higher average gain score ($M = 6.08$) than students who had previously engaged in a research experience ($M = 1.00$). This difference was found to be statistically significant ($t = 2.34$; $p = .04$); however, given the discrepancy in sample sizes for the two groups (12 and 2, respectively), particular caution should be exercised in interpreting this statistical finding. These findings suggest that undergraduate research programs may provide a significant benefit to those students who have not yet previously had the opportunity to engage in research.

Student Interviews

All students were interviewed by the first author. Interviews occurred during the eighth week of the REU program and took place in person ($n = 14$). The interviews lasted approximately twenty to thirty minutes. Informed consent was obtained prior to each interview. All interviews were recorded and transcribed for analysis; the interview transcripts were analyzed utilizing NVivo 10. Interviews were coded based on the derivation of coding categories created from an initial analysis of a selected student interview. The categories were then applied to the coding of each student interview systematically, altering the categories as needed as additional themes from the interviews emerged. Analysis of the interview data resulted in themes related to: motivations for participation in the REU program; experiences working with faculty mentors; changes in conceptions of research as a result of participation in the REU; perceived benefits among students paired in collaboration during the REU; perceived gains from participating in the REU;

impact of the REU on career and/or educational plans and goals; and suggestions for improvement to the REU.

In discussing primary motivating factors for participating in the REU program, a prominent theme that emerged was the desire to gain experience completing a research experience that was perceived as rigorous and as providing insight into a graduate school-level research experience. Many of the students stated the desire to use the REU program as a mechanism for providing information about the potential rigors of conducting research at the graduate level, understanding what working in a research laboratory entails, and understanding what working in a research team and under a research advisor or mentor is like. Several students (43%) described a desire to use the REU program as a mechanism for more closely considering and evaluating the next step in their educational or professional careers. Described as a kind of filtering experience, one student said the following:

> *"I thought it would be a very good jump into potentially finding out what graduate school opportunities are all about. I'm still not sure if I want to go to graduate school or go straight on into the work force, and this primarily motivated me to find out what it's all about."*

Other students (14%) came into the REU experience with solidified plans for pursuing a graduate degree, and instead used the REU program as more of a confirming experience: "So I already knew that I wanted to go to graduate school…I just wanted to get more experience in research."

Experiences with faculty mentors largely revealed positive interactions. Of note, many students (71%) mentioned an important balance among their advisors between providing encouraging and reinforcing feedback, being critical and constructive when needed, and being supportive in pushing students to take an independent role with their research projects. As one student indicated,

> *"…they really push me to be able to achieve things that I want to achieve and also to think on different levels that I wasn't able to think before or didn't really think of thinking about."*

As another student put it, "they let me put some input into the project as well, and also are critical when need be where can I have room for improvement, so a very healthy environment for work with mentors." Despite a prominent theme of supportive mentorship, students (36%) noted a desire for greater mentor involvement during the course of the research projects. In addition, students also noted a desire for greater oversight when working in a laboratory setting as a means for having a more constant and available resource for asking questions, gaining clarification, and executing needed changes in tasks or procedures. This desire is evidenced by the following: "I feel like it would've been helpful to have a little bit more direct oversight in the lab. So I think that was logistically a little bit of an issue with the mentorship… I mean they're professors, they have a lot of other stuff on their plate. But it was a little discouraging, I guess." Such a view was also mentioned in the context of navigating issues that arose during the course of conducting the research (i.e., equipment malfunction, materials issues, etc.) and completing various components of their research projects.

A salient theme from the interviews was the impact of the REU in shaping participants' conceptions of the nature of research as a process – one that requires continuous conceptualization and the ability to navigate issues that arise in a cyclical fashion:

> *"I think my perception of how research actually works on a day-to-day basis has changed just on how, I guess I would say, non-linear it is. Things happen that you don't expect to happen. You have an idea of where it's going and then it doesn't always go there."*

As another example of a change from a previous conception of research, "It's just, I don't know, I guess this idealistic preconception was just, 'Oh, it's going to go perfectly…and it will be a great project'." Students also demonstrated growth in their ability to reflect on the nature of research and how their thinking regarding research has been revised. As another candid description of a change that occurred in a student's conception of research: "…the REU showed me that research is a very painstaking and slow process versus what I would've expected where everything goes perfect, you get the results you want, and then you become famous and you get stuff published."

A primary focus of the study was an examination of the impact of student pairing on students' experiences with the REU program. Selected students were paired with undergraduate students at Penn State; a total of four student pairs were created, allowing for comparison of student pairing experiences and perceived benefits. Students who were paired in collaboration during the REU indicated a significant benefit of working in pairs while engaging in research. REU students paired with undergraduate students at Penn State 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."*

Still other students mentioned the benefit of utilizing student partners in facilitating problem solving and idea generation as well as work and time management:

> *"I think it's been helpful. I really can't imagine not having another undergrad in there or not working directly with someone. First off, it's helpful to have someone to bounce ideas off. We can divide labor…; we can divide readings. So one of us can research one thing that we're working on; one of us does another."*

The perceived benefit of the student pairing also arose in a suggestion for improvement to the REU program offered by a student who had not participated in the student pairing:

"So for me personally, I think…making sure everyone has an undergrad student to work with from Penn State because when you're by yourself, it's hard to get acclimated. And also, I think it might just be more beneficial to the students…and that way…and the undergrad student actually is helped."

Perceived gains from participation in the REU largely centered on those related to experience engaging in research, understanding research as a process, gains in laboratory experience and experience with specific laboratory techniques, and attaining clarity of perspective on the potential requirements and rigors of graduate school. These points are exemplified by the following quote:

"I've definitely gained a lot of experience with procedures, machines, working with people in this field, meeting a lot of people, connections, and that's definitely a good thing. I think I've also gained a greater understanding of what it would mean to go to grad school."

As another example, "I've gained a lot of perspective on what I can expect from graduate school and the research process in general and that it's not always going to go the way you expect it to but there's a lot of upside to it. It's a slow process but if you're involved in it and actively participating, it's definitely worthwhile." Such sentiments echo much of the gains indicated by students.

The impact of the REU on career and educational plans is demonstrated by the following: "I guess it sort of solidified my desire to go into research. Before participating in these programs, I thought I wanted to, but I wasn't really sure…" These findings highlight those from Lopatto and Seymour and colleagues supporting the more qualified claim that undergraduate research experiences such as REUs serve the function of clarifying, refining, and, in some cases, reinforcing a choice to pursue graduate school [4, 7]. The clarifying role of the REU is exemplified by this quote from a student who may be less decided about pursuing graduate school:

"I think I've also gained a greater understanding of what it would mean to go to grad school. And I don't know – possibly the decision that I might not want to. But that's part of the program. I think that's part of what it is – seeing if you do or do not want to, and that's just how I think I came out of it."

In another example, "…it's given me more information about what it would be like to do research, and I think either way I go, I'll be much happier with my decision and more prepared for it." While the majority (64%) of the students participating in the REU indicated concrete plans for graduate school, with additional students (14%) indicating continued consideration of graduate school, it is important to interpret undergraduate research experiences such as REUs as a refining experience rather than a prompting experience. Many students had expressed interests in pursuing a graduate degree coming into the REU program; for some, the REU experience solidified and reinforced these interests, while for others, the REU experience refined students' interests toward industry or another area. Such findings highlight the importance and the utility of undergraduate research experiences in facilitating the decision making of students weighing one or more post-undergraduate options.

Suggestions for improvement to the REU program largely focused on the implementation of additional activities and events that facilitated integration into the research community, interaction among research groups, and social climate among research participants. As this quote indicates, "I think maybe a program in the beginning would help, but we didn't interact too much unless you had someone in your lab…so maybe something early on that would have grouped us together more would've helped with that and just given us a broader experience of stuff." Another suggestion for improvement echoed one offered previously centering on the pairing of REU student participants with undergraduate students at Penn State,

> *"…for me, if I had another student to work with, even someone who was already at Penn State, that might've helped a lot, too."*

Across students participating and not participating in the student pairing, a range of benefits were perceived in having another undergraduate student to work with in the research setting. Finally, another suggestion for improvement centered on increasing the length of time of the overall REU program as a means of facilitating research project completion.

Faculty Mentor Interviews

Faculty mentors supervised one to two REU students. Seven of the total twelve faculty mentors were interviewed for the study. All participating faculty mentors were tenured or tenure-track faculty; faculty ranks were at the following levels: assistant (n = 3), associate (n = 1), professor (n = 2), distinguished professor (n = 1). All faculty mentors held appointments in chemical engineering, with two faculty mentors holding additional appointments in bioengineering and materials science and engineering. Faculty were interviewed by the first author. Interviews occurred after REU program completion and took place in person (n = 6) and over the phone (n = 1). The interviews lasted approximately twenty to thirty minutes. As with the student interviews, informed consent was obtained prior to each interview. All interviews were recorded and transcribed for analysis; the interview transcripts were analyzed utilizing NVivo 10. Interviews were coded based on the derivation of coding categories created from an initial analysis of a selected faculty mentor interview. The categories were then applied to the coding of each faculty interview systematically, altering the categories as needed as additional themes from the interviews emerged. Analysis of the interview data resulted in themes related to: perceived changes in REU students' skill levels; experiences working with and mentoring students; challenges in working with students; perceived benefits in working with and mentoring students; and suggestions for improvement to the REU program.

In discussing perceived changes in REU students' skills levels, salient themes that arose centered on a more developed set of skills related to experimental and laboratory procedures, an improved understanding of the research process, and an improved ability to effectively communicate research-based and scientific findings. As one quote indicates,

> *"…they definitely developed a range of improved experimental skills, but they also seemed to make some progress in having a higher level of understanding of what research was all about and how to go about approaching the project."*

Another faculty member mentioned an improved ability among two REU participants to self-evaluate both their understanding and their research process, to be able to know when things were not working as planned or conceptualized, and to learn from issues that arise during experimentation. Highlighting important developments in presentation and related skills, one faculty mentor said, "I would say that they were better about presenting data to a group or to a supervisor. So in other words, they start to figure out how to communicate research results." while another faculty mentor indicated as follows, "So for the ones in my group, one big change that I saw was I think their presentation skills improved." Such remarks corroborate findings obtained in quantitative analyses indicating improvement in the ability to communicate research or scientific results. Gains in technical skills were also discussed: "As for technical skills, some of them have picked up the skills really quickly. [One REU student], for instance, picked up a lot of the working with proteins and putting them on surfaces very quickly…"

Faculty mentoring students paired in collaboration described several perceived benefits, including the ability to support one another while navigating research projects as well as issues that arose, facilitation of work management, and facilitating of time management. These findings are demonstrated by the following:

> *"…my impression was that they worked well together and were able to support each other as they went through the summer… they really got much more done than they would have just working on their own, and…were able to split up the work in a more effective way than they could have if they were just working on a single project."*

Other faculty perceived it as a benefit in terms of the breadth of topics and techniques students were able to learn from and with one another, "I think in the end, it did allow the project to be broader in scope than it would've been. So the students, I think, learned, a little bit – had a bigger breadth while at the same time they probably also had maybe even a bigger depth because they were allowed to focus on a specific part of a project instead of trying to encompass various things." A potential downside, however, to the student pairing was raised by faculty, noting the potential for students to struggle taking authority over specific components of the research projects as a result of their working together,

> *"…the downside is that I'm not sure that either of the students quite felt that level of ownership of the project that they might have if they were working on a project that they were the only undergraduate who was working in that area."*

The potential for such a downside relates with, and was perhaps mitigated by, gains perceived and evidenced in the ability to communicate research and scientific results.

Faculty were asked to describe challenges that arose in working with students during the course of the REU program. Some faculty described the challenge inherent in the short duration of the program and maximizing both time and experience for the REU students they mentored,

> *"…they all come in with different skill levels, and so you have to be able to quickly assess what their skill levels are in order to be able to best help them to be successful."*

Other faculty mentors described the need to ensure each of their students were adequately engaged and challenged during the course of the program, "It's how do we make sure that they were both doing things in the right schedule so that one didn't slow the other one down? So in other words, it's almost more like time management and project management was the toughest thing." Still other faculty articulated the difficulty in disentangling project components to give students a sense of authority and ownership over research projects, "The biggest challenges were at times where they were looking to have something to work on themselves that they could point to as, 'This is my project.'" Despite challenges expressed in terms of project management given the short, intensive nature of the program, no faculty expressed challenges with respect to personality or related conflicts.

In discussing benefits obtained in working with students during the REU, faculty mentors described increases in the amount of research and project-based work completed, "they definitely helped get more research done, so they added significantly. Their time and energy was very valuable for the project as a whole." This point was corroborated by the following: "lots of productivity, a new way of approaching things that makes things simpler." Other faculty described a benefit to graduate students they had been supervising, noting that the experience also affords graduate students the ability to engage in mentoring,

> *"It also gave opportunity for some of the graduate students to interact with the undergrads, especially for some of the younger graduate students who haven't had the opportunity to mentor the other graduate students."*

Related to production metrics of the program, one faculty mentor indicated the following: "I think some of the big benefits that we have is that the students have been able to produce some high quality data. So I believe that some of the work of the students is going to be in publications."

Finally, faculty mentors described several suggestions for improving the overall REU program. Related to concerns about student ownership of project requirements and components, faculty mentors suggested the need for more clearly delineating and articulating specific project expectations to students: "if the focus is on having students work collaboratively together, it would be helpful to maybe be a little bit clearer in communicating to the students what is expected of them at the end of this program as individual students." Echoing suggestions made by students, faculty also suggested including more – and more evenly dispersed – social events as a means of facilitating inclusion and integration into the research community. Related to research projects completed by students, faculty also mentioned the importance of improving the descriptions of projects to students at the outset, including clear articulation of goals, expectations, and deadlines. This importance was highlighted with consideration to the intensive nature of the 10-week program. Given the relatively short time span in which to complete research projects, students benefit greatly from clear organization and structure of project components, requirements, and expectations. The benefit of pairing students in collaboration was again discussed in suggestions for improving the REU program: "that is a huge plus especially if a Penn State student is connected with an outside student and the Penn State student continues in the same lab. More things can be done; more productivity can happen."

Summary, Recommendations, and Future Research

Evaluation of the REU program indicated successful recruitment of students from underrepresented groups. Of the REU participants, approximately 25% were female and 42% were recruited from underrepresented groups; this representation exceeded that typical of students at the bachelor's degree level in engineering overall. Participation in and benefits of the REU were also equitable across groups. No significant differences in pre- or post-survey responses and gains were detected based on gender or underrepresented minority status. This supports the finding of equitable gains in important research and research-related skill areas, likelihood of pursuing a graduate degree, and openness to collaborating with others in research.

Ratings of core REU experiences indicated favorable appraisals of participants' relationship with their faculty mentor, relationship with their research group members, amount of time spent engaged in research, and advice given by their faculty mentor. Ratings also indicated a favorable appraisal of the overall research experience. This rating was corroborated by participants' rating of overall satisfaction with the REU experience. Of note, participants indicated a desire for more time working with and under the advisement of their faculty mentors; this area comprised the lowest rated area of the core REU experiences, reflecting an area of need and improvement for the REU program in future years. Qualitative analysis corroborated this desire; students indicated a desire and need for more oversight and advisement in the research laboratory setting and while working through various obstacles encountered during the course of conducting research.

Significant gains in broad research experience were achieved by REU participants. This was evidenced by significant increases in participants' experience with research, experience working in a research laboratory, and experience collaborating with faculty while engaged in research. Gains were also evidenced in specific research-based skill areas, including the ability to conceptualize the research process and determine the next step in a research project, communicating and presenting research and scientific findings, and the ability to work independently and collaboratively with others while engaged in research. Limited evidence was also obtained indicating greater benefit and development in research experience among those students who had not participated in an undergraduate research experience prior to participation in the REU. Analysis of key production metrics indicated engagement in talks, posters, and presentation given to other students and faculty as well as those given at a professional conference. Indication of publication outcomes was also obtained in undergraduate and academic journals.

A distinguishing feature of the REU program was the use of student pairing as a mechanism for fostering research collaboration and integration. Perceived benefits from students participating in the student pairing included an improved ability to acclimate to the research and university setting, the ability to utilize undergraduate students as a resource, 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. Perceived benefits from faculty mentors largely corroborated the positive impact of the student pairing, noting the ability for mutually supportive research collaboration, facilitation of work and time management, and potential to lead to increased breadth and depth of project scope and focus. Despite these perceived benefits, some faculty mentors expressed concern about

students having the ability to take authority of and ownership over the completion of specific research project components; the primary suggestion offered to address this concern centered on explicating a clear articulation of project component expectations and individual requirements at project outset.

Participants in the REU overall rated themselves likely to pursue a graduate degree in their respective areas of study. A sizable number of students (64%) indicated plans to pursue either a master's or a doctorate in engineering, or to pursue a graduate degree concurrently with a career in engineering, with additional students (14%) indicating consideration of graduate school. A significant finding of the current study was the functional role the REU served in providing participating students with an introduction into both the research and the graduate education experience. Students utilized the REU program as a mechanism for determining the desire for and appropriateness of graduate school. A common theme derived from the student interviews was the role the REU experience served in clarifying, reinforcing, and, in some instances, refining their plans for graduate education. These findings align with those discussed by Seymour and colleagues, and point to the importance of such undergraduate research experiences in illuminating the appropriateness and fit of graduate education [7]. They also suggest REU experiences as ones that are refining rather than prompting in terms of graduate degree pursuance. However, such findings should be considered in light of the fact that five of the students had had prior experience with a research experience for undergraduates program.

Continued evaluation of research experiences such as REU programs is essential to fully evaluate the impact and effectiveness of the research experiences [4]. As such, the evaluation of the current REU will include follow-up assessments of gains in research-based skills, production metrics (i.e., talks, presentations, and publications), and career and graduate school plans and outcomes at 6-month, 1-year, and 2-year intervals. Each year of the REU will follow the same longitudinal assessment structure; evaluation of the REU will conclude fully after the administration and collection of assessment information following the 2-year assessment interval of the final year. Future evaluation of the REU may benefit from the assessment of faculty mentor appraisals of students' research-based skills. Such appraisals could be used to corroborate students' self-reported gains in various research-based skill areas, presenting the opportunity for obtaining evidence of the validity of observed gains in research experiences [7]. The continued evaluation of each year of the REU program will also result in increased sample sizes, further resulting in increased statistical power with which to conduct analyses of research gains. Such methods hold the potential to further corroborate and illuminate the benefits of undergraduate research experiences.

Several implications for other institutions interested in implementing an REU program are offered. First, the current study employed an intensive but sound assessment methodology, drawing on the use of pre- and post-surveys and both student and faculty mentor interviews, that can be readily implemented in other institutions. The assessment structure is also well-suited to be applied to undergraduate research programs in differing areas of engineering and science education to evaluate student and related outcomes. The study also highlights the importance of clearly articulating evaluation methodology, goals, analyses, and outcomes in the evaluation and corroboration of research gains [7]. Next, significant benefit of student pairings was observed. Institutions may likely benefit from implementing a consistent collaborative research component

within such undergraduate research programs as a means of fostering research collaboration and integration during the short but intensive research experiences in which the students are engaged. Finally, the study also placed a critical lens on the examination of the role of the REU experience in impacting students' plans for graduate education, supporting such research experiences as clarifying and refining graduate education goals rather than as prompting them. Institutions interested in implementing undergraduate research programs may benefit from more careful and qualified examinations of the effect of such research experiences on graduate education outcomes.

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Appendix

Experience with Research Activities Scale (EWRAS)

Please rate the extent of your experience with the following activities:

1 – Not experienced
2 – Slightly experienced
3 – Somewhat experienced
4 – Moderately experienced
5 – Considerably experienced

Research
Working in a research lab
Collaborating with faculty while engaged in a research or related activity
Collaborating with other students while engaged in a research or related activity