# Development and Assessment of a Combined REU/RET Program in Materials Science

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In this paper we present an evaluation and lessons learned from a joint Research Experience for Undergraduates (REU) and Research Experience for Teachers (RET) program focused on energy and sustainability topics within a Materials Science and Engineering program at a public university. This program brought eleven undergraduate science and engineering students with diverse educational and institutional backgrounds and four local middle and high school teachers on campus for an 8-week research experience working in established lab groups at the university.

Using the Qualtrics online survey software, we conducted pre-experience and post-experience surveys of the participants to assess the effects of participating in this summer research program. At the beginning of the summer, all participants provided their definition of technical research and described what they hoped to get out of their research experience, and the undergraduate students described their future career and educational plans. At the conclusion of the summer, a post-experience survey presented participants' with their answers from the beginning of the summer and asked them to reflect on how their understanding of research and future plans involving research changed over the course of the summer experience.

Many participants evolved a new understanding of research as a result of participating in the summer experience. In particular, they better recognized the collaborative nature of research and the challenges that can arise as part of the process of doing research. Participants acquired both technical and professional skills that they found useful, such as learning new programming languages, becoming proficient at using new pieces of equipment, reviewing technical literature, and improving presentation and communication skills. Undergraduates benefited from developing new relationships with their peers, while the teacher participants benefited from developing relationships with faculty and staff at the university. While most of the participants felt that they were better prepared for future studies or employment, they did not feel like the summer research experience had a significant impact on their future career or degree plans. Finally, while almost all of the participants described their summer research experience as positive, areas for improvement included better planning and access to mentors, as well as more structured activities for the teachers to adapt their research activities for the classroom

## Introduction

Research experiences for undergraduate students have long been identified as a powerful tool to support and prepare participants to pursue graduate education in a science, technology, engineering or mathematics discipline[1–3]. Initiatives to promote these experiences such as the National Science Foundation's Research Experience for Undergraduates (REU) program, initially established in 1987, increase access to research opportunities to underrepresented minority students and students coming from non research-focused undergraduate institutions[4].

Research on and evaluations of undergraduate research programs have demonstrated numerous positive outcomes for participants in these experiences. These outcomes include clarifying or reinforcing students' decisions to pursue graduate studies involving technical research, and increasing participants' confidence in their ability to be successful in these programs[5,6]. Working in a laboratory alongside graduate students can help undergraduate see themselves as future graduate students, and support the development of the participants' identity as a researcher, engineer, or scientist[6–8].

Research experiences for undergraduates also support the development of specific skills that will be useful to the participants' future research endeavors. This includes that ability to work through the uncertainty and ambiguity present in open-ended research problems[9], gaining a deeper understanding of their discipline[10], development of skills related to experimental and laboratory procedures[5], and developing communication skills and the ability to present technical work to a general audience[11].

Summer research experiences have also been shown as an effective means for primary and secondary school teachers develop a better understanding of the skills and processes associated with doing technical research and increase their willingness to incorporate opportunities to do open-ended research in their classrooms upon completion of the research experience[12,13]. Like REU programs, Research Experience for Teachers (RET) programs have existed for many years, and result in numerous documented positive outcomes for the participants[14]. RET programs can help teachers to keep abreast of changes in their fields, help expose their students to cutting edge research, and "bridge the gap" between K-12 classrooms and university research laboratories[15].

Both REU and RET programs are well represented across the engineering disciplines, and in the field of Materials Science and Engineering described in the present study. Foci of REU programs in this area include nanotechnology and nanofibers[16] and additive manufacturing[17], while RET programs in Materials Science and Engineering have focused on topics such as polymers and polymers processing[18], applications of materials science in pharmaceutical research[19], and nanoscale magnetic and electronic structures[20].

## Program Overview

The inherent interdisciplinary nature of materials science and the broadness of the theme of our Site (Materials for Energy and Sustainability) lend themselves to a wide spectrum of topics, so in November 2015 appropriate student summer projects were solicited from potential faculty mentors from across STEM fields at Boise State University. The application process went on-line in December with a deadline in mid-February. Received applications were collated over the next several days after which decisions were made by the Site director with input from the academic programs manager and potential mentors. We made the decisions as quickly as possible in order to assemble an excellent cohort of participants for our Site by the end of March, as several weeks are required to process payment data, arrange lab access, and allow sufficient time for mentors to send introductory information and background reading to their participants. During the selection process we must ensure compliance with the NSF mandate that at least 50% of our cohort is comprised of students from non-research-active institutions. The total participation rate of such students in the Site from 2014-2016 was 66%, far in excess of the NSF requirement. We also attempt to include as many participants as possible form under-represented groups in STEM fields. From 2014 - 2016 our Site attracted a participation rate of 44% from under-represented minority groups. Furthermore, we attempt to match as far as possible the applicant's research preferences with appropriate mentors. Students list their top three mentor choices on their application form, and every effort is made to assign them to either their desired mentor or a project for which they seem best qualified. An initial shortlist is typically created based on several factors including GPA, major, and academic level (*i.e.*, freshman, sophomore, junior, or senior). Personal statements and reference letters (two are required) are then considered. In some cases a particular attribute is also required (*e.g.*, a project may require that the participant have their own car).

Ten student participants arrived at the end of May for the REU program and four teachers in early June for the RET. Both cohorts continued their research experiences until the end of July. For some participants, the research experience involved becoming familiar with a faculty member's ongoing research project whereas other participants had the opportunity to work with their faculty member to identify a project that would be of interest and so had a larger role in the design of their project. We met as a group weekly to check in with all participants and address any programmatic issues.

In addition to their regularly scheduled work in a research laboratory, the participants engaged in a variety of other activities including weekly workshops focused on topics critical to both preparing students for STEM careers and fully incorporating them into broad, interdisciplinary research groups; campus-wide social events; and tours of both university laboratories and local industry meant to highlight the role of materials scientists in various fields. Three catered interdisciplinary research seminars were also organized each year, in coordination with the other REU Sites on campus, at which participants had the opportunity to present their work to their peers. The students' experiences culminated with the creation and presentation of a poster describing their project at a state-wide conference on undergraduate research.

In addition to these organized academic and social events, the fact that the majority of the undergraduate participants (9 out of 10 in 2016) came from out of state and spent the summer living on campus, rooming with participants in this and other REU Sites, meant that informal social interactions were also encouraged.

**Research Method**

To assess the impact of this program on both the undergraduate and teacher participants, we administered pre and post surveys to the participants in the program using the Qualtrics online survey software. At the beginning of the summer, we asked the participants to describe technical research, what they hoped to get out of the summer research experience, and what they hoped to do after completion of the summer research experience and after completing their undergraduate degree program. By collecting identifiable data, at the completion of the summer research experience we administered a post survey where we presented the participants with their responses from the beginning of the summer and asked them to reflect on how the summer experiences changed their understanding of research and future career plans, and provided an opportunity for them to make suggestions for ways to improve the summer research experience for future participants. We developed the questions for both the pre and post surveys based on exit interviews conducted with participants from the previous year[21].

To analyze the data, all responses were exported to Excel, where the researchers were able to compare participants' pre and post survey responses side-by-side to identify trends and meaningful outcomes related to participation in the program.

## Results

In analyzing the survey data, we identified four major themes in the participants' responses. The themes were the benefits of doing research, the benefits unique to the teacher participants, dealing with uncertainty in research, and suggestions for changes to the summer research program.

### A. Benefits of Doing Research

While participation in the summer research experience changed many participants' understanding of research, it did not have a strong influence on their future plans. The majority of participants chose to be involved with a summer research program to gain experience with doing research in the hopes of pursuing either graduate study or careers that involve research, and their experiences in the program largely did not alter their future plans. However, the participants described being both better prepared for future research opportunities or more committed to pursuing future research opportunities in graduate school as a result of their summer experiences. At the beginning of the summer, a participant wrote:

> I hope to gain more clarity of the type of engineering career I want. I also hope I can get an idea of what I want to study in grad school. I would also like to get more familiar with how to conduct and present quality research in the field of environmental engineering/material science

When asked to reflect on this statement at the end of the summer, she wrote:

> I did end up learning all of these things. I became set on a graduate program that I feel is a perfect fit for me after being exposed to environmental engineering in the lab. I also became a lot more confident as a researcher and presenter over the summer- I feel incredibly prepared to be a graduate student.

For other participants, the primary benefits for participating in the research program involved developing specific skills that they believed would be helpful for them in future research pursuits. These included developing technical skills like programming and using software tools, and increased familiarity with the tools and techniques of materials research such as using scanning electron microscopes and atomic force microscopy. Other participants emphasized the development of process skills such as learning how to do literature reviews and to formally communicate scientific and engineering ideas via writing and presentations, as well as the ability to communicate informally with people whom the participants worked with or helped.

### B. Benefits for Teachers

The primary benefits of participation in the summer research experience reported by the teacher participants focused on developing connections with the university to identify campus resources and personnel to bring to their classrooms and better support their students that are interested in attending the university and/or pursuing studies or careers in engineering. At the beginning of the summer, one of the teacher participants wrote:

> I hope to gain a better ability to connect my high school students with the university and to become better connected myself. I have found that there are many misconception, misunderstandings and gaps in teachers and students understanding about what is required to study engineering in college and what outcomes should be expected.

At the end of the summer research experience, the same participant wrote:

> I made some great connections over the summer that I can use to help students be better prepared for college and engineering. I hope to have many guest speakers come to my classroom to help students in this area.

Having teacher participants work alongside the undergraduate student researchers allows for the development of relationships between these two groups, and can help the teachers learn more about the undergraduate engineering student experience that they can then bring back to their classrooms and share with their students to better advise and prepare them to study engineering.

### C. Dealing with Uncertainty in Research

Recognizing and being able to deal with uncertainty represented one of the major changes in participants' understanding of research. This included the participants learning how to deal with failure, approaching problems from multiple disciplinary perspectives, dealing with results that did not support initial hypotheses, and learning how to document and present incomplete or inconclusive data.

A critical aspect of dealing with uncertainty is being able to make adjustments when things go wrong, with one participant describing this as, "Fail fast, fail often, and learn from it", while another participant wrote "I understand that research includes things going wrong, but we learn from those things."

Another part of dealing with uncertainty involves being able to approach problems from multiple perspectives, including utilizing disciplinary lenses outside of one's core area of expertise. A participant explained:

> I learned the importance of approaching problems with an open mind. Many different things can go awry in the experimental process, and oftentimes the solutions to these problems are not so straightforward. Further research in tangential fields is sometimes necessary in order to solve fabrication issues. There's helpful knowledge that can change the tide of your research and get you back on the right track. Sometimes you must dig deep outside of your

specific area of study to gain a more thorough knowledge of the components you're working with

Other participants described dealing with uncertainty in learning how to deal with experimental results that did not support their initial hypotheses, and how to present results that are incomplete or inconclusive. One participant summarized this sentiment, writing, “My understanding of technical research has changed over this summer in that I now realize that no result is still a result, and it is okay if you cannot prove your initial hypothesis.

One of the major goals of REU and RET programs is to provide participants with experiences and learning opportunities that they might not encounter in the classroom. Dealing with uncertainty in the form of unexpected results and inconclusive data that arise from doing cutting edge research illustrates one way that the summer research provided a novel learning experience for the partcipants.

### D. Suggestions for Change

While the teachers generally appreciated the opportunity to work alongside undergraduate students as part of a combined REU/RET program, one of the undergraduate participants found this frustrating, writing:

> As an REU, I think it would be better if the RET's had their own projects to work on. In my lab I had to direct my RET on what he needed to do every single day. This took away from my experience a bit in having to manage him.

The undergraduate students participating in the summer research experiences generally have much stronger disciplinary backgrounds than the teacher participants, and these differences can sometimes place the undergraduates in a situation where they are expected to support a teacher participant. This situation could be prevented in the future by placing teachers only in larger research groups that include graduate students or post-doctoral scholars capable of assisting faculty with the mentoring responsibilities associated with REU and RET programs.

Placing summer research participants in larger research groups can also assist with the mentoring needs of all participants, and provide graduate students and postdoctoral scholars the opportunity to develop experience as supervisors and mentors. Lack of sufficient access to faculty members was a common issue identified by several of the participants. Developing clear expectations of faculty supervisors on the amount of time they need to spend with their undergraduate and teacher researchers, and clear expectations among participants in how often they should expect to meet with their supervisors can also help to alleviate these kinds of problems.

Another challenge associated with REU/RET program concerned identifying appropriate research projects for the participants to work on. A participant wrote:

> I recommend that the projects be a little more finalized before the students commit to them. I felt a little lost by myself at the beginning, and I was not always sure of my project because I had limited access to my mentor or any grad student help. I also suggest

> that the program move away from so much literature review for a single project, because mine was first based on that and it was a little hands off.

Faculty members need to balance structuring projects that are sufficiently open-ended such that the participants can be an active part of the design stages of the research process, while maintaining a timeline that allows sufficient time for data collection and analysis prior to the completion of the summer research experience. For example, involving participants in choosing the materials necessary to perform an experiment represents an important part of the experimental design process, however delays in acquiring the necessary materials can be a significant obstacle in completing a project given the shortened timeframe of a summer research experience.

Finally, faculty mentors need to be aware that REU and RET programs should be designed to give participants a broad understanding of and experience with technical research via a diverse set of activities. Having participants spend the bulk of their summer doing a literature review or repeating the same set of experimental procedures in a laboratory, while representative of the tasks researchers engage in, do not help participants develop a thorough understanding of the research process.

**Conclusions**

The mentored laboratory experiences of this summer research program resulted in numerous positive outcomes for both the student and teacher participants. These novice researchers developed more confidence in a wide variety of research skills, ranging from experimental design and literature reviews to increased familiarity with research tools and techniques, to communicating about their research both with their peers and to a wider research community. For the teachers, being immersed in a university engineering research environment helped them become more familiar with campus resources that they planned to utilize in their classrooms. Through their interactions with faculty, undergraduate students, and other members of the university engineering community, the teachers also developed knowledge of the undergraduate engineering student experience and how to better advise and support their students who are interested in pursuing degrees in engineering.

Uncertainty can take many forms in scientific and engineering research, such as dealing with unexpected or inconclusive results and how to present these results in a coherent manner. Performing novel laboratory research exposed the participants to uncertainty that they might not encounter via their coursework, and helped the participants develop strategies to deal with uncertainty. These strategies included recognizing that failure is an inherent part of research, learning to look at problems from multiple disciplinary perspectives, and learning to find value in results that do not support an initial hypothesis.

Many of the suggestions for change from the participants involved issues of guidance and mentorship. Participating faculty members need to establish clear expectations with the researchers that they are supervising regarding regular meeting times and how and who to approach with questions, and ensure that participants in the summer research program are not being delayed to a lack of guidance, feedback, or communication from their faculty members.

Faculty members should also work to identify a diverse set of research activities that expose participants to all aspects of the research process, from planning and experiment design through dissemination of results. In doing this, faculty members need to balance their need for labor to accomplish specific research tasks with recognizing that the primary goal of this program is to create an educational research experience for the participants. Coordinators of REU and RET programs need to actively work with faculty participants to establish clear expectations and work with them to ensure the development of high value research experiences for the participants in these programs.

Despite these challenges, this summer research program provided a valuable opportunity for both the undergraduate and teacher participants to develop a better understanding of technical research and develop the confidence and skills to pursue future research endeavors.

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