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Implementing and Assessing a Joint REU/RET Program in Materials Science

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Implementing and Assessing a Joint REU/RET Program in Materials Science

In this paper we describe 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 ten undergraduate science and engineering students and five local middle and high school teachers on campus for an 8-week research experiences working with different lab groups. Given the relatively small number of participants, we chose qualitative interviews as our primary source of data for assessing the effectiveness of this program.

The participants identified numerous positive aspects of participating in the summer research program. Students appreciated the sense of community they developed with both the other participants in the research program and the other members of their lab groups. Although most of the participants did not report the summer research experience as having a strong influence on their decisions to pursue graduate school or careers involving research, they did report both being more confident in their ability to be successful as a researcher and appreciating the opportunity to learn more about the practice of engineering research in an academic setting. For the teachers involved in the program we describe how participation influenced their leadership, perceptions of adoption educational innovations, and willingness to provide more opportunities to engage their students in authentic STEM research.

The participants also provided several recommendations for improvement to the summer research program. For the students, these included more materials in advance and a more streamlined onboarding process to allow them to get up to speed on their projects more quickly, consistent access to their supervisors, and work that is intellectually challenging. Suggestion from the teacher participants for improvement mostly involved requests for more guidance on how to incorporate what they were learning in their research into lessons for their classrooms.

By describing this program and the successes and challenges encountered by the participants and organizers, we intend to help others considering implementing REU/RET programs or other summer research experiences to design and implement successful programs.

Introduction

Numerous studies have shown that research experiences can have a strong influence on undergraduate students' decisions to pursue graduate education in a science, technology, engineering, or mathematics (STEM) discipline.[1–3] These programs can help students develop valuable research experience and skills, and clarify students' decisions to pursue further graduate study.[4] Encountering unstructured problems in the lab environment can help participants to be more comfortable dealing with the uncertainty and ambiguity of research.[5] These experiences also contribute to participants developing an identity as a scientist, engineer, or researcher.[6,7] Participating in summer research experiences can also help participants develop communication skills and the ability to explain technical work to a broad audience.[8]

Relationships that summer research participants develop, especially with faculty members, have a significant influence on both the participants' perceived value of the research experiences and their decisions to pursue graduate study in their chosen field.[9] Other research has shown that interacting with graduate students in a laboratory setting can help undergraduate students see themselves as future graduate students and increase their confidence in their ability to be successful as graduate students.[10] REU programs are well represented across engineering fields, and in materials science and engineering have focused on topics such as nanotechnology and nanofibers[11] and additive manufacturing[12].

In addition to supporting undergraduate students' development as researchers, summer research experiences can also be an effective way of helping in-service teachers develop a better understanding of research and willingness to incorporate open-ended research projects in their classrooms[13,14]. Research Experiences for Teachers (RET) programs have been in existence for over 30 years, and have numerous demonstrated benefits.[15] Participating in summer research led some teachers to incorporate more inquiry and research experiences in their classrooms, and changed their understanding of science teaching.[16] These experiences also helped teachers to keep abreast of rapid changes in their fields, bring the results of cutting edge research to their students, and "bridge the gap" between classrooms and research laboratories.[17] As with REU programs, numerous RET programs have been implemented in materials science and engineering[18–23]. An RET experience focused on polymers and polymer processing helped teachers to become better researchers, increase their understanding of science, and become more independent working in a laboratory.[24] Lessons developed and assessed as part of a bioengineering RET program were shown to positively affect student motivation interest in bioengineering.[20] Overall, RET programs are a well-established method for encouraging teachers to incorporate cutting-edge research in their classroom and increase teachers' abilities to facilitate authentic research experiences for their students.

Given both the prevalence of undergraduate research opportunities and their effectiveness at helping students develop research skills and professional identities as researchers, along with numerous benefits afforded by summer research experiences for teachers, we created the Research Experienced for Undergraduates and Teachers in Materials for Energy and Sustainability, a combined REU/RET summer program at Boise State University in materials science and engineering research focused on energy and sustainability. We provide a brief overview of this program, and describe how we assessed the outcomes of participation in the program for both the teacher and student participants.

Program Overview

Prior to their summer research experience, we recruited faculty members to serve as mentors and identify the research projects that they feel would benefit from an undergraduate researcher, followed by soliciting applications from interested undergraduates and local teachers. Our application deadline is typically mid-February, and decisions have to be taken fairly quickly thereafter in order both to commit excellent candidates to our program and have a finalized list of participants by the end of March, as several weeks are required to process the payment information and arrange for lab access. During the selection process we must ensure that at least 50% of our cohort are from non-research-active institutions and that we include as many as

feasible from under-represented groups. We must also take into consideration the preferred mentor choices of the candidates. In order to make an initial selection, several other factors are also considered, including: GPA, major, level of each candidate (*i.e.*, freshman, sophomore, junior, or senior), personal statements, and reference letters (two are required). In some cases a particular attribute is required (*e.g.*, the *atmospheric impacts on a semi-arid watershed* project requires that the student has his/her own car in order to visit rural sites). Students are given the opportunity to list their top three mentor choices on the application form, and every effort is made to best align them with either their desired mentor or the project for which they seem best qualified based on their background knowledge and current and future research interests.

Faculty mentors generally provided the participants with relevant background reading prior to their arrival on campus. Participants arrived at the beginning of June and stayed until the end of July for an 8-week research experience. For some participants, the research experience involved becoming familiar with a faculty member's ongoing research project and working through specific tasks, whereas other participants had the opportunity to work with their faculty member to identify a project that would be of interest and have a larger role in the design and execution 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 with a faculty mentor, the participants engaged in a variety of other activities, including tours of university laboratories and local industry and government engineering facilities. The students' experiences culminated with the creation and presentation of a poster describing their project at a statewide conference on undergraduate research.

Participants in the Materials for Energy and Sustainability REU/RET program interacted with other undergraduate student researchers via the university's interdisciplinary summer research community that included three other REU programs along with summer research scholarship recipients. Activities sponsored by the summer research community included a seminar series where participants had the opportunity to present their work to their peers, and general interest academic workshops focused on topics like communication skills or preparing for the GRE and applying to graduate school. The summer research community also sponsored a series of social events such as rafting trips or going to local theater performances. In addition to these formal interdisciplinary activities, the majority of the undergraduate participants in the Materials REU program (9 out of 10) came from out of state and spent the summer living on campus, rooming with participants in the other REU programs.

Research Method

To assess the impact of this program on both the undergraduate and teacher participants, we conducted exit interviews to explore their experiences and identify areas of improvement for the REU/RET program. All ten undergraduate students who participated in the program agreed to be interviewed, along with four out of the five teachers. A single researcher conducted all of the interviews over a period of a week. The interviews were guided by a semi-structured interview protocol that began with an invitation for the participants to describe their summer research experiences. This was followed by questions organized around benefits that they derived from

participation; challenges that they may have encountered; their understanding and interest in research and how this changed as a result of their participation in the program; an exploration of the relationships that they developed with fellow participants, their faculty mentor, and other members of the university research community; any changes that they would recommend to the program; and their overall satisfaction with their summer research experience. In addition, the teachers who participated in the program also described how they would utilize what they learned in their classroom.

All interviews were recorded and transcribed verbatim by a professional transcriptionist. The same researcher who conducted the interviews then analyzed these transcripts using the NVivo qualitative software analysis package. The data were open-coded around the themes of benefits, challenges, views on research, and changes, followed by a secondary analysis of these themes to identify patterns, similarities, and differences in the participants' responses[25].

Results

A. Benefits

For several of the participants, being able to apply what they had only previously read about or studied in a class to a hands-on lab experiment represented one of the major benefits of participating in the summer research experience. Participant 4 explained:

> "I knew I wanted to do batteries. I know that's what I want to pursue in grad school, that's the goal I wanted to do for a very long time so getting that kind of experience here has been good because, I've learned a lot about the whole process in general and about how they work and all that stuff. Getting actual tactile experience and not just reading about it anymore was good."

Though their lab activities, participants developed laboratory skills that they found both rewarding and valuable to their development as researchers. For Participant 1, this involved "Using really careful, cautious techniques, just improving fine motor skills in that sense." Going beyond just the development of skills, many participants found this experience emotionally rewarding as well. Participant 4 felt, "everything coming together, it's nice, you finally, everything, I don't want to sound tacky but everything you've read about and dreamed about, it actually exists, it's a real thing." While sometimes frustrating, participants also mentioned troubleshooting and learning how to deal with problems as valuable outcomes of their summer research experiences. Participant 6 explained:

> There was a lot of trial and error and it got me to think outside the box. I was running samples and they weren't really working out as planned and I didn't know what was going on so I had to rule out multiple things. I added a third bar to make sure solution was equally distributed, that helped a lot. I didn't know it was an O ring until three weeks before the end of the project, maybe two weeks, and that's when we ran our successful samples that gave us detailed information.

Many of the participants came from disciplines other than Materials Science and Engineering,

such as physics or chemistry. Being exposed to other disciplines and learning more about Materials Science and Engineering was a valuable outcome for many of the participants. Participant 3 explained:

> Definitely as far as my material science knowledge I've learned a lot from that week of just studying a textbook. I really learned a lot talking to the grad student and my mentor, I've gained a new perspective on material science, I think."

Participant 12, a teacher, said "Actually I was not aware of material science in general so just having a better understanding of what material science is and I can take that back because I just think of engineering and I kind of have a vague idea of what that is." This was echoed by Participant 13, another teacher who said "I have a better understanding of what, of material science in general, of what a material science lab does or what sort of research they do. Like how a research lab generally operates."

The summer research experience also provided many participants with the opportunity to develop their communication skills. Participant 4 explained: "I understand it's important, especially for the academia side, academic side of things just because you need to do presentations if you're doing your dissertation you need to be able to talk to people and present your data and your research." In addition to making formal presentations and creating posters, conversations and interactions with other lab members also provided a valuable context for developing communication skills. Participant 3 said, "my communication skills have become better because of it…being able to talk to my research group professionally and have them understand what I'm saying is something that I've learned to do and hopefully I'll be able to carry that through to other things."

Many of the participants considered the social connections they developed over the course of their summer research experience as a valuable benefit to participating in the program. For Participant 5, it was about being around like minded individuals, stating "I met everybody from my REU and I was really happy, everybody's really nice and it's a really great environment to be in. Never have I been around a group of people who are my age that all are really smart like this so it was really enjoyable to be in that kind of cohort." This was echoed by Participant 6, who stated, "I really enjoyed being around like-minded people that are in this program. Outside of my research group, exactly, I hang out with all the material science kids, we're all kind of tight knit. It's just good, bouncing ideas off and they're bouncing it back." Participant 4 appreciated the opportunity to get to know undergraduates involved in other research projects, saying "I liked how our living arrangements, it's, for the most part it's two people from one REU and two from another, at least that's the way it is in my apartment so you get to talk to them and learn about what research they're doing, that's been nice to see." Participant 6 summarized the social experience well, saying "I've never had anything like this, I've never really had that many STEM-related friends in a group before."

For some participants, their sense of social connection and belonging was the result of being able to work with helpful colleagues. Participant 5 stated:

> The PhD student I was working with was there pretty much all the time and he was really, really smart and he was able to walk us through things. A lot of chemical transfers, he taught us the etiquette for that. It wasn't too many, it was mostly just me, a couple other students for the REU and then two students who were undergrads here and then the PhD student. There wasn't too many people in the lab and everybody was from a different background so if there was one thing that someone knew more about they were able to help more.

Overall, the participants all described a range of benefits for participating in the program. Learning to develop laboratory skills, seeing real-world applications of theoretical material, being exposed to Materials Science and Engineering, improving communication skills, and developing relationships with other REU participants along with the other people who worked in their labs represented valuable outcomes from the summer REU/RET research experience.

B. Applications to the Classroom

While the teachers who participated in the summer research experience developed their personal skills as researchers, learning how to improve the educational experiences of their students upon returning to the classroom was the primary motivation for having them participate in this program. Several teachers mentioned increasing the focus in their classrooms on various aspects of doing research as a result of recognizing their importance over the course of the summer. These included having their student write up their experimental procedures and keeping good lab notebooks, performing literature reviews and citing references, and presenting the results of research. The teachers also appreciated learning about Materials Science and Engineering, and planned to incorporate content from this discipline into their classes.

The teachers also appreciated the opportunity to work alongside of undergraduate students and be able to interact with and get the honest opinions of individuals who were high school students until relatively recently. Participant 2 explained:

> I really enjoyed working with undergrad students because I worked closely with two and in the lab with about four and then in the offices with several more. It's really interesting to see what they are reflecting on. Being a high school teacher they're very open to telling me about their high school experiences or their college experiences and what has prepared them well and what hasn't so it's very anecdotal. It's very interesting to hear about their experiences, so just making those connections, talking to people about their experiences in high school and what they wish they would have had from a student perspective.

Some of the teachers also described how being recast in the role of a student helped them to better understand the struggles of their own students. Participant 2 said:

> I think it's a very powerful experience to understand what your students may be going into. For me it's directly applicable because I have many students that are going into the engineering field or they think they want to, juniors and seniors in high school, so it really helps me to have a better feel for what they'll be doing.

Participant 1 took this a step further and explained how being a struggling student helped her understand the experiences of her students who may not have the prior knowledge that they need to be successful:

> I feel like I gained a better understanding of kids who come in with really low background knowledge, especially if they maybe have language barriers. There's always this goal of wanting the kid to come to the understanding and not just giving them the answers but for someone who is really, really far behind, really helping them, give them the steps they need to have the background knowledge to get to the knowledge piece. So in essence I feel like the struggling, floundering kid who's way behind everybody else and just by asking questions, asking questions, asking questions I'm not going to get the answer because I don't have the background knowledge to get there so just thinking about how I can help those kids out

Another valuable outcome for the teachers was learning about the resources available at the university and building connections with university faculty and staff. Some of the teachers planned to invite university faculty or staff to present to their classes, while others simply appreciated the opportunity to know more about what was happening at the university and be able to share this knowledge with their students.

Ultimately, being in a lab working on solutions to open-ended design and research problems helped the teachers to be more comfortable with allowing students to pursue these kinds of inquiries in their own classrooms. Participant 1 was, "more open to having students struggle through a question that they're not necessarily going to get an answer for but having that experience of trying it, improvising it and trying it again", while Participant 2 said:

> I'm going to have a little bit more patience for it when, even if a student is doing something that they think makes sense to let them go down that avenue and work through that misconception themself, correct them if they're going way too far off and kind of give them more guidance and teach them more through, I think it's going to help me teach the process of science better.

Participant 13 explained how being in a lab environment helped her to understand the kind of environment she wants to create in her classroom to promote research. She talked about:

> Trying to create an environment that is inquisitive for the students, giving them an opportunity to ask questions because that's what I think the take away was is that you have to have some sort of independent drive to want to seek something out and so a lot of students don't really, or they don't feel comfortable doing it so I'm going to try and create an environment so that they can ask questions so that they do have this instinctual asking questions and problem solving to try and answer their own questions.

Helping students develop research skills aligned with the practices of research scientists and engineers, incorporating materials science and engineering in their classrooms, learning about the research activities at the university, and developing a better understanding of their students

and the struggles they encounter in the classroom represented valuable learning outcomes for the teachers who participated in the summer research experience that they planned to utilize to create more realistic research experiences for their students and contribute to an overall improvement in their teaching.

C. Challenges and Recommendations for Changes to the Program

With many of the participants coming from academic backgrounds other than Materials Science and Engineering and almost all of the participants having minimal direct experience with the topics they were exploring in their research, understanding new material in a new discipline was a significant challenge for many of the participants. Participant 7 explained:

> I definitely was challenged mentally to learn all this new material in material science, which was a good challenge to have because I definitely went away with a better understanding of applied science and applying the physics I knew to actual things in front of you…it was tough being purely a physics major and going into a whole new subject and the trying to make an impact on it.

While some participants had no issues with either developing a good working relationship with their mentor or being able to communicate with her/him on a regular basis, other participants described challenges with finding sufficient time to meet with their mentors. While some of this was due to extenuating personal circumstances that kept some of the faculty members away from campus, it mostly was due to faculty members simply being busy people. Participant 11 said:

> I felt that my professor wasn't quite as involved. He is definitely currently very busy, he's writing a lot of, he's trying to publish a paper right now and writing some grants so I think he was a little bit preoccupied so he wasn't, and maybe this is just his style but he wasn't in the lab very much.

For students who did not have other people in their lab to to turn to, the lack of access to their faculty mentor or other sources of guidance left several of the participants feeling like they did not make as much progress with their research as they would have liked. In addition, participants working largely on their own without the benefit of other lab members found the experience isolating. Participant 9 said, "working in a lab alone was not very fun and also not really having my mentor around, she wasn't around for most of the summer."

Monotony in their work presented another challenge to several of the participants over the course of their summer research experiences. Participant 6 described:

> Mindless sample preparation where I'm just sitting there and polishing to one micron for hours and hours on end…that was a challenge because I really couldn't do anything at the time. I couldn't research anything or read any literature…I knew I had to do at least 50 of these so that was pretty challenging.

In contrast to the monotony of repeating the same tasks, dealing with the unexpected was a challenge for several of the participants but one that also presented significant opportunities to learn and understand the process of doing research. Participant 14 explained:

> I guess a lot of unexpected things happen in research, definitely with lab research. Try through literature, try to figure out what the challenges will be before I encounter them because we have such a short period of time, that was really challenging. I guess I wasn't very good at that but I think that was a big challenge, try to find all areas where something could go wrong, even a process that didn't seem so involved so that I wouldn't waste too much time trying to fix what I messed up.

Issues surrounding time represented a major challenge for many of the participants. This included dealing with waiting for materials to arrive or simulation computations to complete. Given that the participants were constrained to research experiences over the course of a summer, many felt that they were just getting started when it was time to leave and wished that they had more time to work on their projects. Participant 7 explained:

> Because it took me a couple of days to even get oriented to that, know really what I was doing or be able to talk without sounding like an idiot sometimes. Besides that, once I got oriented and into it I'd say the past four weeks have been great. I felt like I found a place to be. Kind of sad I can't keep working on it because it's picking up now.

Finally, for the teacher participants, figuring out how to adapt what they had learned over the course of their summer research experiences to teaching in their classrooms was a major challenge. This challenge stemmed from a lack of access to equipment and software similar to what they used over the summer and students not having the scientific or technical background to understand the material. To address this challenge, several of the teachers recommended structured activities focused on helping them to develop lesson plans as part of the summer research experience.

D. Decision to be A Researcher and Understanding of Research

Many of the participants described feeling more confident in their ability to do research as a result of their summer experiences, with several of the participants also mentioning that they would use what they learned over the course of the summer to initiate their own research projects upon returning to their own institutions. Participant 5 said:

> I'm starting my own research thing at my school to do independent research. I had this idea to do this last year, oh, I'll just continue with the stuff I'm doing during the summer and that was as far as I'd gotten with it, I didn't really know too much more than that. But now since I've gotten here I feel completely prepared to go and set up all the funding, go and apply for all the grants.

Participant 5 went on to explain how the experiences of the summer helped him see himself more as a researcher and as an engineer:

> I've thought so much more about it and I've seen what research is like, I've seen kind of what an engineering life is like, being able to go on the tours that we went on, those were really good and just becoming more confident with, OK, this is something that I could see myself doing rather than some far off, abstract idea.

Several of the participants came from smaller educational institutions focused exclusively on undergraduate education, and appreciated the opportunity to see how research was done at a larger institution and learn more about what it would be like to be a graduate student. Participant 11 stated:

> Having the experience at a larger institution gives you a better perspective on what it's like to work in a larger institution and be a part of research in a larger institution. I think, I don't know, I think it's given me a little bit more perspective on the frustrations of research.

Participant 5 felt that the combination of doing research, presentation on topics like taking the GREs, and learning about what life would be like as a graduate student helped convince him that he was interested in graduate school and could be successful as a graduate student. Speaking about the dissertation process, he said:

> I was able to get into a couple of the graduate students thesis proposals and defenses here throughout the summer, they're just kind of advertised around and I feel like not many people take advantage of those but I went to a couple of them and just sat down and listened to how the faculty interacted, how the person explained their research and what kind of questions were asked and that really was a very good experience as well.

Other participants learned about the role of teamwork in research and understanding what it was like working on an interdisciplinary research team. Participant 7 stated:

> It's much more of a collaborative, team effort. You can't do research by yourself, you always, I think you always need somebody and you need to bounce ideas off each other otherwise you get too focused and you'll miss something along the way.

Finally, despite having positive experiences doing research as part of the summer program, some of the participants did not feel like the experience significantly affected either their understanding of research or decision to pursue a career or further study related to research. Participant 8 said, "I thought I was pretty sure I wanted to go to grad school before and I think it's pretty much unchanged." While the participants learned more about the process of research, the challenges and unpredictability of research, what it would be like to be a graduate student, and gained confidence in their ability to be successful as researcher, many of the participants began the summer research experience with a strong commitment to pursuing careers or further study that involved research and exited the program with these feelings confirmed as opposed to significantly changed.

Conclusions

The combination of intensive laboratory work, field trips and industry tours, career planning workshops, and social events helped the participants in the REU/RET summer research experience develop their skills as researchers and confidence in their ability to do research. Benefits of participation described by the participants included the opportunity to apply theoretical knowledge to the solution of real problems, developing technical and communication skills, learning more about materials science and engineering for the teachers and students coming from disciplines outside of engineering, and developing strong connections with faculty members, other people working in their labs, and the other participants in the summer research program.

The teachers participating in the research experience described an additional set of benefits related to the application of what they had learned to their students and their teaching. These included appreciating the opportunity to work alongside undergraduate students and learn about their experiences as high school students, a greater knowledge of the opportunities available for students and for collaboration at The University, and an increased willingness to incorporate research experiences in their classrooms.

The participants also described numerous challenges that they encountered over the course of their summer research, some of which resulted in their growth as researchers whereas others represented issues that needed to be addressed in the structure of the summer research experience. Learning how to manage time and complete their research projects in the relatively short timeframe along with dealing with unexpected issues and setbacks presented a challenge to several of the participants that resulted in personal growth.

Conversely, lack of access to faculty mentors and lack of guidance in the lab were programmatic challenges described by several of the participants. We plan to address these issues in several ways to improve future summer research programs. Participants need to have clear guidelines on the amount of time to expect meeting with their faculty mentors, and mentors need to commit to meeting with students on a regular basis to both ensure progress on the participants' research projects and help them participants develop as researchers. Lack of guidance and feelings of isolation were much less of an issue for participants working in labs with other undergraduate students, graduate students, and lab managers and other employees. When possible, students should be placed in labs where they can develop and rely on these relationships as opposed to working solely with a faculty mentor. Participants also felt that they benefited from being part of the research design process and developing a full understanding of their project, whereas participants relegated to repetitive work suffered from the monotony of these tasks. When possible, involving students in the design of their research project presented the most engaging experiences to the students. This needs to be balanced with the logistics of making sure that necessary materials have been acquired and appropriate background reading provided to participants to expedite their integration in the research project.

Ultimately, the summer research experiences helped the participants to become more confident in their ability to undertake their own research projects, develop a better understanding of the

research process, and encourage further graduate study and careers with a significant research component.

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