

## **AC 2009-744: USING A MIXED-METHODS APPROACH TO INVESTIGATE STUDENTS' PERCEIVED LEARNING AND CHALLENGES FACED DURING A SUMMER UNDERGRADUATE RESEARCH EXPERIENCE**

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# **Using a Mixed-Methods Approach to Investigate Students' Perceived Learning and Challenges Faced during a Summer Undergraduate Research Experience**

## **Abstract**

Undergraduate research experiences offer many benefits to our students and serve as a primary mechanism to recruit students to graduate school and expose them to the practice of research, which also enables students to learn problem solving in the context of discovery and innovation. This paper employs a mixed-methods approach and a Community of Practice (CoP) theoretical framework to investigate how participation in summer undergraduate research promotes situated learning. The mixed-methods approach, incorporating pre- and post- survey instruments as well as weekly self-reflective journal entries were utilized to study undergraduate researchers ( $N=10$ ) participating in an NSF-funded Research Experiences for Undergraduates (REU) program at a large research university. Positive learning outcomes gains pertained to communication skills, validation of career path, experimentation skills, valuing cross-disciplinary expertise and lifelong learning, and gaining confidence in working independently. Low ranked learning outcomes pertained to (a) leadership skills, (b) project management skills, (c) understanding ethical issues, and (d) identifying problems. Further, qualitative data analysis revealed that undergraduate researchers faced a number of challenges and frustrations pertinent to (a) scheduling, (b) time management, (c) running experiments with limited familiarity to instruments and equipment, and (d) at times limited guidance from mentors. This study has implications for better understanding and evaluating successful undergraduate research experiences (sponsored and unsponsored) with implications for recruiting and retaining students for graduate studies and research careers. Discussion of students' learning outcomes and challenges are presented, as well as implications for improving REUs. This paper can aid REU program directors, coordinators, and faculty advisors to improve their program and assessment efforts.

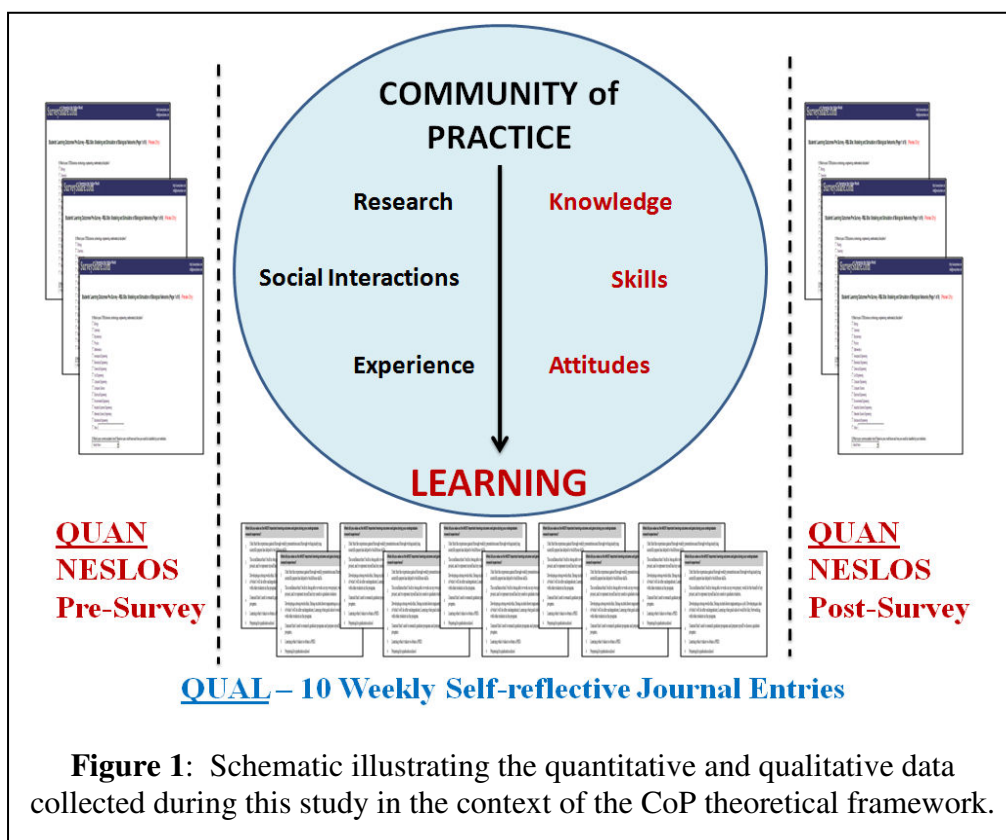
## **Introduction**

With global competitiveness driving many changes in engineering education, it is imperative that engineering educators provide students with experiences that promote innovation, creativity, and problem solving. Undergraduate research experiences provide one venue for students to learn these critical skills. Over the last two decades, the National Science Foundation (NSF) has been one of the biggest proponents of undergraduate research and currently supports hundreds of REU (Research Experiences for Undergraduates) programs totaling over \$300 million. In particular, REU program funds two types of grants related to undergraduate research: REU sites consisting of six or more undergraduate researchers typically participating at an eight to ten week summer experience, and individual supplements for a principal investigator to involve an undergraduate in ongoing work for a NSF-sponsored grant. Additionally, NSF Engineering Research Center supplements fund an average of nine students and therefore essentially function as sites<sup>1</sup>. The REU program solicitation<sup>2</sup> states:

The REU program is a major contributor to the NSF goal of developing a diverse, internationally competitive, and globally-engaged science and engineering workforce. It draws on the integration of research and education to attract a diversified pool of talented students into careers in science and engineering, including teaching and education research related to science and engineering, and to help ensure that these students receive the best education possible.

In spite of the significant investment in REU programs and the belief in the value of undergraduate research (sponsored and unsponsored) to improve education, there are limited studies that apply the principles of rigorous educational research to better understanding student learning as a result of undergraduate research experiences, and to connect practical recommendations regarding design of program elements with anticipated skill gains. *This effort was designed to meet this critical need for research and to contribute to our understanding of student learning during undergraduate research experiences as a means of structuring programs to provide successful experiences for our undergraduate researchers.* The remainder of this section presents some previous studies, the theoretical framework grounding this effort, and the research questions.

The *theoretical framework* guiding our current effort is based on constructivist learning theory<sup>8</sup>, including communities of practice<sup>9,10</sup>. Constructivist learning theory is a framework of learning involving a process of integrating new knowledge with prior knowledge such that knowledge is continually constructed and reconstructed by the individual. Communities of practice refer to communities of practitioners into which *newcomers* would enter and attempt to acquire the sociocultural practices of the community<sup>9,10</sup>. So, in a Community of Practice (CoP), *newcomers* are socialized into the practice of the community through mutual engagement with, and direction and support from an *old-timer(s)*. According to Lave and Wenger, there are three crucial characteristics of a CoP: (1) Domain – defined as the shared commitment, membership, and interest, (2) Community – defined as engagement, interaction, and sharing in learning activities, as well as, (3) Practice – defined as shared experiences that lead to shared practice and to the members as practitioners<sup>9,10</sup>. Lave and Wenger<sup>10</sup> also proposed situated learning as a model of learning in a CoP. Situated learning is learning that takes place in the same context in which it is applied and is often thought as apprentice-style learning which is student-centered and involves social constructivism. Crucial to student-centered learning is the role of the educator as a ‘facilitator’ of learning. During undergraduate research, the students as the newcomers work under the direction of faculty mentors and graduate students as the old-timers. The old-timers provide expertise and resources to enable the student newcomer to engage in the practice of research. Peer undergraduate researchers being a part of the research laboratory community also play a key role in fostering a successful experience. **Figure 1** illustrates the data collected during this effort in the context of the CoP theoretical framework. The two main tools utilized were the National Engineering Students’ Learning Outcomes Survey (NESLOS) and weekly self-reflective journal entries. The figure illustrates that pre-NESLOS was administered at the beginning of the REU experience (during the first day), post-NESLOS was administered at the end of the experience, and the journal entries were submitted electronically at the end of each week.



A recent large-scale, national study by SRI International, under contract to the NSF,<sup>3, 4</sup> investigated undergraduate research experiences in funded by the NSF's Directorate for Engineering, Division of Engineering Education and Centers, and Engineering Research Centers. These researchers found that undergraduate research experiences were important in shaping career decisions, citing increased expectations for graduate level work. Participants reported gains in understanding the role of the researcher and how to conduct a research project. Increased confidence and self-awareness were also reported.

Utilizing a CoP theoretical framework and interviews, Seymour and her research group<sup>5, 6</sup> studied the role of undergraduate research experiences on students' intellectual, personal and professional development, finding gains in (a) thinking and working like a scientist, (b) "becoming a scientist," (c) personal/professional gains, (d) clarification/confirmation of career plans, (e) enhanced career/graduate school preparation, and (f) other gains and skills. Although these studies provided a strong foundation of findings, one limitation was that the study predominantly focused on science students and not engineering undergraduate researchers.

Our own prior work<sup>7</sup> on undergraduate research experiences previously focused on social cognitive aspects of an NSF funded Research Experiences for Undergraduates (REU) program, finding that the experience positively impacted participants' academic and career plans, especially for doctoral level work. We utilized a mixed-methods approach to gain in-depth information about the impact of the undergraduate research experience, and particularly the role of graduate student mentors, on participants' self efficacy.

As evidenced, there are numerous ways in which students benefit and learn from being involved in undergraduate research. In the current paper, a mixed methods approach, utilizing pre- and post- survey and weekly self-reflective journal entries, we investigate the REU participants' skill gains and learning outcomes in the context of a CoP theoretical framework described in the following paragraph. In this paper, the participants are the same ten undergraduates studied in our previous paper<sup>7</sup>.

Grounded on the need to better understand student learning during undergraduate research experiences and the CoP theoretical framework, the **research questions** guiding this effort were:

1. What are students' perceived learning outcomes (knowledge, skills, attitudes) as a result of being a part of research community during a summer experience?
2. What challenges are students facing during summer research experiences and to what extent can experiences be shaped to improve students' learning?

## Methodology

A mixed-methods approach incorporating survey instruments and weekly self-reflective journal entries were utilized during this effort. A mixed-methods approach is appropriate for this study because triangulation enables researchers to neutralize the disadvantages inherent in all types of methods, and different methods are needed to understand the complexities of social phenomenon such as how people learn and interact with their environments<sup>11</sup>. The qualitative methods will provide data to enhance quantitative instruments, and qualitative data will be transformed in the analysis phase into quantitative terms that enable integration of both sources of information. The following paragraphs provide more details about the quantitative and qualitative methods used herein.

Participants completed online pre- and post-program survey instruments, utilizing the National Engineering Students' Learning Outcomes Survey (NESLOS), which included over fifty learning outcomes, derived from the ABET criteria "3a-k" and review of the literature. NESLOS included (a) approximately thirty technical learning outcomes closely linked to the ABET criteria, (b) about twenty personal and professional learning outcomes, (c) several open-ended questions about the expectations, strengths, and weaknesses of the undergraduate research experience, and (d) questions about the team, demographics, etc. NESLOS enabled us to measure students' perceptions of their learning during the REU experience. More details about NESLOS are included in previous ASEE publications<sup>12, 13</sup>. NESLOS learning outcome items were based on a 5-point Likert scale. Item analysis procedures revealed good reliability indices (Cronbach's alpha coefficients) varying from 0.60 to 0.90.

The weekly self-reflective journal entries provided an open-ended format for exploring undergraduate researchers' perceptions of their learning and their interactions within their research environment. Participants were asked to write a reflective statement which addressed their accomplishments, frustrations or challenges, what they had learned, and their laboratory and REU cohort dynamics. Each participant completed seven entries, starting after the first two weeks of the program, and going through the ninth week of the program. In lieu of a journal entry, individual interviews were conducted during the final week. Institutional review board approval was obtained for this study.

Journal entries were read by both authors and a research assistant, and a list of emergent themes were made. In the initial list, 54 themes were identified. The transcripts were then coded with the themes at the paragraph level using NVivo 7, a software package for qualitative data analysis. During the initial round of coding, six additional themes were identified and agreed upon, for a total of 60 themes. The entire set of journal entries (170 entries in all) were then coded by the research assistant, and were periodically checked and discussed with one author. NVivo was then used to produce coding reports for each theme, allowing the authors to determine the number of participants (*n*) who discussed a given theme, as well as the total number of references to a given theme.

The data collected herein enabled us to understand student learning in the context of a CoP theoretical framework. More specifically, during an undergraduate research experience, the students as the *newcomers* engage in the *practice of research* under the direction of faculty mentors and graduate students as the *old-timers*. The *old-timers* not only provide expertise and resources, but also enable the *newcomers* to be a part of the research social network - the laboratory environment and the individuals (faculty, postdocs, grad students, peers, technicians, etc.) who are a part of this network.

### ***Participant Profile***

Our sample consisted of 10 undergraduate researchers participating in a nano-technology themed summer REU program at a large, urban, research university during the summer of 2007. Participants were recruited and selected from around the country. More specifically, participants came from six universities and their majors included engineering (biomedical, chemical, electrical and mechanical), chemistry, physics, and mathematics. The sample included one African American, two Asian Americans, six Caucasians, and one Mexican American student. The participants included five females and five males. All these students were rising seniors with in-major GPA being equivalent to A, A-, B+, or B.

Although faculty experts from three engineering departments served as the primary research mentors, graduate students, and in some cases, post-doctoral fellows also served as mentors for participants. All these individuals/mentors served as the “old-timers” in the context of the CoP theoretical framework described previously. Weekly professional development sessions included events such a panel discussion with current engineering graduate students and professors on the topics of applying to graduate school and academic and industry career opportunities, as well as several weeks of written and oral technical communications instruction and practice. Participants were housed in on-campus furnished apartments, and social activities designed to foster camaraderie among participants were coordinated.

### **Results and Discussion**

In this section, we present results from the pre- and post- NESLOS responses as well as the weekly journal entries. A mix of qualitative and quantitative results is presented in order to illustrate not only the knowledge and skills gained as a result of the REU, but also to better understand the social interactions of the research laboratory community as well as the

frustrations and challenges that the participants faced. The quantitative and qualitative data presented herein serve to illustrate how learning is influenced by the CoP (research).

### ***Summary of Quantitative Findings***

Participants' responses from the pre- and post- NESLOS instruments are summarized herein. Both pre- and post- NESLOS instruments included the same fifty learning outcomes in order to enable students to rate these outcomes prior to starting their REU experience and also at the end of the experience. Comparison of the pre- and post- NESLOS responses (students' perceptions) provided insight into the learning gains which can be attributed to the undergraduate research experience. Also included in pre- and post- NESLOS were open-ended questions to assess students' expectations and additional outcomes gained during the experience. Thus, in this section, both results from the fifty learning outcomes and open-ended questions are presented.

Starting with one of the pre-NESLOS questions focused on what students expected to get out of their research experience, we observed that students' main expectations were to learn and understand the practice of research and to validate their interest in graduate school. These observations align well with the CoP theoretical framework described previously. A few of these students also expected to become better engineers as a result of participating in research.

In terms of the fifty learning outcomes assessed in the pre- and post- NESLOS instruments, we begin by focusing on the pre-NESLOS results, which give us insight about the skills the students perceived to have achieved during their past academic experiences prior to starting their REU. These results gave us a measure of the participants' perceptions of their existing skills upon starting their REU experience. The following list represents the top rated pre-survey outcomes:

- Convey ideas verbally and in formal documents
- Communicate effectively with others
- Conduct (or simulate) an experiment
- Identify and establish scientific/engineering requirements and constraints
- Apply experimental engineering/scientific tools (e.g., machining, oscilloscopes, instrumentation, laboratory equipment)
- Analyze and interpret data
- Value the diversity of a team (students, faculty, customers, etc.) leading to diverse talents and ways of thinking
- Use evidence to draw conclusions or make recommendations
- Identify and define problems for which there are engineering/scientific solutions
- Engage in critical and reliable self-assessment
- Gain strong leadership skills
- Gain leadership skills in managing team members and project tasks
- Recognize intrinsic interest in learning/intellectual curiosity
- Understand assumptions needed to solve my engineering/scientific research project

*These top rated pre-survey learning outcomes encompass the themes of (a) communication, (b) problem solving (identifying problems, understanding assumptions, establishing requirements,*

*drawing conclusions, data analysis, etc.), (c) applying experimentation tools, (d) valuing team diversity, (e) engaging in self-assessment, and (f) gaining leadership skills.*

Continuing with the post-NESLOS results, the following list represents the learning outcomes that students rated the highest at the end of their REU experience:

- Convey technical ideas in formal writing and other documentation
- Communicate effectively with others
- Recognize the need to consult an expert from a discipline other than my own when
- Know what I NEED to do to attain the goals I have for after graduation
- Know what I WANT to do after graduation (get a job, go to graduate school, etc.)
- Conduct (or simulate) an experiment
- Convey ideas verbally and in formal presentations
- Identify and establish scientific/engineering requirements and constraints
- Recognize intrinsic interest in learning/intellectual curiosity
- Apply experimental engineering/scientific tools (e.g., machining, oscilloscopes, instrumentation, laboratory equipment)
- Design an experiment
- Analyze and interpret data
- Understand assumptions needed to solve my engineering/scientific research project
- Recognize the need for life-long learning
- Recognize contemporary engineering and scientific issues

*These top rated post-survey learning outcomes encompass perceived gains focused on (a) communication skills, (b) career validation, (c) experimentation skills, (d) analytical skills, (e) valuing cross-disciplinary expertise, and (f) valuing lifelong learning.* Some of these high ranked outcomes may be attributed to some specific REU activities. For example, the high ranked communication skills may be attributed to formal training during the REU. Such training was offered in the form of workshops (by a technical communications faculty member) and peer-review practices focused on designing effective presentations and writing technical papers. A panel with current and former graduate students, as well as professors, was part of the REU to provide necessary discussion about career paths, getting in to graduate school, selecting a research advisor, etc. REU students would also frequently have informal interactions with their mentors (faculty, graduate students, postdoctoral researchers, REU director) to discuss career paths.

Although we have presented the top rated pre- and post- NESLOS learning outcomes, it is also important to compare pre- and post- responses in order to gain insight into the learning outcomes that revealed the highest perceived gains as a result of the REU experience. Some of the highest learning gains included (a) validation of career path, (b) applying technical codes, (c) designing an experiment, (d) recognizing cross-disciplinary expertise, and (e) formulating a range of solutions. On the other hand, learning outcomes that revealed the lowest gains included (a) leadership skills, (b) project management skills (time, organization, people resources, task management), (c) identifying ethical issues associated with a project, and (d) identifying problems (this is expected since students join a research lab with prescribed research problems).



To supplement the quantitative nature of the learning outcomes in NESLOS, students were also asked a number of open-ended questions. In one such question from the post-NESLOS, students were asked to list their *learning outcomes* they perceived as most valuable during the REU experience and their responses are summarized as follows (in no specific order):

- Oral communication skills from periodic presentations
- Analyzing and writing scientific papers
- Confidence gained in being able to work on their own
- Gaining strong work ethic
- Valuing the engineering profession
- Understanding graduate school environment
- Networking with other students
- Understanding research and the unique contributions that can be made

This list provides some additional learning outcomes that were not included as part of the fifty rated outcomes and thus serves to illustrate that these are also valuable learning outcomes. In the future, such responses could be included in NESLOS.

In the form of an open-ended question in post-NESLOS, students were asked to describe the *most valuable aspects* of their REU experience. Representative quotes included:

The most valuable aspect of this summer was the strong relationships built with members of the lab and of the program. Learning to work with others is not always easy especially when coming from such diverse backgrounds; this experience really helped in gaining experience with working with others.

The hands-on experience of handling, preparing, and running actual experimental tests. This helps to build confidence and research skills.

The most valuable aspect was knowing how graduate school really works and what is expected from you.

*These student responses illustrate the perceived value of a strong social environment in conducting their research and the importance for them to gain insight into the research community and the practice of research. These observations strongly align with the CoP theoretical framework, which identifies the social environment as a fundamental and critical factor for establishing a strong sense of the community and understanding of the community's practices.*

In post-NESLOS, students were also asked to list some of the *biggest challenges* that they faced during the undergraduate research experience and their responses included:

The biggest challenge was having to work on computer simulations which is something I never really cared much for. Also, having to give presentations to my superiors.

Working with graduate students because of their schedule and their work. You don't want to be bothersome, but at the same time it's your 10 week investment.

One part of the process we were trying to develop just would not work. We tried about ten different things and just could not find a proper solution. It was very frustrating, but working on it involved a lot of critical thinking.

I am an Electrical Engineering major. I found designing physical and mechanical systems and thinking three-dimensionally very difficult.

Dealing with problems as they came up. Learning how to fix an issue, and still remain on schedule, was a little different.

Understanding the explanations behind the results that we got.

The biggest challenge was facing such an open-ended problem with minimal guidance.

*These responses suggest that challenges arose during the course of their research experience with scheduling, time management, frustrations of the work, understanding and making sense of the results, and applying technical skills to which students had little exposure.*

In post-NESLOS, students were also asked about their interactions with faculty advisors and interactions with their peers. More specifically, students were asked to rate how strongly they agreed with a number of statements which were based on a 5-pt Likert scale. Nine of the ten participants “agreed (4)” and “strongly agreed (5)” with the following statements: (a) my faculty advisor(s) expected high quality work for me, and (b) the respect among team members was good. Eight of the ten participants “agreed (4)” and “strongly agreed (5)” with the following statements: (a) I received good guidance from postdocs and graduate students, (b) I felt comfortable in contributing to discussion and/or asking questions, (c) the cooperation among the research team members was good. Lastly, seven of the ten participants “agreed (4)” and “strongly agreed (5)” with the following statements: (a) I received good guidance from my faculty advisor, (b) students taught and learned from each other, and (c) the group meetings had an open and positive atmosphere. *Overall, these results suggest positive interactions with peers, graduate students, postdoctoral researchers, and faculty advisors.* In the context of the CoP theoretical framework, which identifies the role of the mentors (old-timers) as providing support, direction, and portraying the sociocultural practices of the community to the students (newcomers), these results illustrate the power of strong mentorship.

### ***Summary of Weekly Self-Reflective Journal Entries***

Coding of the students’ weekly self-reflective journal entries resulted in 60 emergent themes related to (a) lower-order and higher-order skills, (b) professional and personal skill gains, (c) technical skill gains, (d) confidence gains, (e) community membership and interactions, (f) faculty and graduate student interactions, (g) emotional growth, and (h) formation of the research identity. Ten of the most prevalent themes, based on the number of references, are listed below:

- Frustrations with research and processes (N=10, 71 references)
- Establishing and understanding REU student group dynamics (N=10, 55 references)

- Understanding and applying new knowledge, concepts, and processes (N=9, 37 references)
- Gaining analytical, critical thinking, and reasoning skills (N=10, 37 references)
- Gaining confidence (N=8, 27 references)
- Positive and negative research team environment (N=9, 25 references)
- Gaining independence (N=8, 22 references)
- Communicating technical ideas to a variety of audiences (N=8, 22 references)
- Improving time management and planning (N=9, 21 references)
- Gaining positive mentoring from faculty or graduate students (N=9, 20 references)

Most of these themes are in alignment with outcomes measured using NESLOS, but the one most prevalent and the hardest to measure using NESLOS pertained to frustrations faced during the research experience. Therefore, it is this theme that we will focus on for the remainder of this section. The following list of responses includes some of the frustrations the participants included in their weekly journal entries in response to prompts about frustrations. The responses can be summarized as frustrations encompassing: (a) scheduling, (b) instrumentation and equipment malfunctioning, (c) running experiments, (d) becoming familiar with instrumentation and equipment, (e) receiving timely guidance from mentors (including graduate students, postdoctoral researchers, and faculty), (f) preparing technical documents, (g) communicating with many audiences.

#### *A. Scheduling and Time Management Conflicts*

The day started off with rooting around for 2 hours trying to find out why the pump wasn't working, and blossomed into an entire day of bad samples. We didn't bother to ask around on how to set up the samples and it came back to bite us. Thankfully we got it all done on Tuesday, but with schedules as tight as they are, it is really frustrating to lose a whole day.

The most frustrating thing this week was waiting for a grad student who I needed to run a machine. He didn't get in till about four the day I was ready to work on part of the project, and I felt as if I'd wasted 8 hours of the day. Also frustrating was the [equipment] is behaving strangely, but since I'm not working on it so much, it's hard for me to diagnose the problem.

#### *B. Instrumentation and equipment malfunctioning*

The [instrument] had to be disassembled once again. We tore a gasket somehow and it sprung a leak. Wasting 2 days fixing it and then having to re-characterize it afterwards to make sure it works the same as it once did has proven to be a gigantic pain. Getting unexpected and irrational results from the simulations was the biggest frustration, especially because last week's results were good and reasonable.

BAH! Nothing works! To get the results to repeat is not so simple. Because of lots of little factors which I mostly understand and am aware of, the process is simply not a good

enough solution. I do have one solution, but I'm not even sure that will work. But this is what research is all about, and I knew what I was getting into when I signed up.

*C. Running experiments with limited familiarity to instruments and equipment*

The biggest frustration I faced has probably been learning the best way to run the experiments we're doing. I possess very little knowledge of some of the experiments we undertook. As a result, we [two undergraduates] foolishly set up how long and how many experiments we wanted to run when we should have a) asked for some suggested lengths of time to run the machine, or b) run a single test, looked at the results, and continued on armed with some extra preliminary knowledge. We probably could have accomplished more if we had run the experiments better. In fact the next day, we did ask for some suggestions and then ran a test run, and ended up doing twice the number of experiments in half the time.

*D. Limited guidance from research mentors (includes faculty, postdoctoral researchers, and graduate students)*

My biggest frustration was that my mentor had been out of the country for the start of the internship. Unfortunately, he did not leave instructions with the post-doc in charge of the research project for my role for the summer. I had to wait for my mentor to return to receive any tasks.

Perhaps because they [graduate students] know me and are used to my spending time proofreading, they don't think too much of my boredom. But, I feel the situation is starting to become somewhat ridiculous. If I don't go find them [graduate students], they don't have a task for me. It's like they don't have anything actually planned for me to do. Sometimes, I wonder if they were even informed of what I have to accomplish by the end of the summer for the REU.

*E. Need for Training on Specialized Topics*

The biggest challenge was to understand the physics and math behind the project because I have taken few physics courses. Another challenge was learning how to use [programming language] even though I'm still learning how to utilize the language. My biggest frustration was waiting for the extremely long simulation times in the computer. Another frustration is that I can only perform these simulations in the computers in the engineering lab room in the first floor. Sometimes, because of classes occurring in the lab, I cannot complete these simulations.

My biggest challenge was to code various infinite series equations and learn some [software] functions that I had never used before. My biggest frustration was discovering and concluding that our simulations were incorrect compared to existing data.

One of the largest frustrations this week was trying to write an introduction to the final paper. I found it difficult to introduce everything that the paper will contain as well as

background information when it is still not clear exactly which treatments we will get to use. It was good practice and nice to know that I have a good start on the paper, however the assignment seems redundant as I will most likely have to change a large portion of it before the final article.

What went wrong was that when I thought I was finished analyzing my data, the graduate student told me that I had plotted the wrong range of data and the analysis was insufficient. Thus, I had to go back, re-plot all of my data, and re-analyze my plots.

*These findings illustrate the value of weekly self-reflective journal entries, which provided valuable assessment of student learning in ways that a survey could not measure and in ways that most of the literature on this topic have not addressed in detail.*

## **Conclusion**

In spite of such widespread support and belief in the value of undergraduate research (sponsored or unsponsored) to improve education, the bodies-of-knowledge and learning outcomes comprising of the countless ways in which students benefit and learn from being involved in research projects have been understudied. To address such a need, in this study we utilized a CoP theoretical framework and a mixed-methods approach, in which qualitative and quantitative data were collected to aid in gaining insight about student perceptions of their learning as a result of participating in a summer undergraduate research experience. A mixed-methods approach is appropriate for this study because triangulation enables us to neutralize the disadvantages inherent in all types of methods, and different methods are needed to understand the complexities of the research environment. The qualitative data, acquired from students' weekly journal entries, provided data to further enhance an existing National Engineering Students' Learning Outcomes Survey (NESLOS), developed by the lead author and utilized in prior efforts<sup>12, 13</sup>. The strength of the mixed-methods approach used herein is that such qualitative and quantitative tools can be used across project-based learning experiences (undergraduate research, industry internships, capstone design, service learning, etc.), across engineering disciplines and engineering programs. Key findings are likely to be transferable across other engineering REU programs as well as other undergraduate research opportunities.

Overall, findings from this study revealed that students perceived to learn essential problem solving and research skills during their summer REU. Significant learning outcomes pertained to (a) gaining communication skills, (b) validating their career path, (c) applying technical codes, (d) designing an experiment, (d) recognizing the value of cross-disciplinary expertise, (e) valuing lifelong learning, (f) gaining analytical skills, and (g) formulating a range of solutions. Additional learning outcomes perceived by students as a result of the research experience (measured using open-ended questions in NESLOS), included technical writing skills, confidence gained in working independently, valuing the engineering profession, networking, and understanding the unique contributions of research. Also, overall NESLOS results revealed positive interactions with peers, graduate students, postdoctoral researchers, and faculty advisors.

Although we have presented many of the positively perceived learning outcomes as a result of participating in REUs, our mixed-methods approach enabled us to also gain insight into

challenges and frustrations that students faced. Learning outcomes that revealed some of the lowest gains pertained to (a) leadership skills, (b) project management skills (time, organization, people resources, task management), (c) identifying ethical issues associated to project, and (d) identifying problems (this outcome is expected considering that students join a research lab with prescribed research problems). Further, challenges and frustrations that were addressed by students included (a) scheduling conflicts, (b) time management frustrations, (c) instrumentation and equipment malfunctioning, (c) running experiments with limited familiarity to instruments and equipment, (d) at times limited guidance from mentors (including graduate students, postdoctoral researchers, and faculty), and (e) limited knowledge to prepare technical documents. Frustrations and challenges like these are common with research, but by understanding these challenges we can provide suggestions to improve REU experiences. Moreover, these frustrations and challenges are well understood by the community of practitioners (the researchers/mentors as the old-timers in the CoP theoretical framework) and it is imperative for the undergraduate researchers (as the newcomers) to understand that such challenges are part of the practice of research. As evidenced by results from our previous effort the experience served as mastery experience and contributed to their self efficacy for research despite these frustrations<sup>7</sup>.

So, where and how can improvements be made to increase student learning during undergraduate research experiences? From the findings presented herein, a number of suggestions can be recommended for REU directors and faculty advisors. Some of these recommendations include:

- (a) Mentors and undergraduate researchers should consider collaboratively outlining the 10-week summer experience and developing a project management plan. Such a task would address the low rated outcomes pertinent to project management which were observed from NESLOS results and weekly journal entry analysis. Further, collaboratively working through the practice of research (procedures, processes, project tasks, deliverables, challenges, frustrations, community, etc.), mentors as the old-timers can guide and support the students as the newcomers to better understand the procedural practices of research and project management.
- (b) Ethics should be integral to the REU experience and address the fact that understanding ethical concerns was rated as some of the lowest outcomes.
- (c) Given the nature of undergraduate research experiences, which are predominantly independent, some level of team-work should be encouraged. This is particularly important because during this typical 10-week REU duration students begin and need to better understand the practice of research and the social environment in the laboratory and outside. So, social interactions of not only the students and mentors, but also amongst students as the newcomers are critical in establishing a strong sense of membership and identity as researchers for the undergraduate students.
- (d) Because summer REU experiences have a short duration and it appears that many students in our study focused on designing and conducting experiments rather than analytical skills, it is recommended that students be allowed to more extensively focus on analysis and applying computational/numerical tools (which was a low rated outcome) even after their REU experience has ended. This is important because the practice of research requires both experimentation and analytical skills, so the students should be able to get exposure to most aspects of research, even if that exposure is limited.

- (e) Open discussion between mentors and students about the frustrations/set backs of the research process should occur regularly. Students should understand that such challenges are common, but mentors should encourage and reassure students so that they are not discouraged. This student-mentor interaction is critical for not only building a strong sense of community, but also important for students as the newcomers to understand the practice of research with all the challenges (positives and negatives) associated. Painting an authentic picture of research is critical for students to identify with being researchers and belonging to the research community.

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