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Experiential Learning in a Summer Program: Engaging Undergraduate Students in STEM Research Experience

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Abstract

This study explored experiential learning opportunities for undergraduate students in the area of energy and environment as part of a National Science Foundation (NSF) funded Research Experience for Undergraduate students (xREU). This summer research project was conducted in a private university located in the northeastern United States. Since the primary objective of the xREU program was to attract students from non-research-intensive universities to interdisciplinary research, the program was specifically designed to address the development of key learning and working skills that will serve participants throughout their careers.

Using several instruments (including the National Engineering Students' Learning Outcomes Survey [NESLOS], a survey administered biweekly, and a 24-item demographic questionnaire), we collected both qualitative and quantitative data. The results showed that, overall, participants' content knowledge and other related skills were enhanced over the summer through experiential learning opportunities. At the beginning of the program, most students learned more about conducting an experiment from their coursework learning, whereas toward the end of the program they learned more from their engineering service experiences.

Introduction

Science, technology, engineering, and mathematics (STEM) education is vital to the United States' interests and will be an integral part of maintaining our leadership when tackling the impending grand challenges associated with energy and the environment. Experiential learning is one means recognized by the National Academy of Sciences to improve retention of STEM students and advocate learning paths for successful future STEM careers (Freeman, Eddy, McDonough, Smith, Okoroafor, Jordt, & Wenderoth, 2014; Thiry, Laursen, & Hunter, 2011).

Broadly speaking, experiential learning is the process of generating meaning and gaining knowledge from experiences that combine applied and theoretical concepts with real-world implications (Kolb, 1984; Mughal & Zafar, 2011). Experiential learning, which involves various opportunities for practice-based activities, can be a valuable learning model for engineering students and can help them improve relevant knowledge and skills outside the traditional classroom settings (Ghrayeb & Vohra, 2011; Yates, Wilson, & Purton, 2015).

Research focused on fulfilling the needs of high school and college students has been conducted on summer bridge programs (Barnett et al., 2012; Kezar, 2000). Yet, very few summer programs or research studies have focused on undergraduate students who are studying at non-research universities. This group of students usually does coursework in their program and does not find opportunities for developing research skills. Thus, this study focused on the following three objectives in the Research Experience for Undergraduate students (xREU) experiential learning summer program:

- Providing experiential learning research opportunities for students and their faculty advisors who come from institutions that do not typically offer research experiences to undergraduate students
- Encouraging participants to explore and pursue graduate education and research careers in cutting-edge science and engineering fields
- Exposing participants to the benefits of experiential learning (*do*, *reflect*, *apply*) through the synergy of hands-on research projects, active discussion and feedback, reflection of pursuits, and awareness of how their efforts fit into the broader scientific and engineering challenges associated with energy and the environment

Benefits of Experiential Learning

Experiential learning draws on the work of prominent 20th-century scholars, such as John Dewey, Carl Jung, Jean Piaget, William James, and others (Kolb, 1984). Kolb, Boyatzis, and Mainemelis (2001) believed experiential learning theory is a holistic model of learning and a multilinear model of adult development in which the experience plays a pivotal role. The term experiential learning is defined as "the process whereby knowledge is created through the transformation of experience. Knowledge results from the combination of grasping and transforming experience" (Kolb, 1984, p. 41). Sawyer (2005) defined experiential learning as the ability to transfer knowledge that builds on prior knowledge, integrates knowledge across domains, can be implemented and put to use, reflects on the learners' own learning processes, and is affected by the experiences and information gathered from the learner.

According to Kolb et al. (2001), experiential learning theory portrays two modes of grasping experience—concrete experience and abstract conceptualization—as well as two modes of transforming experiences—reflective observation and active experimentation. These four modes, which are illustrated in Figure 1, show the iterative process of learning and can be used as a guide in creating new experiences. Grasping and transforming experiences can be better facilitated by designing project-based environments based on the needs and interests of the students.

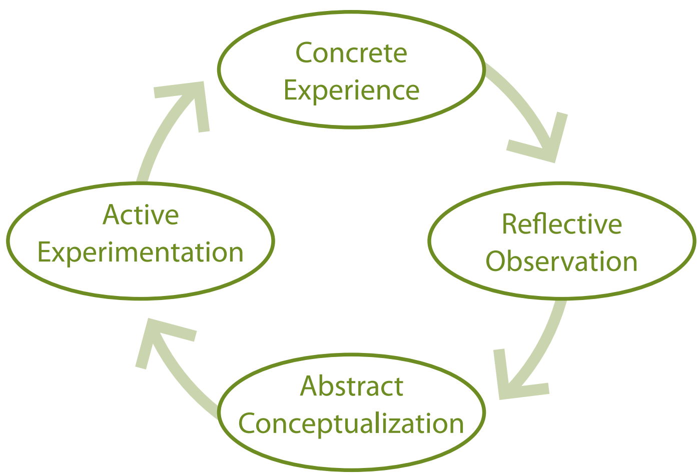

Figure 1: Experiential Learning Process
(Kolb, Boyatzis, & Mainemelis, 2001)

For instance, some students get more excited about learning when they are actively involved in the learning process through discussion, group work, hands-on participation, and applying information outside the classroom (Wurdinger & Carlson, 2009). Implementing experiential learning theory modes in everyday classes in higher education settings can fulfill this preference. Wurdinger and Carlson (2009) emphasize the importance of implementing a project-based approach to motivate students and improve their real-life skills. They argue that, as a teaching method, project-based learning allows students to tap into their interests through projects that involve "meaningful learning experiences" (Wurdinger & Carlson, 2009, p. 45).

Railsback (2002) indicates that the benefits of project-based instruction are that it is active rather than passive, it creates opportunities for self-directed and autonomous learning, it enhances communication skills, and it motivates learning. In project-based learning, the students are engaged in problem-focused instruction required to pursue solutions to authentic problems. They are asking and refining questions, debating ideas, collecting and analyzing data, communicating their findings with others in the project, and creating products or artifacts (Blumenfeld et al., 1991).

Recently, many programs in various undergraduate disciplines have started shifting toward project-based approaches using the tenets of experiential learning. Alvarez and Schultz (2018) adapted an interactive preclinical course based on experiential learning theory and implemented it with 81 dental students. Their aim was to help students communicate more effectively with patients, which is vital for patients and physicians. Students found the course important for their future careers and had the opportunity to reflect on their own actions.

In another project by Fischbach and Guerrero (2018), the instructors tried to engage and motivate 173 students using a marketing project for mobile business (e.g., food trucks, mobile dog groomers). The students experienced two key challenges: promoting a mobile retailing event on campus and developing a marketing plan for a unique mobile business retailing idea.

Experiential learning is not limited to in-class pedagogical practices between instructors and students. In a study by VanSchenkhof, Houseworth, McCord, and Lannin (2018), experiential learning courses were implemented with 477 students to describe peer-assessment processes as a critical component of team-based and problem-based teaching methods.

Research continues to expand the literature on experiential learning and project-based learning in colleges and universities. Yet, new applications of experiential learning opportunities for undergraduate students from non-research universities in the form of summer programs need further exploration. In addition, lack of a robust theoretical framework in the design and implementation of experiential learning programs has caused the loss of some of the most important aspects, such as reflection.

Theoretical Framework of Experiential Learning

Dewey (1938) and Kolb (1984) believed that experience without reflection is not learning. They argued that reflection is an integral part of experiential learning since it requires learners to think about past experiences and learn from them (Kolb, 1984). As illustrated in Figure 2, direct experiences can come from hands-on projects and real-life learning skills that go beyond core subjects taught in a traditional lecture environment (Diem, 2001).

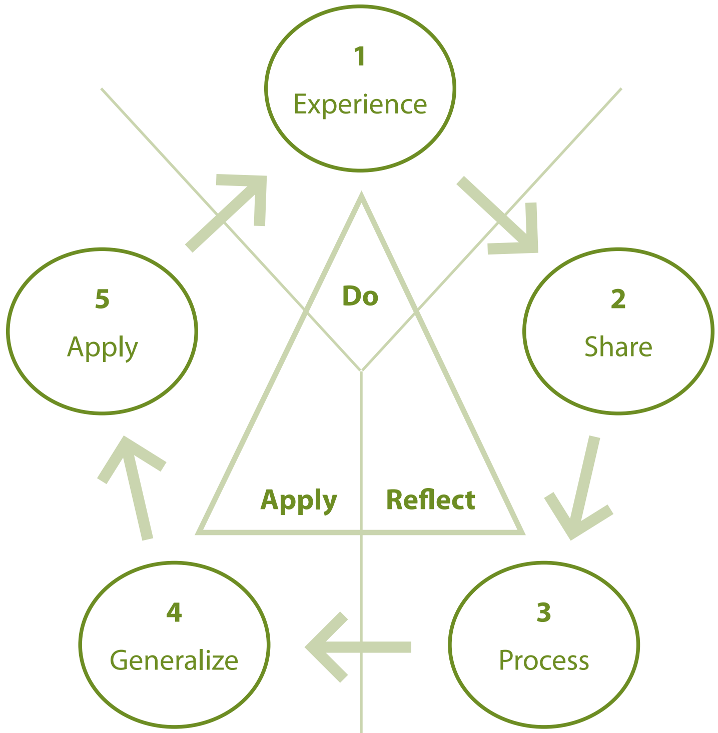

Figure 2: Adapted from the "Do, Reflect, Apply" Experiential Learning Model (Diem, 2001)

Diem's model is, in many respects, similar to Kolb's experiential learning model presented earlier in this paper (see Figure 1). The *concrete experience* in Kolb's model is aligned with *experience* in Diem's model. However, in Kolb's model there is one component named *reflective observation*, while Diem's model has broken this section into two components—*share* and *process*. They both refer to the importance of reflection in this process, but Diem's breakdown has made the process easier to observe in classroom activities of experiential learning projects.

Diem's model has further broken Kolb's *apply* component into *generalize* and *apply*, which is more aligned with the inquiry processes that happen during experiential learning. By contrast, Kolb's model merges these two into one component called *active*.

Diem's experiential learning model was used as a theoretical framework for this study on undergraduate experiential learning practices in the area of energy and environment. One significant facet of experiential learning is providing undergraduate research opportunities for relevant global scientific challenges, such as the delicate interplay between energy needs and environmental implications (Gregerman, Lerner, von Hippel, Jonides, & Nagda, 1998; Shellito, Shea, Weissmann, Mueller-Solger, & Davis, 2001). Undergraduate research opportunities have long been recognized as an important tool for improving enrollment, learning experience, retention, and graduation rates in STEM fields (Lopatto, 2004; Thiry et al., 2011). Hence, this study is based on experiential learning principles and is focused on examining the changes in experiences and learning outcomes related to experiential learning. The broad research question that guided this study's data collection and analysis was this:

> What are the changes in the participants' learning outcomes (cognitive, affective, social, professional) and skill gains as a result of the Research Experience for Undergraduate students (xREU) experience?

Description of the Research Experience for Undergraduate Students (xREU) Summer Program

The xREU summer program consisted of an intensive 9-week summer research experience at a 4-year private university located in the northeast of the United States. Each student worked closely with a faculty mentor and their research group within the energy and environment team on a specific research problem. The program was specifically designed to address the development of equal learning and working opportunities for students with less experience at a research-intensive university (Galoyan, Talafian, Hammrich, & Lamberson, 2019). The research-intensive activities included the following:

- Research problem identification, critical literature review, and hypothesis development
- Research plan design and implementation
- Research techniques, including new methods and/or skills
- Results dissemination in both written and oral form

In addition to research, the following activities, which address the most vital components of experiential learning (*do*, *apply*, and *reflect*), were planned for the xREU participants.

Lunchtime discussions (apply-reflect)

Students learned about the varied paths to successful research careers through weekly interactive lunchtime discussions. Each discussion included ample time for students to ask questions and interact with the faculty speaker in an informal environment.

xHow[1] experiences (do-apply)

Participants attended weekly sessions specifically designed to enhance their understanding of how research

- is conducted (by performing literature searches, research topic selection, and data analyses),

1 The "x" in "xHow" represents "experiential."

- is communicated (by preparing posters, oral presentations, and papers, and by discussing grant proposals),
- fits into society (ethics and public policy learning), and
- can be made more accessible (aiding in teaching research fundamentals, educational pedagogy, and age-appropriate lesson development).

Intergenerational xMentoring[1] (apply)

The interdisciplinary research teams consisted of faculty, graduate students, and undergraduate students who interacted with each other. Graduate students were usually assigned as mentors to the undergraduate students, who could easily reach out to them to ask questions or get help. Graduate students also facilitated the progress of undergraduate students and connected them with faculty when they needed expert support.

Digital imaging journals (reflect)

Participants kept digital imaging journals of their projects. Digital imaging is a journaling method in which students take screenshots of their progress on computers. Journaling was an added feature of the program that was based on experiential learning theory and allowed students to actively reflect on their projects and evaluate their progress throughout the program.

Field trips (apply)

Trips were arranged so participants could see energy and environment research in action at nearby industrial and national laboratories. These visits were arranged for undergraduate students to see potential future careers in industrial settings.

Group interactions and networking (do)

Participants were given ample informal opportunities to interact with other students, researchers, and fellows across the university campus. Since the program was designed as an informal project-based experience, students, when they were not working on their projects, could interact with mentors, graduate students, and instructors. These networking opportunities were specifically designed for the students to interact with experts in the area of energy and environment and learn about broader scientific and engineering challenges in the field. One of the goals when designing this xREU program was to create opportunities for students to be involved in active discussions and get feedback on their research projects from experts.

1 The “x” in “xMentoring” represents “experiential.”

Methodology

Participants

The sample for this study consisted of 13 undergraduate students enrolled in the xREU program offered by a four-year private university. The majority of the students who participated in this program were junior (54%) and senior students (39%). The participants majored in three engineering fields: mechanical engineering, chemical engineering, and environmental engineering.

Instruments

To answer the research question, a pre- and post-survey instrument called the National Engineering Students' Learning Outcomes Survey (NESLOS), derived from the Accreditation Board for Engineering and Technology (ABET) criteria and backed by an extensive literature review, was used. This survey allowed participants to self-assess their learning outcomes as a result of their experiences.

Other evaluation instruments included the 24-item demographic questionnaire administered at the beginning of the program and an open-ended survey administered biweekly. The items in the xREU evaluation survey were grouped into six major categories:

- Academic status and factors influencing their decision to choose a major
- Abilities and skills
- Stress and support
- Off-campus activities
- Motivation
- Future profession

The biweekly survey was aimed at collecting qualitative data on the participants' subjective experiences and attitudes toward the program content, materials, and activities.

Results and Data Analysis

Demographic Questionnaire

Factors influencing the decision to choose a major

The engineering students had various reasons for studying engineering (see Table 1). The students were given different reasons on a Likert scale (from "minimal reason" to "major reason") and the students rated them according to preference. Table 1 shows the percentage of students who gave the reasons listed as a "major reason."

Table 1: Reasons for entering an engineering major

Reason	%
I like to figure out how things work	62
I like to build things	58
A mentor or teacher encouraged me	54
I like to do computer programming	54
Engineers make more money than professionals	54
I can use the engineering skills to make a better society	39
My parents want me to be an engineer	39

Among the most frequent major reasons was their preference for figuring out how things work (62%) and for building things (58%). They also indicated that parental push had less effect on their choice of these engineering majors (39%).

Abilities and skills

The students were also asked to rate their abilities regarding various cognitive skills (including math, science, critical thinking, and problem-solving). The responses were measured on a Likert scale of 1–5, with 1 being the lowest score and 5 being the highest one. The mean scores for students responses are presented in Table 2.

Table 2: Self-reported abilities

Ability	Mean	Standard deviation
Math	3.8	0.4
Performing in teams	3.8	0.7
Science	3.7	0.6
Leadership	3.6	1.0
Communication	3.6	1.2
Problem-solving	3.5	1.0
Critical thinking	3.5	1.0
Solving problems with multiple solutions	3.4	1.0
Self-confidence (social)	3.4	1.0
Applying math and science principles in solving real-world problems	3.3	0.8
Self-confidence (academic)	3.2	0.9
Public speaking	2.9	1.1
Business	2.7	0.9

The lowest mean was for business ability ($M = 2.7$, $SD = 0.9$) and the highest means belonged to math ability ($M = 3.8$, $SD = 0.4$) and the ability to perform in teams ($M = 3.8$, $SD = 0.7$). Participants reported having average to above average knowledge of 21st-century learning skills, including problem-solving, critical thinking, and divergent thinking. For instance, on average, the students reported having rather strong math ($M = 3.8$, $SD = 0.4$) and science abilities ($M = 3.7$, $SD = 0.6$), as well as critical-thinking ($M = 3.5$, $SD = 1.0$) and problem-solving skills ($M = 3.5$, $SD = 1.0$). Also, most saw themselves as sociable students with average to above average social self-confidence ($M = 3.4$, $SD = 1.0$), communication skills ($M = 3.6$, $SD = 1.2$), and ability to perform in teams ($M = 3.8$, $SD = 0.7$).

Among respondents, 69% reported that they liked to work both individually and in groups, while 15% liked individual projects more than team projects, and 8% liked team projects best. The rest preferred not to respond to these questions.

Stress and support

The questionnaire also asked respondents to provide information on whether they experienced stress related to their coursework and how well they were able to handle the workload. All respondents said they experienced stress in the coursework for their current major. They reported either a moderately high level of stress (85%) or very high level of stress (15%). They saw their level of stress as being associated with their workload and considered the load to be very hard to manage. The majority (84%) indicated that they are meeting all demands even though it was hard work. The rest either were not able to meet the demands (8%) or could easily meet the demands (8%).

Some items on the questionnaire assessed the frequency of student interaction with instructors during the current school year, whether by phone, email, instant message, or in-person meeting. Most of the communication between the students and their professors took place during either class hours or office hours. Participants rarely or almost never socialized with their instructors outside of class or office hours or in the Teaching and Learning Center.

The questionnaire also asked about the types of support services the students used at the university (students could choose as many options as needed). The most frequently used support was from faculty members (77%), followed by mentoring support from upper-year students (62%). The Alumni Association Career Counseling was the least favored among respondents (8%; only one student chose this option). About 39% of students also used help from the Teaching and Learning Center and the Writing Center.

Off-campus activities

Participants were asked about their involvement in various types of off-campus or non-engineering activities, including sports, hobbies, civic or church organizations, campus publications, student government, and social fraternity or sorority. Descriptive analysis showed that such activities were perceived as very important to most students and they frequently engaged in them.

The questionnaire also asked students how they got their knowledge about the engineering profession. Most students learned about the engineering profession from school-related experiences (92%). Some respondents also reported gaining knowledge from family members (46%) or from experience as a co-op student or intern (23%).

Another question asked about the most influential people in students' decision to persist in engineering at college. Interestingly, many of them mentioned that they made this decision by themselves (69%). Some (15%) indicated that their family played an important role in the decision to persist in engineering. The rest mentioned either mentors (8%) or faculty (8%) as affecting their decision.

Motivation

The last section of the questionnaire evaluated the participants' motivation to learn the course material and engage in various course-related activities. The self-reported data showed that all of them preferred materials that aroused curiosity. Most participants reported that they wanted to do well in their engineering course to be able to show off their ability to family and friends. The motivating factors for taking engineering courses are presented in Table 3.

Table 3: Factors affecting motivation to learn in engineering courses

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Completely disagree
Prefer materials that arouse curiosity	69	31	–	–	–
Show ability to family, friends, etc.	46	46	8	–	–
Study in a space to concentrate more on engineering coursework	46	31	23	–	–
Work with other students to complete assignments	39	39	15	8	–
Ask instructors to clarify concepts when I don't understand	31	46	8	15	–
Make good use of study time	23	39	15	8	8
Discuss course materials with other students	15	31	31	23	–
Master skills in engineering courses	8	39	46	8	–
Confident about complex material presented by instructors	8	23	39	31	–
Even with having trouble in learning, I don't get help from others	0	23	54	15	8
Hard to stick to a study schedule	–	8	31	62	–
Rarely find time to review notes/readings before exams	–	–	15	46	39

Future profession

There were three questions in the questionnaire that asked specifically about future plans in engineering professions. Most of the participants (77%) indicated that they would definitely choose an engineering major. Another 15% said that they would probably choose an engineering major. More specifically, in response to a different question, most students (69%) indicated that they intended to practice, conduct research, or teach engineering for at least three years after graduation. The rest were unsure of their future plans (31%).

National Engineering Students' Learning Outcomes Survey (NESLOS)

NESLOS was designed to assess participants' knowledge and skills pertaining to but not limited to the following:

- Problem solving
- Writing and communication skills
- Teamwork
- Confidence gains
- Organization and management skills
- Interest and engagement with research project

The survey consisted of 16 items. It was administrated prior to and after the program. Inferential statistical analysis using paired-sample *t* tests was conducted for the purpose of tracking and evaluating changes in learner responses.

To analyze the results of NESLOS, researchers computed data further into the main constructs of Diem's model of experiential learning theory (Diem, 2001). To do this, new variables were made using SPSS version 24.00 (software used for statistical analysis) and the pre- and post-test data were combined into three constructs of experiential learning theory: *do*, *reflect*, and *apply*. The students' sum scores were then put into pairs and a paired-sample *t* test was run to analyze the results.

Table 4: Mean differences (student sum scores) of three constructs of experiential learning theory: *do*, *reflect*, and *apply*

Construct	Number		Mean		Standard deviation		Standard error mean	
	pre-test	post-test	pre-test	post-test	pre-test	post-test	pre-test	post-test
Pair 1 – *do*	13	13	39.76	30.07	12.33	9.97	3.42	2.76
Pair 2 – *reflect*	11	11	30.09	26.18	10.64	9.83	3.20	2.96
Pair 3 – *apply*	12	12	32.58	30.08	9.81	8.53	2.83	2.46

The mean differences for all three constructs (*do*, *reflect*, and *apply*) decreased from pre-test to post-test, which shows that xREU changed the overall mean score of the three constructs of experiential learning theory. The decrease of mean suggests the reliance on coursework learning decreased when engineering service experience increased. In other words, after the program, students relied less on their coursework and more on what they learned from the service experience provided by the xREU program.

Table 5: Paired-sample *t* test results

	Paired Differences							
				95% Confidence interval of the difference				
Constructs	**Mean**	**Standard deviation**	**Standard error mean**	**Lower**	**Upper**	***t***	**df**	***p***
Pair 1 – *do*	10	12	3.2	2.7	16.7	3.0	12	0.01
Pair 2 – *reflect*	4	10	2.9	−2.6	10.4	1.3	10	0.21
Pair 3 – *apply*	3	13	3.8	−5.8	10.8	0.7	11	0.52

A paired-sample *t* test between the constructs of experiential learning theory showed the following:

- There was a statistically significant difference in mean scores for the pre-test condition of the *do* construct ($M = 40$, $SD = 12$) and the post-test condition ($M = 30$, $SD = 10$), $t(12) = 3.0$, $p = 0.01$.

Although the mean scores decreased for all the constructs of experiential learning theory, the difference was not significant for the *reflect* and *apply* constructs.

- The results of paired-sample *t* test for the mean score of the *reflect* construct were not significant for pre-test ($M = 30$, $SD = 11$) and post-test ($M = 26$, $SD = 10$) conditions, $t(10) = 1.3$, $p = 0.21$.

- The results of paired-sample *t* test for the mean score of the *apply* construct were not significant for pre-test ($M = 33$, $SD = 10$) and post-test ($M = 30$, $SD = 9$) conditions, $t(11) = 0.7$, $p = 0.52$.

Biweekly Surveys

Qualitative data were collected through a survey administered biweekly. The survey consisted of five open-ended questions asking students about their perceptions of the knowledge and skills they learned during the program and the various activities in which they participated.

Thematic analysis of the qualitative data was conducted using an open coding technique. The data were analyzed using MAXQDA software. Two raters independently coded the data to identify broader themes and categories. All ambiguous items were later calibrated in discussion sessions between the two raters until agreement was reached. Table 6 shows example themes and their descriptions.

We identified a number of recurring themes and interesting results, as can be seen in Table 3.

Table 6: Examples of student responses to biweekly survey

1. Over the last two weeks, which activities were most useful for you and why?			
Weeks 1–2	**Weeks 3–4**	**Weeks 5–6**	**Weeks 7–8**
• hands-on activities • reading literature • discussions with mentors and professors • feedback • learning content knowledge	• hands-on activities • getting feedback • discussions with faculty	• making a poster • conducting experiments • using graphics software	• making a poster • guidance from staff
2. Over the last two weeks, which activities were least useful for you and why?			
Weeks 1–2	**Weeks 3–4**	**Weeks 5–6**	**Weeks 7–8**
• lack of direction	• workshop 2 (how to do experiments)	• workshops (e.g., entrepreneurship workshop, poster layout workshop)	• literature review • different activities (e.g., wing cell assembly, reading articles)
3. Over the last two weeks, what did you learn the most about and why?			
Weeks 1–2	**Weeks 3–4**	**Weeks 5–6**	**Weeks 7–8**
• content knowledge, hands-on experience • conflict resolution	• experiments, SAT model	• content knowledge • research	• making a poster, chemistry • research-related activities
4. Over the last two weeks, what did you have the most trouble learning and why?			
Weeks 1–2	**Weeks 3–4**	**Weeks 5–6**	**Weeks 7–8**
• lack of background knowledge	• Lack of/little background knowledge • using software	• content difficulties • research difficulties	• analyzing data
5. If there were anything you would like to see changed in the last two weeks of activities, what would it be and why?			
Weeks 1–2	**Weeks 3–4**	**Weeks 5–6**	**Weeks 7–8**
• more direction • more independent work • learning about work at other labs	• more communication • clear expectations	• no change is needed	• working more closely with professor/mentor • having more time in the last two weeks

Question 1

The first question in the survey asked about the most useful activities the students engaged in during the past two weeks. Some of the major themes that emerged as a result of the thematic analysis of the student responses included

- doing hands-on activities,
- learning content knowledge,
- conducting experiments,
- reading literature,
- making a poster,
- receiving feedback,
- participating in discussions, and
- using software.

Some example responses from the students are presented below:

> I learned how to use a milling machine to manufacture my part that I designed. I learned about the flaws in my design, as well as how much of my previous machinery experience was useful/useless.

> Meeting with the professors and hearing their feedback was extremely helpful because we got more direction for our project and got confirmation that we are on the right track.

> Reading papers helped me get a deeper understanding of what experiments I will be conducting.

> Meeting with the professionals, going over our progress, and getting feedback was great. It helped me feel confident that we were doing the right work.

Question 2

The second question in the survey asked about the least useful activities that the students were engaged in. The results showed that some of the least useful activities, as perceived by the students, included some of the workshops and conducting literature reviews. During the first two weeks, lack of direction was the most common theme of the biweekly surveys. Later, students were more dissatisfied with the workshops and reviewing the literature, which continued to be the dominant theme in the last two weeks. Example responses are provided below:

> Reading articles—I've done too much of that.

> The entrepreneurship workshop was kind of too long and I lost the track once.

Question 3

The third question in the survey asked what the students learned most about during the two weeks prior to the survey. Some of the major themes for this question included learning content knowledge, hands-on experience, making a poster, and research-related activities. These themes were similar to the themes in the first question of the survey (What are the most useful activities?). Below are example responses from the students:

> I learned about how to make a good poster and how to use pictures to attract audiences. It is a lot of work to make a good poster.
>
> I learned most about the experiments I am going to do. I read a paper about the exact experiment I am going to be doing so I now have a deeper understanding of what I am going to be doing and why.

Question 4

The fourth question in the survey asked about the difficulties experienced by students during the program. The most frequently mentioned reasons for experiencing difficulty learning the course content were the lack of relevant background knowledge, using software, and trouble analyzing data. Example student responses are presented below:

> Learning about which existing framework we should be studying and why. This is because this topic (peacebuilding) is completely new to me (from an engineering background).
>
> I had the most trouble learning the electrical background about my experiments because I have not taken electrical physics yet, so I have no base to build on.
>
> I have trouble with analyzing data because the approach was wrong. I reviewed lectures and verified the correct approach.

Question 5

The fifth item in the survey asked about course-related changes the learners would like to see. Some of the frequently mentioned changes included

- providing more opportunities for independent work,
- learning about work at other labs,
- working more closely with professors and mentors, and
- having more time.

Example student responses are presented below:

> I would have preferred to work closely with my research advisor . . .

> More enrichment activities/opportunities to learn about the work that other labs are doing.
>
> I wish I had started my project sooner so I wouldn't have been as rushed.

Over time, students' recommendations changed from giving more direction and clarity in the first two weeks to interacting more with professors/mentors in the last two weeks.

Discussion and Conclusion

Tracing Changes in Learning Outcomes and Skill Gains

This study was conducted to trace changes in the participants' learning outcomes (cognitive, affective, social, professional) and skill gains as a result of the xREU experience. The xREU evaluation focused on several measures and tools to obtain information about the participants' learning outcomes and detect changes in learner experiences throughout the program. The analysis of the quantitative data obtained from the pre- and post-test survey instruments (NESLOS) assessed participants' knowledge and skills related to problem-solving, writing and communication skills, teamwork, confidence gains, organization and management skills, and interest and engagement with a research project.

We aligned these skills with three overarching constructs of Diem's (2001) experiential learning theory (*do*, *reflect*, and *apply*) and traced changes. The results showed that at the beginning of the program, students, on average, learned more about conducting an experiment from their coursework, whereas toward the end of the program they learned more from their engineering service experiences. This trend was the same for all three constructs of Diem's experiential learning model. However, the results of paired-sample *t* test were only statistically significant for the *do* construct, and the differences of means for the other two constructs were not statistically significant. This might be due to the small number of participants, which might have made statistical analysis insignificant.

Neither Quantitative Nor Qualitative Data Alone Can Validate Effectiveness

In evaluating the benefits of experiential learning programs, using pre-tests and post-tests is the most desirable study design (Gredler, 2004). We also used some additional biweekly surveys to capture the processes under which the students experienced research opportunities. Gredler (2004) says many of the scholars in this field prefer pre-tests and post-tests with random assignment of treatment and control groups to get a better understanding of the effectiveness of their program. Even though this study followed the steps of previous researchers in collecting quantitative data, the design of the study was not experimental and combining qualitative (open-ended surveys) and quantitative data (pre- and post-test surveys) provided better insights into experiential learning opportunities for undergraduate students.

In this study, we also used demographic data, such as participants' academic status and their professional abilities and social skills, as well as the things that motivated them to learn and engage in course-related activities. This gave us a better understanding of the participants' identities when we were coding open-ended surveys administered biweekly. Similarly, Talafian, Moy, Woodard, and Foster (2019) gave daily open-ended surveys to delve into the students' change in STEM identities in a summer program.

Wolfe (1990) argues that, in experiential learning studies, the results of program evaluations are often not enough to assess the experience of the participants. Conversely, the perceptions of students regarding what they think that they learned are inadequate and invalid (Gentry, Commuri, Burns, & Dickinson, 1998). It seems that in both scenarios, quantitative or qualitative data alone cannot validate the effectiveness of a particular program. Hence, we gathered both qualitative and quantitative data to be able to get more tangible results to determine the strengths and weaknesses of experiential learning programs while participants were engaged in the designed experiences.

The analysis of the qualitative biweekly instrument did indeed yield some interesting findings regarding students' attitudes and perceptions. More specifically, students enjoyed many research-related activities, such as reading literature, learning content knowledge, conducting experiments, making posters, and receiving feedback.

Implications for Practice

Both the quantitative and qualitative data enriched our understanding of the strengths and weaknesses of the experiential learning programs as research experiences for undergraduate students.

Programs could include more hands-on experiences

In spite of our small sample size, the quantitative results showed a significant difference between the mean scores from pre-test to post-test in the construct of *do*. Although these results cannot be generalized for a bigger population, the difference in mean scores for the *do* construct was still meaningful for this particular population, which was supported by qualitative findings.

The qualitative themes revealed that the students enjoyed hands-on (*do*) experiences more than other activities in the program. The fact that reviewing literature was one of the least interesting activities gives direction to the future iterations of similar programs. Programs could be geared more toward hands-on (*do*) experiences and cover less background knowledge.

Student could learn background information before the program begins

As a recurring theme during the program, covering background information or literature related to the students' projects in energy and environment was the least useful activity for some students. Since covering background information is essential in formulating a valid research question and designing a research study, our suggestion is to ask students to cover some preliminary literature before entering similar programs. A couple of online sessions could be organized before the program and they could develop solid research questions before entering the program.

Students could be given more support when applying their knowledge

The students also experienced trouble analyzing the results of their projects' data, which was the most prevalent theme during the last two weeks of the program. This qualitative finding, together with the means of the pre-test and post-tests in the *apply* construct of experiential learning (which had the least difference among all three), indicated that the students needed more support in applying their knowledge. This, together with another prevalent theme (the need for faculty/mentor support), shows that the students need more support to be able to apply their knowledge in experiential learning programs.

In research-based programs such as this, because the students come with varying degrees of research knowledge, offering an online course before the program might not be effective for all participants. Instead, one suggestion is to encourage mentors and faculty members to direct students toward narrower research questions or give them more individualized resources or comments.

Continue research with bigger sample

Future research could focus on bigger sample sizes, including students with more demographic diversity (from all ethnicities, including underrepresented minorities).

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Appendix I:

Modified National Engineering Students' Learning Outcomes Survey (NESLOS)

Directions:

Rate how helpful your engineering service experience (SE) was compared to your coursework learning (CL) in enabling you to achieve the following skills.

Choose the option that best depicts the percent impact from engineering learning through service and coursework (e.g., 10CL/90SE = 10% impact from coursework and 90% impact from engineering service experiences).

0CL/100SE	60CL/40SE
10CL/90SE	70CL/30SE
20CL/80SE	80CL/20SE
30CL/70SE	90CL/10SE
40CL/60SE	100CL/0SE
50CL/50SE	I already had that skill (please list from where)

1. Apply math, science, and engineering knowledge
2. Design a system, component, or process to meet desired needs
3. Design an experiment
4. Analyze and interpret data
5. Apply techniques, skills, and modern engineering tools in practice
6. Conduct (or simulate) an experiment
7. Communicate effectively with others
8. Operate in the unknown (i.e., open-ended design problems)
9. Function within a team
10. Engage in critical, reliable, and valid self-assessment (i.e., reflection)
11. Persevere to complete an engineering design task
12. Maintain a strong work ethic throughout an engineering design project

13. Understand the impact of your engineering design/solution in a societal and global context
14. Identify potential ethical issues and dilemmas of a project
15. Know what you want to do after graduation (e.g., get a job, go to graduate school, etc.)
16. Recognize the need for life-long learning