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Developing Research Identity: Experiences and Influences Leading to Undergraduate Students' Growth as Researchers

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Abstract

The purpose of this research full paper is to examine the development of undergraduate students' research identity during a summer undergraduate research experience. Identity development through socialization experiences is crucial for students to explore future career paths, especially in careers that require research-focused graduate degrees. However, literature is limited on how effective socialization occurs for research and future research-related careers. This paper follows 10 undergraduate engineering and physics students participating in an engineering-focused Research Experiences for Undergraduates (REU) program at an R1 institution to explore this gap in knowledge. As part of a longitudinal multi-method study, participants completed a pre- and post-experience survey, and participated in three interviews over the course of the summer. Survey data were analyzed using descriptive statistics and a Wilcoxon signed-rank test. Interviews were analyzed through the lens of academic self-concept theory for common themes of socialization and identity development in research through the course of the program. Findings indicate that undergraduate students' research self-concepts are heavily influenced by research experiences and comparisons to their peers. The students' increase in research self-concept as well as their experiences and interactions within the program allowed them to see research careers as attainable and increased their interest in pursuing graduate degrees after the program. Survey data showed a statistical increase in research self-efficacy and research identity at the end of the program, reinforcing the idea that students' experiences in the REU helped them grow as researchers and engineers. This research increases our understanding of students' research identity development and provides potential ways to implement research self-concept and identity development to similar undergraduate research experiences.

Keywords: engineering socialization, research identity, academic self-concepts, undergraduate research

Introduction and Literature Review

The U.S. Bureau of Labor Statistics [1] projects that jobs requiring master's degrees and Ph.D.s in science and engineering will grow by 17% and 13% respectively between 2016-2026, compared to the projected 7% growth for all occupations. While more careers requiring graduate degrees in industry and academia are becoming available, graduate program enrollment is not matching this growth. Student enrollment in engineering graduate school has remained stagnant, even as enrollment in undergraduate engineering degrees has increased [2]. Lack of adequate graduate school enrollment will not only prevent current students from pursuing new and innovative careers but will also slow technological advancements. To improve enrollment in graduate degree programs, it is important to understand what factors affect students' interest in engineering graduate school and research, including previous research experiences. This paper aims to examine undergraduate students' socialization into research to further understand these factors and promote enrollment in graduate school and research careers.

As researchers aim to encourage more participation in engineering graduate schools and the development of skilled engineers, it is important to showcase our current understanding of the climate and experiences of engineering graduate school. In the Council of Graduate Schools' 2008 survey of graduate student data [3], researchers found the ten-year completion rate for engineering Ph.D.'s is only around 62%. Studies have indicated many factors within engineering graduate school culture that lead to attrition from graduate school, especially relating to students' expectations, goals, and quality of work and life [4]-[6]. Specifically, Zerbe et al. [6] identified that mismatched expectations and preconceptions for graduate school directly led students to question or depart from their programs. Recognizing the challenges related to pursuing an engineering graduate degree, undergraduate students motivated to pursue graduate degrees would greatly benefit from additional preparation for the culture and expectations for graduate students.

Socialization, learning social norms and expectations through observations and interactions [7], within engineering programs plays a significant role in preparing students for the culture and expectations of future engineering-related careers. Positive socialization experiences allow students to engage with people with similar interests and motivate them for their future careers in engineering fields. However, many components of engineering socialization, both in school and careers, are still influenced by outdated stereotypes and limited demographic diversity in the field. Beddoes [8] found that people from underrepresented groups and women entering engineering jobs were perceived as less capable and experienced more negative interactions within their companies than their white male colleagues. Engineering at the undergraduate level is still predominantly white and male, and lack of diversity increases for graduate school enrollment and engineering-related careers [9]. While engineering is extremely welcoming to its predominant group across all career stages, people from underrepresented and marginalized groups have more difficulty identifying themselves within engineering culture and experience socialization differently [8], [10], [11].

Many studies on socialization in engineering graduate school investigate how graduate students perceive and adapt to their new academic and research environments [12]-[14]. Hocker et al. [13] found that many students struggle with adjusting to expectations and norms within their graduate school environment, which then negatively impacted their mental health and their interest in pursuing academic careers. Specifically, students indicated the shift in workload from undergraduate to graduate programs took time to adjust to and led them to seek additional support from their advisor and peers. Socialization in undergraduate engineering students has not been as thoroughly studied. Researchers studying undergraduate socialization have focused mostly on students' perceptions of engineering culture and expectations for engineering, and less on the modes of engineering socialization [15]-[17]. Even fewer studies have looked at research socialization for undergraduate engineering students. Faber et al. [18], [19] found that socialization into research culture allows students to develop their identity as researchers before graduate school and can help build more accurate expectations of graduate school and research lab culture. Specifically, Faber et al.'s findings indicate that undergraduate researchers gained clearer understandings of what engineering research is and identified inaccuracies in their preconceptions of research through their own experiences. As noted by Bragg [20], socialization in the undergraduate setting allows students to build their identity and develop the necessary skills for their future professions. Further acquainting undergraduate students with engineering and research environments provides opportunities for them to identify with these fields and better explore their interests as engineers and researchers.

Related to the processes of socialization are scholarly conversations around engineering identity, as researchers seek to explore students' motivation and future goals. Godwin and Kirn [21] found that engineering identity is a significant motivator for students to pursue engineering tasks and prepare for their future careers. Research has also shown that an important component of developing engineering identity is through "learning by doing" and socialization into the engineering culture. Hsieh et al. [16] found that engineering students' goals are often formed by observing and experiencing engineering tasks and building their beliefs about their own capabilities, also known as self-efficacy. Preconceptions about engineering culture can also prevent students from allowing themselves to identify with and pursue engineering [16], [22]-[24]. For example, students may have difficulty identifying with engineering if they do not see themselves as having strong math or science skills, since engineering is typically perceived as being math and science focused [23], [24]. Similar to engineering identity, research identity development is heavily related to observations and experiences that socialize students into research culture and prepare them for graduate school [11], [18], [25] . However, due to the relatively low number of engineering students who participate in undergraduate research, it is more difficult to study research identity development.

Across disciplines, undergraduate research experiences are commonly used as an introduction to graduate research and research for future careers in industry and academia. These experiences are also a significant investment for foundations and institutions. In 2024, the National Science Foundation will fund over 1,300 REU programs, providing 8 to 10 undergraduates in each program with opportunities to explore research [26]. For science and engineering students especially, undergraduate research has been shown to be a direct influence on their decisions to go to graduate school [18], [27]-[31]. Undergraduate research experiences have also been shown to increase students' research career aspirations, especially in students from underrepresented and minority populations [31], [32]. However, studies have yet to explore the socialization experiences in undergraduate research that influence students' research identity development. To address this gap in literature, this paper seeks to investigate how undergraduate engineering researchers socialize into research expertise. The research questions this study aims to address are as follows:

1) How do students' academic self-concepts influence their socialization into research?
2) What components of students' research experiences do they identify as important for their growth as researchers and engineers?

Theoretical Framework

The primary lens of this study focuses on socialization theory. Literature notes the importance of socialization, especially at the undergraduate level, for students' identity development within their educational and future career spaces [7], [20]. Further, students' identities provide a supporting structure to self-concepts, which is how an individual views themselves and their abilities [33]. Often self-concept and identity definitions are conflated; however, their distinction relies on the social component of identity. Identities are developed through interactions with social groups, whereas self-concepts are imposed by the individual and can be informed by their identity [34]. For the purposes of this study, we investigate academic self-concept theory, within a research context, as an additional theoretical frame to explore students' research socialization. Academic self-concept, students' perception of themselves and their performance within an academic setting, is formed by students' prior experiences and achievements in academic settings, especially through internal and external comparisons [35]. Internal comparisons occur when students compare their individual academic performance across different classes, while external comparisons occur when students compare their performance in a class to that of their peers. This theory has been applied for elementary, high school, and undergraduate-level students [36]-[38] mainly focused on classroom specific impacts on academic self-concepts. By employing this additional framework, we gain valuable insights into students' socialization and research self-concept in engineering research experiences and future research carers.

Methods

Research Context. This longitudinal multi-method study was conducted in the first year of a ten-week National Science Foundation Research Experience for Undergraduates (NSF REU) at the Pennsylvania State University with engineering-related research projects related to low-carbon propulsion and power technologies. Undergraduate student participants in this REU were assigned to a project proposed by research advisors within several departments, including Mechanical Engineering, Aerospace Engineering, and Materials Science and Engineering. In addition to their research advisor, students were designated a graduate student mentor from the advisor's research lab, typically a senior member of the lab, to support more day-to-day lab work. Research advisors and mentors attended mentorship trainings before the start of the program to prepare for mentoring the undergraduates in research environments. An additional non-research faculty member supported by the REU provided additional support by answering general and logistic questions for students as they arose and facilitating communication for important updates for the students. While students mainly interacted with their research advisors and lab mates, the program facilitated activities including weekly research lab tours, technical and non-technical seminars, and group lunches. Also, the program directors scheduled two professional trips: one to a large professional conference on turbomachinery and the other to an aerospace operations and manufacturing company. As part of the trip to the aerospace company, students presented their summer research to the company's technical experts. In preparation for the technical presentations, students presented their research the week before the professional trip to their advisors, communication experts, and program leadership to receive feedback.

To follow the students' summer progress and to gain feedback for program improvement, surveys and interviews were included in the REU's structure. Pre- and post- REU surveys were distributed on the first and last days, respectively, of the program and interviews were conducted in the third, seventh, and ninth weeks of the program. Outside of the scope of this paper, we are also following the students longitudinally after the program. Students were informed of the program's interest in publishing findings from these surveys and interviews and given the option to consent to include their data in published research. All students participated in the data collection as part of the evaluation component of the funded project. Of the 15 REU students, n=10 consented to participate in this research study, such that their data are reported and analyzed here.

Interview Structure

Semi-structured interviews were conducted both in-person and on Zoom, based on the participant's schedule and preference, by the first author and lasted between twenty minutes and one hour. The first interview focused on getting to know the participants and identifying participants' goals for both their REU experience and future careers. The second and third interviews related to the participants' experiences within the program. Specifically, the second interview was focused on monitoring student progress and observing their experiences. In contrast, the final interview looked to determine what the students learned about engineering, research, and themselves, over the summer and to see if their goals had changed. The trips to the turbomachinery conference and aerospace company occurred before interview two and three, respectively, and were also discussed to understand how students felt about those experiences and the trips' value to their research experience overall.

Survey Structure

Participant demographic information was collected using the pre-REU survey and is shown in Table 1. The pre-survey also included three baseline statements, Bieschke et al.'s Research Self-Efficacy Scale [39], and Godwin's engineering identity scale [40], while the post-survey asked the same style of questions, except for the demographic information. The three baseline statements seek to understand students' confidence and knowledge of research, propulsion and power, and gas turbine technology on a 7-point Likert scale. The research self-efficacy scale [39] asks students to students to identify where they feel confident in their research ability and where they may feel they are lacking confidence in their ability by scoring, from 0 to 100. Finally, the engineering and research identity scale [40] looks to understand how strongly students agree with statements and identify themselves as researchers and engineers on a 7-point Likert scale.

Table 1. Demographic information of participants

Characteristics		Number of participants
Gender	Woman	2
	Man	8
Race/Ethnicity	Hispanic/Latin American	1
	Multiple	2
	Asian/Pacific Islander	1
	White	6
Year in Undergraduate	Rising Junior	4
	Rising Senior	6
Undergraduate Major	Mechanical Engineering	3
	Aerospace Engineering	3
	Electrical Engineering	1
	Physics	3
Prior Undergraduate Research Experience	Yes	6
	No	4

Notes: "Rising" indicates the grade level student is classified as in Fall 2023

Data Analysis

Longitudinal Interview Analysis. Transcription of the interview data was performed through Microsoft Word's Transcribe feature while connected to a secure server, in accordance with institutional security guidelines, and checked by the first author, removing any identifying information. Participants were then assigned pseudonyms. To analyze the interview data, we performed thematic analysis [41] on the transcripts using NVivo 14. Thematic coding was performed following an abductive approach using academic self-concept theory as the initial coding scheme (e.g. *internal comparisons* and *external comparisons*) and allowing for additional socialization-related themes to emerge (e.g. *graduate school experiences* and *encouraging interactions*). The emergent themes were identified to encompass both the experiences and the interactions that students had while in the program that students identified as influential to their socialization and identity as researchers. The full codebook used for the thematic analysis is available in Appendix A.

Survey Data Analysis. Descriptive statistics were performed on the survey data using SPSS to determine an appropriate statistical test to identify changes to students' answers for the baseline, research self-efficacy, and engineering and research identity questions. Based on sample size and lack of normality in the data, the Wilcoxon signed-rank test was used to analyze differences in the students' pre- and post-survey responses.

Limitations

One important limitation in this study was students included in this research were part of the first cohort of this REU program, creating a relatively small sample to study the effects of the REU on their socialization and research self-concept development. However, the intention of this paper is to provide preliminary insights into successful research socialization strategies and some identifiable impacts on these students. Another limitation focuses on the structure and intention of the student interviews and surveys. The main goal of the interviews is for program assessment and improvement. Questions asked in these interviews included students' background information and previous influences to get to know the students better and understand what attracted them to the program. We recognize outside influences motivate students to pursue research and graduate degrees. However, the scope of this paper is on students' socialization experiences within the REU, thus some outside influences that may have been mentioned in the interviews were not included in this analysis.

Results

In this section, we present the major themes of research socialization from the interviews and identify students' development into researchers through the interview data and the self-assessments in the surveys. The prominent themes from the interview data indicate research socialization relied heavily on students' comparisons, research and graduate school related experiences, and supportive interactions throughout their REU program. This results section includes quotes from students as examples of the identified themes. Survey data supports the interview findings and further shows students' research identity and self-efficacy increased as participants in the REU.

Applying academic self-concept through comparisons.

The first major theme from the interviews was the comparisons that students used to understand their performance and improvement in research knowledge within the REU. We observed both internal and external comparisons from all participants. Internal comparisons manifested as students' performance comparisons to their other research experiences and undergraduate classes. Students with previous research experience indicated that having some background in research allowed them to feel more prepared for this experience and felt they were able to adjust to research life faster than they did in their previous research experience. However, many students indicated that this REU experience gave them more practical experience in graduate research and culture than their previous research and made them feel more capable as researchers. For example, Luis participated in another REU in 2022 at an undergraduate-focused institution and had no interaction with graduate students while conducting his research and very few interactions with his research advisor. He notes that he appreciated having more interactions with his current REU advisor:

> "In previous lab experience that I have, I only [saw] my [advisor] like two times… in the whole summer. Now [my advisor] is in the office… [and] she has personal meetings with the undergrads… She's very in touch with her undergrad students, also with her grad students, and her grad students are very in touch with undergrad [students], so it's a very, very cool thing." – *Luis (rising senior)*

Luis also enjoyed his current REU project more because he did not feel very challenged in his previous REU. His previous advisor focused more on tailoring a project to his undergraduate major background instead of giving him opportunities to apply his knowledge to new concepts:

> "[The previous REU] told me, like, OK, we have never [had] a student with your experience and they didn't know what project to [give] to me. So they were giving me stuff that I already knew what to do… It was something far away from being new, just doing the same thing that I did back home but with different facilities… I think that's one of the thing[s] that I didn't like about that. Here I am not having the same [problem]…So whatever I'm doing I'm just happy with that because I'm just learning a lot of new stuff so I'm glad that I found this project because… everything I'm doing is new and just thinking about how can I relate, like have this straight connection with material science and aerospace engineering..." -*Luis (rising senior)*

Students like Luis felt challenged by their research projects because they were outside of their comfort zones, which were typically formed through their academic experiences. Doing challenging work that was peripherally related to their academic knowledge led many students to expand their potential future research interests and also look forward to their upcoming classes. Academic internal comparisons were common in these participants, where students compared the impact of their school and research performance. Multiple students, like Sarah, found greater motivation to perform better and learn for projects with larger, real-world applications, especially outside of the classroom:

> "Working on my project and like trying to find like examples and stuff in forums, especially, [made me realize] there is like a limited amount of work that has been done [related to my project] and it was kind of cool to see that, you know, maybe it's not like 100% novel, but I'm working on something that's not like a school project." -*Sarah (rising junior)*

External comparisons were often used in situations where students did not have clear definitions of success, (e.g. individual advisor interactions, technical presentation performance). Students used external comparisons to their peers and other lab members to establish another level of feedback, especially in technical areas they were inexperienced with. Many students indicated their lack of experience with presenting technical research was a source of anxiety coming into the program. In addition to the feedback they received after their presentations, students compared their preparation and presentation experiences to their peers to gage their performance. When preparing her presentation for the aerospace company trip, Ariel found that her interactions while developing her slides were fairly different from her peers based on the level of input she received from her advisor and lab:

> "I actually did most of [the presentation preparation] on my own. I know a lot of people said that their graduate students and, like, professor had a lot of input on theirs and definitely like the material was from my grad student and professor, but the presentation I did, I would say, completely on my own and then I showed it to them and they gave me the thumbs up." -*Ariel (rising junior)*

Other students, like Mike, relied on comparisons to their peers on the success of their actual presentation, especially based on the number of questions they were asked and how they answered those questions on their research:

> "I think I was able to communicate everything… I think my project has a lower technical ceiling than a lot of other ones, so that made it a lot easier to talk about it…So then all the questions surrounding it were not as complicated. And I have a good grasp of the total breadth of what I did…I feel like I got the same amount of questions as everyone else, I think I only got three. I was a little bit over time, so I got cut short. But I think I was just able to answer them better than other people did." – *Mike (rising senior)*

Graduate school experiences.

An emergent theme of socialization in these interviews was the importance of authentic graduate school experiences within the REU. Many students indicated an interest in graduate school during the first interview, and through these experiences the students felt more socialized into different aspects of graduate school. These experiences relate to research and non-research experiences. Research related experiences identified by students were typically unique to their lab's culture, but generally focused on learning how graduate research labs work, learning their lab's expectations, and understanding the process of conducting graduate research. The program's non-research related experiences introduced students to facets of graduate culture outside their research labs. These non-research experiences were more generalized to cover potential areas of interest for the students or other components of graduate school outside of research overall, including the lab tours, seminars, social events, and trips.

Students indicated that many of the non-research parts of the REU gave them a more well-rounded experience and answered many of their questions about graduate school life. For example, the program included a variety of seminar topics, both technical and non-technical, that students felt were extremely informative. Two major non-technical topics were a graduate school seminar and a technical presentation workshop. The graduate school seminar detailed some of the lesser-known aspects of applying and choosing a graduate program, since many of the students had preconceived notions of the application process. Neil stated that he appreciated the graduate school seminar:

> “I appreciated the grad school talk. I thought it was incredibly helpful because before that I was like, OK, it's basically just applying to college, but it's like, no, the main factor is like finding a lab that you actually want to work in. I was like, OK, yeah, everyone who I talked to had implied that, but I don't think either they directly said it or I interpreted it correctly.” -*Neil (rising senior)*

The seminar on presentations provided them opportunities to learn effective technical presentation styles. Since many students noted giving technical presentations as a source of anxiety when they think about future careers, learning presentation skills during the REU was extremely helpful for all students. Students also participated in tours of research labs around the university’s campus that allowed them to see other research fields they could pursue in their future.

When asked about the most impactful experiences from the REU, students consistently identified the trips to the professional conference and aerospace company. All students, including those less interested in turbomachinery for their future research and careers, felt that attending the conference and presenting at the aerospace company helped to prepare them for future research and career events. Program faculty actively encouraged students to network while on these trips, which students indicated was a daunting task due to their limited knowledge as undergraduates. Shane indicated that both trips allowed him to get over his nervousness towards presentations and networking and gave him confidence in his ability for the next time he attends a conference or presents technical research:

> “I'd say [the program experiences] definitely [prepared me]. [The aerospace company trip] because it's like you get to present in front of all these technical people and that's what you'll be doing later in life as a job. You know, you might have to present to people. So it's nice to get over that kind of anxiety of presenting, especially when you're presenting to actual professionals. So like, that's like kind of like a first. I'd say [the conference] was definitely a helpful thing because if I ever attend another conference, I know what to expect and what it’s like.” *-Shane (rising senior)*

Encouraging interactions.

Another emergent theme from students’ interviews was the importance of their interactions within the REU. Interactions with advisors, graduate students, and REU peers were important for developing students' identity as researchers. These interactions also helped encourage their interest in continuing research, especially for graduate study, by again showcasing some of the essential interactions during graduate research. Most often, students talked about their advisors as the biggest influence on learning how to conduct research and motivating students in their research. Most students, including Charlie, had weekly meetings with their advisors for progress updates, answering questions, and to give encouragement:

> "She has a way of motivating, like she's a very motivational person and I think that that comes from like a combination of intensity and encouragement. Like every time I walked away from a meeting with her I found myself like very excited to go do whatever I was about to go do, which I think is a good thing, and in general that was like fantastic."
> *-Charlie (rising senior)*

One student, Greg, experienced communication issues in the first weeks of the program between his advisor and his mentor, mainly surrounding lab expectations and how instructions were delivered. Greg shared these issues with the program leadership team, who then worked behind the scenes, unbeknownst to Greg, to facilitate additional guidance and clarification of expectations between Greg and their advisor. After this intervention, Greg saw an immediate change in interactions and felt more comfortable in meetings and lab:

> "[My advisor] and [graduate student mentor] have both tried to make sure that we're on the same page now and are both… Well, I just came from a meeting today that had both of them in it at once, so it wasn't just the kind of weird back and forth … And I'm also getting more instruction. Now I'm getting told what to do more so that's good.. kind of actually helps me focus." *-Greg (rising junior)*

The relationship between REU students and graduate students in their lab was different from relationships with advisors, where REU students felt they could ask different questions about their research and graduate school in general. The mentors and other graduate students in the lab tended to interact more with the REU students on a day-to-day basis, which allowed for open and trusting relationships to form. REU students indicated when asking graduate students about graduate school culture, they felt they received a more accurate and honest depiction of graduate school, allowing them to better picture themselves as graduate researchers in the future. John and other students talked about appreciating learning about the good and bad parts of graduate school:

> "It's been great because like in terms of, so the program has done a really good job at fostering like a grad school mindset. But what I really like that I haven't necessarily heard as much from the faculty, but I've heard a lot more from my mentor and the students working my lab is also, you know, sometimes it's not all that great. Like I've learned the good but also a little bit of the bad, which I actually like because… it's good to know like both the good and the bad about like something like this." *– John (rising senior)*

Finally, this cohort of REU students found value in the community that they created with one another. The program faculty only facilitated one social event during the program and allowed the students to form their own social group. Students mentioned that their social interactions with the rest of their cohort helped them to develop a community where they felt they could talk to one another about research as well as have fun outside of research. Teddy talked about enjoying the balance of research and non-research conversations with his friends in the cohort:

> "With my peers, we ask good questions about each other's research, and I would say that while we take an interest in each other's research. It's luckily not just about the research like we're able to hang out and just be friends like I don't know, just do normal college stuff together, which I appreciate. Like it's not strictly the REU 24/7, but when we do, we ask each other really good questions about our research, and I enjoyed that part." -*Teddy (rising junior)*

Survey findings.

The REU students were also given a pre-/post-survey to ascertain quantitative levels of development across a variety of validated scales, including Bieschke et al.'s Research Self-Efficacy Scale and Godwin's engineering identity scale. Survey statements are available in Appendix B, with their pre- and post- survey means and p values.

In support of the socialization and preparatory experiences within the REU, the Wilcoxon signed-rank test of longitudinal survey data indicated improvement in confidence and perceived ability in many areas. For the first three baseline statements, students had strong increases for confidence to conduct undergraduate research, knowledge of propulsion and power technology, and knowledge of gas turbine technology. Survey data relating to the research self-efficacy scale had 23 out of 46 statements with significant ($p<.05$) increases to students' responses with five of those having strong ($p<.01$) increases. These strong increases were seen in statements asking about the student's ability to search for related research, perform analyses, and present research. Finally, the engineering and research identity scale found 11 out of 30 statements with increases in answers. Only one statement that specifically related to engineering identity, *I consider myself an engineer*, had a significant increase. Eight statements focused on understanding and performing research had increased answers. Two statements, *I consider myself a researcher* and *I feel strong ties to researchers in my discipline,* had strong ($p<.01$) increases.

Discussion and Implications

Literature has widely identified that research experiences are extremely helpful in promoting graduate school attendance and pursuing research careers [31], [32]. Findings from these interviews indicate that tailored experiences focused on introducing graduate school culture in addition to research experiences have significantly more impact on students, increasing their positive attitudes towards research and their research identity. Survey results also indicate that students gained experience and knowledge in multiple facets of research and engineering and that the designed components of this REU facilitated their growth as researchers and engineers. These findings support current literature recognizing the importance of these tailored experiences for career exploration and preparation [42]. The student interview data better showcased the research self-concept development within the students. Specifically, students' research self-concepts were influenced by their internal comparisons to their prior research and academic experiences and external comparisons with other REU students. Several participants relied on previous research experiences to identify how they were learning different components of research and graduate school culture. Coupled with their academic experiences, these internal comparisons allowed the students to better identify achievements and performance expectations in research. Also, external comparisons to other students were relied on to rationalize participants' performance in situations with less clear performance assessments, especially for the technical presentations. Internal research comparisons provided the most information on what knowledge students felt they gained from this program. Another potential indicator of improvement in students' self-concepts was the overall increase in intention to attend graduate school. All students indicated that they intend to pursue graduate school during the final interview and attributed their experiences within this program as a driving force behind their decision. Overall, students' data from both the interviews and surveys showed that the students' perceptions of their research abilities had improved, suggesting that their research self-concepts increased through their summer research and graduate school experiences. Table 2 summarizes the types of activities within the REU program and the associated component of socialization and research self-concepts.

Table 2. REU activities with related socialization and research self-concept component developed

REU Activities	Socialization and Research Self-Concept Component
Professional development *Examples:* conference, industry tour, technical presentations, networking opportunities	• Experiences • Interactions
Research topic exploration *Examples:* research lab tours, seminars, literature exploration	• Internal comparisons • External comparisons • Experiences
Graduate school experience *Examples:* advisor and student mentorship, individual and group meetings, technical presentations, cohort social events	• Internal comparisons • External comparisons • Experiences • Interactions

Other interesting findings from this study were focused on the REU students' identity development. The survey data indicated that research identity was greatly influenced by the experiences within the program. However, while students were participating in engineering-related research projects, their engineering identity did not significantly change from beginning to end of the program. The data indicates that the students entered the program with fairly high engineering identity from their undergraduate programs, leading to somewhat similar answers. However, the survey data does indicate that many facets of research knowledge and identity were developed during this program, including literature search abilities, presentation skills, data analysis skills, and result interpretation.

Findings from this study further support the importance of experiences and interactions to socialize students into research culture, which can be difficult to implement in a short-term program. From the student-identified successes in this REU program, we have recognized components of this program that could be implemented in other research experiences to better socialize undergraduates into research. To begin, authentic lab experiences should include interactions within those labs, not just performing research tasks. This specifically includes interacting with their advisors on a regular basis and being able to interact with other members of the lab for help. Assigning a graduate student mentor can also provide undergraduate students with another person to ask questions to with seemingly lower stakes than their research advisor. Previous literature has indicated the impact of positive and supportive mentorship on REU students and also notes how difficult implementing effective mentorship strategies can be [43]. We also recognize that a lot of graduate students' socialization occurs through those lab interactions [12], and maintaining those interactions for undergraduates is extremely helpful to their development as researchers. The interviews also indicate that non-research components of the REU gave students a more well-rounded idea of graduate school. Including professional development components of the REU, like the professional trips, seminars, and lab tours, gives students the freedom to investigate their own interests and gain experience in other common areas of graduate school. By not forcing students into one research area and allowing them to explore their own research interests, students can be encouraged to pursue those interests further into their future careers. In future work, we intend to continue interviewing participants of this REU program to provide a larger sample of experiences that may develop a more transferrable understanding of undergraduate research socialization.

Conclusion

In this longitudinal multi-method study, we followed 10 undergraduate students through an engineering REU program to explore their socialization into research and development of their research identity. We found that the students' research self-concepts increased during the program through their internal and external comparisons, which allowed them to develop better expectations for research and graduate school. Also, students were socialized into graduate school and research culture through different experiences and influences within the REU program. Specifically, students indicated both research and non-research related experiences were influential in their understanding of research and graduate school culture, highlighting that the program's balance of both experiences contributed to furthering their interest in research. Interview responses also emphasized that interactions with advisors, graduate students, and peers were important to learning graduate school norms and expectations. Overall, the students' REU experience allowed them to develop their identity as researchers and reinforced their interest in future research in graduate school and their careers.

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Appendix A: Thematic codes and definitions from interview analysis.

Table 3: Thematic codebook developed from interview analysis.

Code	Definition
Internal Comparison	Reflections on previous academic or research experiences and using previous experiences to assess their abilities in the program
External Comparison	Comparisons between students' experiences to assess their abilities and achievements in the program
Graduate School Experiences	Experiences within the program that students identified as impactful to growing their knowledge of graduate school culture.
Encouraging Interactions	Interactions with other members of the program (e.g. advisors, professors, graduate students, cohort members) that socialized students into research culture and further encouraged their interest in graduate school

Appendix B: Wilcoxon signed-ranks test for all survey statements, including pre- and post- survey answer means and p values.

Table 4a: Wilcoxon signed-ranks test statistics for baseline and engineering and research identity statements on a 7-point Likert scale.

Survey Statement	Pre-Survey Mean	Post-Survey Mean	p value
Baseline			
I feel confident in my ability to conduct undergraduate research.	4.30	6.80	0.003*
I feel I know a lot about propulsion and power technology.	2.40	5.00	0.007*
I feel I know a lot about gas turbine technology.	2.00	4.70	0.004*
Engineering and Research Identity			
I consider myself an engineer.	4.80	5.80	0.016*
I am proud to be an engineer.	5.56	5.89	0.180
Being an engineer is an important reflection of who I am.	5.11	5.56	0.334
I feel strong ties to other engineers in my discipline.	5.00	5.78	0.114
I consider myself a researcher.	4.90	6.20	0.009*
I am proud to be a researcher.	5.60	6.60	0.016*
Being a researcher is an important reflection of who I am.	5.10	6.30	0.010*
I feel strong ties to other researchers in my discipline	4.40	6.70	0.003*
I can create prototypes to test an idea.	4.80	5.50	0.084
I can design a system, a part/component of a system, or a process based on realistic constraints.	4.60	5.50	0.071
I can build and test systems to learn more about how they work.	4.70	5.30	0.236
I can design and conduct experiments to test a research idea.	5.00	5.80	0.058
In general, I find working on engineering projects interesting.	6.22	6.44	0.157

Survey Statement	Pre-Survey Mean	Post-Survey Mean	p value
I like doing engineering.	6.22	6.22	1.000
I am interested in my engineering work.	6.33	6.67	0.180
I am interested in learning more about engineering.	6.60	6.60	1.000
I can obtain research articles relevant to my research from library systems or online	5.60	5.60	0.763
I can keep up to date on my research topic(s).	5.10	5.70	0.035*
I can replicate key findings in journal papers.	4.00	5.00	0.070
I can understand research trends and research topics.	4.20	5.40	0.016*
In general, I find working on research interesting.	6.30	7.00	0.026*
I like doing research.	6.00	7.00	0.015*
I am interested in my research topic.	6.30	6.60	0.096
I can understand and apply scientific and mathematical relationships based on the conditions.	5.60	6.30	0.046*
I can apply math and science concepts to make new systems/models.	5.00	5.90	0.021*
I can use calculations and equations to evaluate things.	5.70	6.20	0.272
I can work with people with different skills and interests.	6.60	6.90	0.180
I can communicate verbally, for example, in discussion with others.	6.30	6.60	0.257
I can convince others to accept my ideas.	5.30	6.00	0.053
I can learn new things from the people I'm working with.	6.50	7.00	0.102

Notes: asterisk (*) denotes significant change ($p<0.05$)

Table 4b: Wilcoxon signed-ranks test statistics for research self-efficacy statements for confidence in ability for each statement from 0 to 100.

Survey Statement	Pre-Survey Mean	Post-Survey Mean	p value
Research Self-Efficacy			
Follow ethical principles of research.	93.4	96.5	0.293
Brainstorm areas in literature to read about.	77.5	80.0	0.446
Conduct a computer search of the literature in a particular area.	84.6	88.5	0.398
Locate references by a manual search.	69.8	80.5	0.113
Find needed articles which are not available in your library.	62.2	79.5	0.023*
Evaluate journal articles in terms of the theoretical approach, experimental design, and data analysis techniques.	65.1	75.0	0.067
Participate in generating collaborative research ideas.	84.0	85.2	0.725
Work independently in a research group.	85.6	93.7	0.212
Discuss research ideas with peers.	91.3	90.1	0.837
Consult senior researchers for ideas.	84.0	90.5	0.083
Decide when to quit searching for related research.	56.4	83.9	0.005*
Decide when to quit generating ideas based on your literature review.	57.9	78.1	0.017*
Synthesize current literature.	63.7	78.1	0.026*
Identify areas of needed research, based on literature.	66.1	78.1	0.212
Develop a logical rationale for your particular research idea.	74.9	85.5	0.016*
Generate researchable questions.	78.2	86.1	0.049*
Organize your proposed research ideas in writing.	80.8	82.8	0.370
Effectively edit your writing to make it logical and succinct.	80.9	82.0	0.282
Present your research idea orally or in written form to an adviser or group.	74.5	89.7	0.021*
Utilize criticism from reviews of your data	85.5	93.0	0.037*
Choose appropriate research design.	70.3	83.0	0.066
Choose methods of data collection.	70.3	81.0	0.050
Be flexible in developing alternative research strategies.	78.4	86.8	0.108
Choose measures of dependent and independent variables.	73.9	87.6	0.036*
Choose appropriate data analysis techniques.	69.3	85.1	0.011*
Obtain approval to pursue research (e.g. human subjects committee, animal subjects committee, special approval for fieldwork, etc.).	47.0	60.0	0.182

Survey Statement	Pre-Survey Mean	Post-Survey Mean	p value
Obtain appropriate subjects, supplies, or equipment.	50.4	67.4	0.053
Train assistants to collect data.	44.7	65.3	0.050
Perform experimental procedures.	76.1	78.2	0.285
Ensure data collection is reliable across trial, rater, and equipment.	66.0	85.0	0.029*
Supervise assistants.	48.2	68.4	0.026*
Attend to all relent details of data collection.	76.8	82.8	0.212
Organize collected data for analysis.	80.5	89.0	0.050
Develop computer programs to analyze data.	48.7	74.3	0.059
Use an existing computer package to analyze data.	57.3	88.7	0.010*
Interpret and understand statistical results.	64.2	86.9	0.005*
Organize manuscript according to professional format and standards.	61.6	74.9	0.033*
Report results in narrative and graphic form.	69.3	87.3	0.008*
Synthesize results with regard to current literature.	52.9	75.8	0.041*
Identify and report limitations of your study.	71.9	86.3	0.081
Identify implications for future research.	69.7	88.9	0.012*
Design visual presentations (e.g. posters, slides, graphs, pictures).	80.7	93.9	0.018*
Orally present results to your research group/department.	72.4	93.4	0.011*
Orally present results at a regional/national conference or meeting.	45.8	82.2	0.008*
Defend results to a critical audience.	49.0	80.8	0.012*
Write manuscripts for publication.	49.1	71.7	0.016*

Notes: asterisk (*) denotes significant change ($p<0.05$)