2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering Education for 130 Years
ASEE
Paper ID #37951

The Grand Challenges Scholars Program Research Experience: A Great Opportunity to Cultivate Belonging in a Community of Practice

Dr. Olgha Bassam Qaqish, North Carolina State University at Raleigh

Olgha B. Qaqish, Ph.D. is an engineering educator and researcher, who has experience working with students at all levels in science, math, engineering, and technology (STEM). Dr. Qaqish is an author of a mathematics textbook: Algebra Essentials.

Chloe Grace Hincher, North Carolina State University

Chloe Hincher is an undergraduate pursuing a B.S. in Biomedical and Health Sciences Engineering concentrating in Regenerative Medicine and Pharmacoengineering, with a minor in Economics at North Carolina State University.

Ton Nguyen
Nicholas Goodwin

The Grand Challenges Scholars Program Research Experience: A Great Opportunity to Cultivate Belonging in a *Community of Practice*

Abstract

This full paper describes the implementation of a summer research experience for undergraduate (REU) engineering GCSP scholars. The Grand Challenges Scholars Program (GCSP), at a southeastern public research-one institution, provides aspiring undergraduate first- and second-year students a welcoming environment to promote a *community of practice*. Applied research experiences for undergraduate students can foster learning while simultaneously empowering their professional growth. One of the most effective situational learning environments was introduced over three decades ago and promotes learning alongside personal growth. Ettiene Wenger's concept of *community of practice* outlines a group of people that share a similar interest and solving global grand challenges and learn how to develop their professional career identity as they meet, discuss, share, and interact regularly.

This GCSP-REU is a mentoring research program that was established in the summer of 2022 at the prescribed institution. The goal of the GCSP-REU program is to empower early-career undergraduate engineering students that were newly accepted in the GCSP by cultivating a nurturing environment and building a *community of practice*. This work describes the approaches and strategies used to develop the research scholars' *engineering identity*. It provides the platform to build a *community of practice* that cultivates a sense of belonging for all 15 undergraduate engineering scholars who participated in the 10-week GCSP-REU program. Each participant applied and received a $6,000 stipend award to supplement their hands-on research with self-identified research mentors (faculty, staff, and/or graduate students). Additionally, this work describes the assessment data collected to determine the effectiveness of these strategies with regards to both recruitment and retention of students in the Grand Challenges Scholars Program and their future interest in research and graduate school. In addition, it includes reflections and insights gained from the REU curriculum design, development, and execution, and offers future recommendations for improvements. Approximately 88% of the research participants started this summer program with minimal research experiences and presented their research findings and results at the end of the summer experience at the university's undergraduate summer research symposium. All of the participants (100%) who responded to the program survey highly recommended this summer experience. The analysis of the administered assessment of this program indicates that the majority of the participants increased their *self-efficacy* in engineering research.

Introduction

The National Academy of Engineering (NAE) and engineering educators envision a better tomorrow by preparing undergraduate STEM students to define and build a sustainable, secure, healthy and enjoyable future [1-3]. The NAE fourteen grand challenges encompass the greatest challenges and opportunities that engineers face and will continue to face in the 21st Century.

This work describes the design, implementation and assessment of a summer undergraduate research experience curriculum that was established in 2022 to strengthen an existing engineering Grand Challenges Scholars Program (GCSP) in a southeastern Research-One Land Grant institution. The goal of this 10-week summer Research Experience for Undergraduates (REU) program was to provide hands-on experiences for participating scholars to fulfill their GCSP talent competency. The talent competency encourages engineering students who are part of the GCSP to engage in undergraduate research in an approved team, individual research, or design project with a university faculty member, focusing the research on one of the fourteen NAE grand challenges by completing an appropriately approved independent study project focusing on one of the four grand challenges' themes (sustainability, security, health, and joy of living). This summer experience consisted of 15 students conducting research in labs for 25 hours per week over a 10-week period with additional workshops and weekly hangout meetings with the director of the GCSP and participating scholars. The bulk of this work describes the design, implementation, execution and evaluation of a structured GCSP-REU program that 15 of the grand challenges scholars participated in the summer of 2022 along with lessons learned from this experience. At the completion of the 10-week research program, the participating scholars present their research findings at university's summer undergraduate research symposiums alongside hundreds of other REU students who've participated in 20 plus university-lead research programs.

Background

Research shows that active learning environments promote student engagement and increase their curiosity, impacting their learning and professional development [4-11]. In addition, studies show that students' involvement in hands-on undergraduate research experiences impacts their *engineering identity* and *self-efficacy* developments [4-7]. In addition, enhanced *self-efficacy* positively impacts *engineering identity* [4-6]. Other research explores the impact of a sense of belonging and community building on student development [8-11]. This paper examines the impact of building a *community of practice* conceptual framework on both *engineering identity* and *self-efficacy* development of engineering students who participated in 10-week summer research experiences focusing on the engineering grand challenges as identified by NAE. Through building a *community of practice*, students experience a sense of belonging which we believe adds to the *engineering identity* and *self-efficacy* scholarship.

Engineering Identity Development

Career identity is the construct that individuals formulate around their perception of themselves and their career choice. Therefore, *engineering identity* can be defined as the construct that engineering students and professionals construct at the intersection of their perception of themselves and their career in engineering [8-9]. Research shows that *engineering identity* is directly correlated to personal values that can assist in the development of becoming an engineer and their understanding of engineering as a field. This development can lead to the enhancement of the altruistic and individualistic goals of engineering students [8]. Student's e*ngineering identit*y development is needed for a growing engineering program and helps to promote student success. Student engagement in an REU provides intentional and strategic opportunities for students to develop and establish their individual *engineering identity*. This hands-on research experience benefits the students' *engineering identity* development as students engage in immersive activities that challenge their critical thinking and problem-solving skills by applying their engineering knowledge through project-based work and collaborating with research teams [10]. *Engineering identity* may influence students' personal goals, *self-efficacy* and expectation outcomes in engineering careers [10]. *Engineering identity* is unique, ever changing and individualistic for students throughout their engineering educational journeys [10-11]. Research shows that undergraduate students who have a strong *engineering identity* were more likely to pursue graduate degrees [10].

REU programs in general implement a strategy known as the Goal Congruity Theory (GCT). The GCT expresses that students will be more likely interested in participating in research that aligns with their personal goals. This theory is essential for engineering education as well as *engineering identity*. Undergraduate engineering researchers are more committed and invested in particular hands-on projects as they are associated with their personal goals [10]. Hence, participating in an REU strengthens the student's *engineering identity*.

Self-Efficacy Development

Self-efficacy is defined as an individual's belief in their abilities to perform and succeed in a certain task or behavior [4-6]. It. *Self-efficacy* consists of four attributes: performance, competence, recognition, and interest [4]. The remainder of this paper we will be referring to *self-efficacy* in the context of research or research *self-efficacy*. As students participate in hands-on undergraduate research, their *self-efficacy* is impacted (positively or negatively depending on their research mentoring experience) and therefore can influence their academic success[4-6]. In this paper we explore how building a *community of practice* in addition to providing Research Experience for Undergraduates (REU) is needed to help ensure a positive experience for students to improve their *self-efficacy* [4].

Building a *Community of Practice*

For undergraduate engineering education, a *community of practice* conceptual framework is a great model to use to construct a pragmatic approach to designing an effective mentoring research experience program for undergraduate students [12]. A *community of practice* is defined by Ettiene Wenger, a sociologist, as an apprenticeship framework that outlines a group of people (experts and novice) that share similar interests and career aspirations [12-13]. New and seasoned individuals in a *community of practice* learn from one another about the topic of interest [12-13]. The seasoned individuals in this group model to the new individuals practical ways of approaching the domain of interest as they become more knowledgeable modeling to the new individuals that learning effectively includes failing forward and is a process. This paper shares our findings about how one can build an effective *community of practice* for an engineering Grand Challenges Scholars program at a Southeastern Public Research-One Institution.

The three attributes of a *community of practice* are the domain, the community, and the practice [12]. A *community of practice* is beyond a group of friends or a network of connections among individuals. Rather, a *community of practice* develops an identity defined by a shared domain of interest [12]. Implying a commitment by all members to solving the task at hand, forming a shared experience that makes members unique from other people [12-13].

In addition to the commitment to the domain of interest, members in a *community of practice* build relationships as they interact with one another. The community engagement of members consists of joint activities, discussions, helping each other, and sharing their knowledge and information around the domain of interest. Hence, the members build relationships that enable them to learn from each other and develop empathy towards one another [12-14].

The final and third attribute is practice. All members of a *community of practice* come with unique experiences as practitioners in the domain of interest. They develop their shared repertoires of resources including their narratives, tools, experiences, and strategies to problem solve recurring issues in the field. This is a process that takes time and effort and allows individual growth and change [12-14].

Effective Mentoring and Student Success

The benefits of undergraduate research rely a great deal on the quality of mentoring provided [16].When strategies like strategic pre planning and clear expectations are used, it makes mentoring significantly more efficient and understandable for the student [16]. Mentoring is a dynamic process that involves both the mentor and the student. Mentoring is a developmental experience and a supportive relationship that is intended to advance students that are being mentored toward their career and research identity. Effective mentoring relationships positively impact students and mentors when they communicate messages of invitation, inclusivity and belonging to a community or group and empower students to take on grand challenges in engineering by increasing their knowledge, skillsets and abilities in engineering research.

"Developing and articulating a multipronged mentoring strategy is one way to invest in student success while communicating that investment to diverse prospective students" (p. 5) [15].

When collegiate students, especially from low socioeconomic backgrounds, experience effective mentoring relationships, they are more likely to earn higher GPAs and persist in their academic field of study. Mentoring is a high-impact activity and can result in improving student engagement and retention as a result of its investment [15].

Grand Challenges Scholars Program Overview

The GCSP gives its students flexibility in the path they choose to complete the requirements of the program within their graduation date and meet their academic and professional goals. Therefore, there is not a linear program sequence that the scholars must undertake to complete the obligations. A typical model for successfully carrying out the five competencies includes participating in a research experience early on in their engineering education career, preferably the first or second summer of their scholarship program. This will enable students to present their research findings at a GCSP summit, research symposium or any national grand challenge summits by their senior year. All graduating scholars will have a completed electronic portfolio available online to highlight all of their accomplishments in the five GCSP competencies. All graduating senior scholars are celebrated and share their final e-portfolio with interested students and other scholars through the annual GCSP symposium held in the fall and spring of each academic year.

The GCSP's five core competencies are designed to better prepare future engineers (GCSP scholars) for future leadership careers and to problem-solve complex and global engineering grand challenges. The five competencies include talent (research), multidisciplinary curriculum, entrepreneurship, multiculturalism, and social consciousness competencies (Fig. 1) [17].

Fig. 1. The Grand Challenges Scholars Program (GCSP) core competencies.

a. Talent or Undergraduate Research

Each grand challenge scholar is required to tackle the engineering grand challenges that our world faces. They must complete a Capstone experience and utilize one or more of the following opportunities provided by our institution:

1. Engage in undergraduate research experience in an approved team or individual research or design project with a university faculty member, focusing on one of the fourteen NAE grand challenges.
2. Complete an Entrepreneurial Initiative project approved by the instructor and the scholar's grand challenges mentor, focusing on one of the grand challenges.
3. Complete an approved independent study project focusing on one of the four grand challenges' themes (sustainability, security, health, and joy of living).

As mentioned earlier, the GCSP offers paid undergraduate research experiences for current and future scholars to pursue a summer research experience in their first- or second-year in the scholar's program. All scholars are required to present their findings at one of the university's undergraduate research symposiums [17].

b. Interdisciplinary Curriculum

To prepare our scholars to become engineering leaders for the twenty-first century, we must prepare them with technical and essential skills necessary when working with other groups and disciplines. Our scholars must take advantage of one or more of the following: complete a major or a minor in an approved interdisciplinary program, perform an internship with an interdisciplinary focus, complete a research experience with an interdisciplinary focus or take course(s) relating to a grand challenge theme (sustainability, security, health, or joy of living) [17].

c. Entrepreneurship

Grand challenges scholars are capable of translating inventions and innovations into market ventures and future global solutions to benefit the public interest and private citizens. The scholars must take advantage of approved entrepreneurial experiences or internships with significant entrepreneurial focus to complete this competency. Undergraduate research experiences with an entrepreneurial focus or course(s) focusing on entrepreneurship also satisfy this requirement. Scholars may choose to focus their research on this competency and present their entrepreneurship research findings at the undergraduate research symposiums [17].

d. Multiculturalism

Multiculturalism brings global awareness to our grand challenges scholars who will be leading international innovation and economic development as future engineers in the twenty-first century. Scholars participating in our GCSP are required to undertake a study abroad international experience or an internship or co-op experience with a significant global focus. Scholars can also fulfill this competency requirement by either taking courses that detail global experiences or by completing a Student Certificate in Developing Cultural Competence [17].

e. Social Consciousness

The social consciousness component engages scholars in service-learning and K-12 outreach programs to better prepare them to become contributing citizens. To strengthen scholars' motivation to tackle societal problems with technical engineering experiences, each scholar takes advantage of opportunities provided by service learning organizations. They could volunteer with the local chapter of Habitat for Humanity or obtain memberships in some student-led organization available to all students on campus. Students could also become affiliated with the Student Leadership and Engagement, an organization that focuses on service learning [17].

Grand Challenges Scholars Program Benefits

The GCSP offers scholars an amazing opportunity to apply what they learn in their engineering education curriculum and showcases research, innovation, and education focusing on today's most pressing grand challenges. Everything from climate change (managing the Nitrogen cycle and developing carbon sequestration) to meeting the needs of a growing population (providing access to clear water and restoring and improving urban infrastructure) are discussed. This program improves our engineering education field by providing more opportunities for experiential learning and increasing the recruitment and retention of all engineering students especially women and underrepresented student population groups.

The scholars produce electronic portfolios that are comprehensive and include all five completed competencies. This is including but not limited to undergraduate research, projects, and high-impact experiences that can be leveraged to pursue future academic and professional careers. Once accepted in the GCSP, scholars are presented with various opportunities on- and off-campus to strengthen their portfolio. Through the institution's Engineer Your Experience (EYE) program, students are able to offset travel expenses for research conferences, international travel, professional development training and certification, and research experience. Graduating seniors in the program will be recognized on their official university transcript and acknowledged publicly by the NAE upon completion of the program.

In addition to offering these research sessions in a fall series, research experiences for undergraduates (REUs) are now available for current and future scholars to pursue a paid summer research experience in their first- or second-year in the scholar's program. The Engineering Enhancement fee provides the funding for the GCSP-REUs. In order for the students to apply for this REU opportunity, the students must complete the following steps:

- Complete the online GSCP application, if they are not already a current scholar.
- Submit a one-page resume
- Submit an unofficial college transcript
- Submit a letter of interest indicating their understanding of the program and their future goals, linking their past experiences with this research opportunity to help them obtain these goals
- The name and e-mail address of at least two professors, faculty members, or other individuals who plan to conduct research during the 10-week GCSP-REU.

The REU program runs during the first and second summer terms in a hybrid format. As an outcome of the 10-week summer research experience, all REU scholars will present their research findings at the University Summer Undergraduate Research Poster Presentation at the end of their summer experience, which fulfills the capstone experience requirement. Over 42% of the accepted scholars for spring 2022 received a summer research award of $6,000, where they begin their research at the end of May and work an average of 25 hours/week with a research faculty member for 10-weeks. All research scholars will then celebrate their successes and disseminate their summer research results at the end of July at the Summer Research Symposium held by the Office of Undergraduate Research.

Grand Challenges Research Mentor

Each scholar identifies and selects a STEM research mentor to guide them through their GCSP experience. The research mentor is either a faculty or staff member who is responsible to keep scholars on task with their GCSP goals and in completing their five core competencies by graduation. The scholar's mentor reviews the student's initial application to the program along with their proposed portfolio and submit a letter of commitment along with the student's application to the GCSP admission committee. Scholars meet with their GCSP research mentor each semester to provide progress updates on their present program and to plan for the following semester's goals to complete their five competencies. Upon the conclusion of the program, the research mentors write a letter of completion to the GCSP committee in support of the scholar's application [8].

Establishing an effective *community of practice*, the steps taken this summer to create a community between the GCSP-REU's has effectively established a Grand Challenges Scholars Program *community of practice* that will continue to evolve. For example, the summer GCSP-REUs were invited to participate in a weekly GCSP-REU hangout discussion. Both in person and virtual options were provided for all scholars (hybrid). By extending this invitation to the scholars, the research scholars were recognized for their progress and validated by their peers and members of the engineering research field. Both invitations to academic and cocurricular activities have been shown to be powerful in students' sense of belonging [18]. The structured curriculum that was implemented in the GCSP-REU summer program provided many opportunities for community building, where scholars felt welcomed and safe in the spaces that were provided during the weekly hangout meetings and participating in summer outreach activities. This GCSP-REU program was designed "to increase access to professionals and peers who are a step or two ahead who share the students' demographics, characteristics and provide positive images of people in the engineering field" (p. 18) [15]. Student connections formed through collaborative and engaged learning in small groups boost their sense of belonging. Students who are given these opportunities to engage in leadership roles are more likely to envision themselves connected to the engineering profession and developing their professional engineering identities.

Effective Mentoring and Sense of Belonging

According to research, capacity, interest and sense of belonging are the three main factors that influence undergraduate students' persistence in STEM. Understanding how these three factors influence undergraduate students' experiences provide opportunities for mentoring initiatives [15]. Traditionally, engineering students demonstrate their capacity to successfully complete their engineering work through completing their in class assignments and taking their exams. However, summer research experiences are another way to assess special learning experiences for undergraduate engineering students. During a formal and structured mentored research, students often demonstrate their capacity to apply what they have learned in the classroom and during their research lab experiences. The summer research experiences provide a platform for students to deepen their understanding in courses and increase their capacity in engineering problem-solving and critical thinking skills [15].

Providing high-impact activities such as summer research programs equips undergraduate students with opportunities to enhance their confidence and competence in engineering, by providing students with hands-on research opportunities to experiment with research methodologies and equipment in engineering labs to increase their familiarity with these hands-on tools.

Oftentimes, first- and second-year engineering students, especially women and people of color, experience obstacles in their early career courses that challenge the students' emergent capability development. "Even the strongest students' *self-efficacy* can be shaken if they do not receive timely, effective feedback necessary to understand their performance and improve their competence in STEM" (p. 13) [15]. Additionally, many early career students learn and study alone in class and in isolation outside of class, resulting in missing great opportunities to actively engage with the materials and other students to improve in their knowledge, understanding, application and skills. Students involved in summer research projects are provided with mentoring opportunities to help increase their capacity to learn while practicing problem-solving skills as they acclimate to conducting research in the engineering labs [15]. When engineering students are interested in the engineering grand challenges, they are more likely to persist in engineering. "Interest can be positively influenced by a perception of relevance or usefulness in the future. Alternatively, the combination of enjoyment and challenge can foster interest" (p.15) [15].

Mentored research experiences can encourage early-career engineering students and solidify their interest by promoting engagement in the professional practices of engineering. Structured summer research programs provide multiple opportunities for students' involvement in actively practicing engineering problem-solving and critical thinking skills. These GCSP-REUs provide students opportunities to train and participate in hands-on experiments outside of the classroom. This allows the students to apply what they have learned in the classroom and during their research experience and engagement to help students visualize the relevance of engineering to the world and that engineering careers can be engaging and innovative [15]. A sense of belonging is a sense of shared identity, where individuals feel included in a membership of a

certain group or community [15]. Student's sense of belonging is defined as their "perceived social support on campus, a feeling of connection, and the experience of mattering or feeling cared about, accepted, respected, valued by, and important to the campus community or others on campus like faculty, staff and peers" (p.4) [15]. When students feel that their identities are valued and find meaningful connections with other individuals in the community, they are more likely to feel a sense of belonging and solidify their commitment to the *community of practic*e [15-18].

In the next sections, we will discuss the structure and implementation of building a *community of practice* during a 10-week GCSP-REU for 15 undergraduate GCSP students and our exploratory findings and discuss future work to continue to improve this program.

Implementation of GCSP-REU Moodle Project Site

To virtually support the *community of practice*, the GCSP-REU Moodle Project site was created prior to the start of the GCSP-REU program. The Moodle site houses several sections including a scholar online-forum that focuses on resources and opportunities for scholars to work towards the five core GCSP competencies. Among those, the highlight of the site is the timeline of the GCSP-REU program, in which every scholars' activity throughout 10-weeks was logged. This timeline was efficient in keeping the scholars updated about the events going on during the summer. Furthermore, the timeline serves as the community pillar, cementing how every scholar who participated in the program had grown personally, educationally, and professionally.

Fig. 2. Timeline for the GCSP-REU Summer Program Moodle site.

Findings

Population Statistics

In the spring prior to the start of the summer GCSP-REU program, 35 new engineering Grand Challenges scholars were accepted into the GCSP program from the host institution, as compared to the previous year during COVID-19 pandemic and isolation acceptance of only 10 new scholars. Furthermore, 42% of the 35 admitted scholars were awarded a paid GCSP-REU. Fourteen out of the eighteen engineering disciplines (78%) were represented in the scholars' population and a high number of women participated in the GCSP program (Table I). Additionally, an overwhelming majority of the new scholars were rising sophomores (47%), followed by 39% rising juniors and 13% rising seniors for the Fall of 2022 (Fig. 3).

Approximately 67% of the incoming scholars awarded a paid GCSP-REU were rising sophomores, followed by 20% rising juniors and 13% rising seniors (Fig. 3).

Table I
Demographics of GCSP scholars and scholars who participated in a summer GCSP-REU

Demographic	GCSP	REU
Engineering Majors*	78%	44%
Women in Engineering	50%	60%

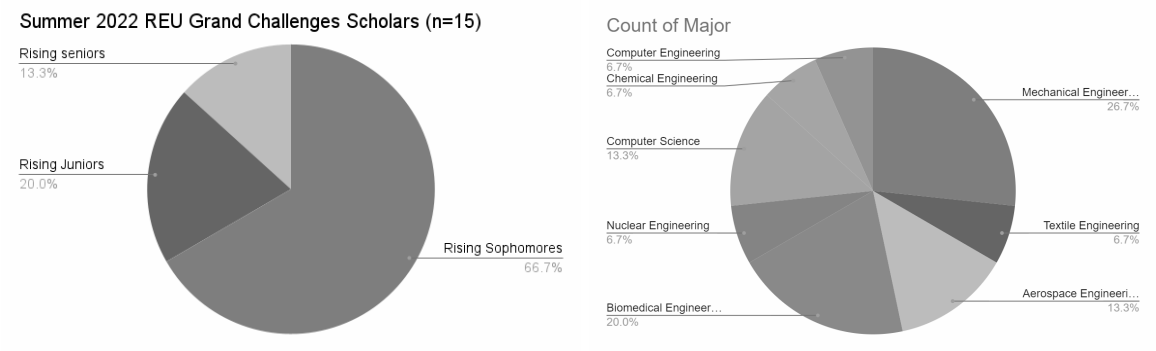

Fig. 3. Major breakdown of the scholars that participated in summer GCSP-REU

Insights gained from the REU curriculum design

The summer GCSP-REU program effectiveness was assessed by conducting online surveys and collecting informal in-person feedback. In the online survey, scholars rated their summer research experience and their perspectives on the opportunities given to exercise the *community of practice*. Approximately 40% of the scholars who participated in the summer GCSP-REU program completed the survey (n=6). All scholars who responded to the survey highly recommended the REU program. Giving the reason for this high rating, the scholars found this summer research opportunity highly educational and valuable for the mix of activities and freedom to pursue research.

Among the activities provided during the 10-week period, the weekly hybrid meetings received the most positive feedback from the scholars since 83% of the respondents saw it as a great way to build relationships with other fellow scholars. One of the scholars wrote in their response that: “I feel much closer to the other scholars who showed up frequently at the hang-out space, and I feel like I have established several relationships with my peers from our Friday meetings.” This is in agreement with the *community of practice* framework where students gather and share ideas

and resources around the domain of interest (research around the grand challenges of engineering). Every Friday afternoon, the scholars met in a conference room that the director secured with refreshments and where student researchers have a welcoming and safe space to network and discuss their research projects and current findings throughout the summer. Students shared ideas about how they can improve their peers' research projects and shared resources and technology that they saw beneficial to others. Over 50% of respondents felt that it was difficult to develop a connection with scholars who worked remotely and dialed in to the Zoom hangout session (hybrid option) due to their lack of interaction due to the virtual aspect of the meetings. Most scholars agreed that the weekly Friday hangout meetings would have been more engaging if they were fully in-person, allowing more room for interpersonal interactions. In addition to weekly Friday hangouts, the career development center provided two 90-minute workshops including CliftonStrength and Developing E-Portfolios. Both workshops were well-received by the attendees, with 83% of the participants finding them informative and helpful. “These workshops helped me to form better relationships with my GCSP peers and mentors, and led me to learn more about myself,” said a scholar. During these workshops, the scholars learned how to build a complimentary team of individuals with different strengths following the Gallup CliftonStrength assessment.

At the end of the 10-week GCSP-REU experience, the scholars presented their individual research poster alongside 250+ undergraduate researchers at the university’s summer research poster symposium. This was the finale and highlight of the summer GCSP-REU program to all students. 100% of the participants enjoyed presenting their research poster at the events and learning about the wide range of topics covered among the undergraduate researchers. Furthermore, the Symposium appeared to be an opportunity to recruit more scholars into the program. The scholars reported that incoming freshmen came to the Symposium and asked generic questions about research, engineering, and their overall freshman experience. Therefore, this was later implemented in the following GCSP Fall Symposium and was offered to all first- and second-year engineering students, where over 12 scholars who participated in the summer GCSP-REU program presented their research poster at the event. While networking with the current scholars, first- and second-year engineering students who are interested in the program posed engaging questions about the paid summer research opportunity through the scholars’ program from the perspectives of the scholars.

In addition to the GCSP-REU program, research scholars were also invited to travel and participate in the 2023 GCSP Network Annual Meeting. This meeting included representatives from many industries, universities, and disciplines collaborating in events to support the GCSP Network. Seven GCSP-REU scholars (50% of the total scholar participation from the institution) were students who previously participated in the previous summer GCSP-REU program while the remainder of the students participated in REUs from different university programs. All of these previous research GCSP scholars (100%) presented research at this meeting, totaling 14 undergraduate engineering students.

Discussion

STEM collegiate students express more interest in research than any other major. Engaging in research can enhance their *engineering identity* and encourage a better understanding of engineering as a field in industry and academia [4-6]. Benefits include an increase in research and communication skills, and paving new pathways of interest into engineering, all leading to an increase in enrollment and retention rates of undergraduate and graduate schools [4-5]. In addition to academic success, REUs enhance students' professional development by empowering students to think independently and gain technical lab skills (conducting experiments, maintaining proper lab notebooks, data collection and analysis, and the ability to comprehend and disseminate their research findings in published literature). When a student was asked to name two accomplishments after participating in a REU, the result was an increased level of confidence and an increased appreciation for research. These answers, as well as previously collected data, suggest a daily laboratory experience for undergraduate students is necessary for development of *engineering identity* and research *self-efficacy* [5]. Daily laboratory experience is something the REU can provide since participants would be carrying out original research while working on their project each day. Since the REU gives engineering students experience in their career paths, it also gives them a taste of what graduate school would be like and has indirectly led to an increase in positive attitude towards graduate school as well as graduate school enrollment [4-5].

Research shows that collegiate students' "preconceptions about research can negatively shape experiences with research" [4]. To counteract this preconception, our institution built effective mentoring programs such as a 10-week REU program that was important to student development and success. In addition to having effective mentorship, participating in small group activities with like-minded peers encourages students' sense of belonging into this community. The opportunity to begin research early and instill the belief that the student can conduct efficient research has shown to do wonders for students' research experience as well as their *self-efficacy* [4]. Building their research *self-efficacy* has also strengthened their interest in research [4].

Students who are interested in their research topic are intrinsically motivated in the success of their research experiences and develop a more positive outcome overall for the students and everyone involved in the process, including the research mentors. By engaging in 10-week REUs, the students develop technical skills, knowledge and sharpen their critical thinking and problem-solving skills, while enhancing their essential (soft) skills through participating in informal and formal networking and professional development activities.

Members of the summer GCSP-REU were accepted into their departments of choice within the college of engineering and completed all first-year requirements. While there are many different disciplines that the REU members are part of, with the GCSP representing 12 of the 14 engineering disciplines offered at NC State, the passion that links all of the scholars together are the Grand Challenges. Each student in the program has taken E101: Introduction to Engineering and Problem Solving, and E102: Engineering in the 21st Century, two classes that give insights

into the Grand Challenges. The majority of students pass through the class gaining basic information on the Grand Challenges. Each REU member desired to learn more, taking one or more of the Grand Challenges to heart and developing a passion to help solve it and shape the future of humanity. Each REU is driven by the students' genuine passion in the methods of helping the world advance and develop. Grand Challenges are the area of interests that the REU members are part of that serves as the domain pillar in a *community of practice*.

Each week during the REU program, there would be a hybrid meeting with all the REUs where participants discussed their research, helped each other, and participated in collaborative activities. Some weeks there would be discussion on methods of optimizing time management in research, while other weeks there would be career development workshops to aid in setting up life after graduation. Each meeting led to more and more collective interest and passion into the work being done and allowed for communication and growth as individuals. The program had taken a hiatus following the beginning of the COVID-19 pandemic resulting in most if not all members being new to the program, which united the members even stronger beyond their passion for the Grand Challenges alone.

While each GCSP-REU scholar has shared passion and interest in the Grand Challenges and the beginnings of most of their research, almost all of the members had research in different areas. Research ranged from anterior cruciate ligament (ACL) tears to Organic Semiconductors with many REU members undertaking research that was not part of their intended major. This resulted in many of the REU members gaining experience in new fields as well as applying those experiences to their primary field and personal life. The REU scholars had many ways to share their knowledge, from the weekly hangouts to the University Summer Research Poster Symposium. This sharing of stories, experiences, and ideas allowed each REU member to learn more and grow personally as well. Each REU scholar would be able to achieve this with their own research that they undertook, but the sharing of knowledge with each other is what allowed the establishment of the *community of practice* [12-13].

In addition to the weekly meetings, many of the REU members attended workshops provided by the university's Office of Undergraduate Research. These workshops encompassed a multitude of topics from Diversity and Inclusion in research to research Ethics. These additional opportunities allowed for even more growth, as REU members who attended communicated with 250+ undergraduate researchers from 23 different university programs including none STEM disciplines. Scholars discussed their experiences from attending these university-wide workshops to other scholars during the weekly hangout which also benefited the scholars who weren't able to attend the workshops offered by the university. GCSP-REU scholars shared their knowledge with one another leading to a further dissemination of knowledge and perspectives while also fostering personal growth. Furthermore, a GroupMe was established to ensure effective communications between the GCSP-REU members. Having access to this digital application allowed scholars to share communication quickly and effectively, disseminating information and serving as a great way to effectively communicate any issues to the proper stakeholders. The

weekly meetings and other opportunities for the REU members to communicate allowed for a group of people that did not know each before to turn into a strong community, serving as a *community of practice* with scholars that felt a sense of belonging.

The three elements – domain, community, and practice – create a *community of practice*. By developing these three elements conjointly, one allows for such a community to occur. The simultaneous creation of the domain of interest in the Grand Challenges and research, the community in weekly meetings and other opportunities, and the practice in experiences of each REU member and the collective group are what allowed the Grand Challenge Scholars Program *community of practice* to be effectively established this summer. These three pillars being established in tandem allowed for REU members to gain new experiences, gain greater knowledge, and most importantly, grow both personally and as a collective. With the presentations that the REU members gave to incoming students at New Student Orientation and plans to create a Scholar's Council to govern the day to day activities of the program, the *community of practice* will only continue to grow and evolve as more and more members join.

The impact of the *community of practice* is evidenced by the increased participation of accepted REU students. It has increased by 60% since the beginning of the program, which expanded the opportunity availability and community size for scholar interaction. Nearly 30% of eligible students who participated in the summer GCSP-REU program received acceptance to participate in another REU experience while peer mentoring students new to the REU program. First- and second-year students benefit from REUs as they further develop their *engineering identity*, leading in their persistence of pursuing their engineering undergraduate and graduate degree [8]. Their engagement continued throughout the school year as they participated in the bi-weekly hangout discussions throughout the school year. These scholars who participated in the REU also became active leaders in the GCSP Fall and Spring symposiums, sharing their engineering experience with fellow scholars and attendees. Therefore, effective mentoring that includes impactful and intentional REU programs are necessary to counteract the barriers that many of our women and underrepresented student population experience in the STEM field. Effective and intentional REU programs assist in fostering positive social and working conditions in a safe environment that fosters a *community of practice*.

Future Work

In preparation for the upcoming summer GCSP-REU program, the reflection upon the past summer REU program is critical for the improvement of the curriculum design. The curriculum is continuously evolving and revised to provide the scholars the most beneficial experience possible over the course of the 10 weeks. Firstly, the weekly meetings will continue to resume in person with a Zoom option for researchers that are unable to participate in person. We plan to improve the weekly hangout meetings by including team activities to engage all participants and ask scholars to reflect on their weekly research experience by responding to a few questions as they document their responses in their lab notebooks. We believe these changes will increase

participation and effectiveness. In an effort to cultivate a *community of practice*, returning GCSP-REU members will be paired with new students entering the program. The returning participants (6 out of the 27 new summer REUs who plan to participate this summer) are a resource to peer-mentor the new participants as they develop an *engineering identity* and learn research skills. The scholars participating in the program will fill out a poll and choose a day in the week they would like to meet, as well as the meeting location that would be most convenient for them. In-person attendance of these meetings will be incentivized with provided refreshments and engaging team-building activities. Secondly, informing the scholars about helpful resources prior to the beginning of the program will greatly assist them. We are hosting an informational networking event prior to beginning research where we will introduce the program leadership, Moodle site, and program expectations while allowing students to meet their peers. Other useful information is distributed early and regularly. For example, it is important to encourage scholars to get the parking pass early as they will be commuting to their research labs or to in-person meetings. The scholars are also encouraged to apply for the Office of Undergraduate Research Award to earn financial support that pays for non-educational fees. Thirdly, a focus on weekly goal-setting and reflection will be implemented in order to add individual structure and guidance to the experience, contributing to development of engineering *self-efficacy*.

A final point to mention is that upon completion of the GCSP-REU program, the scholars will be required to write a reflection essay, along with submitting research artifacts on the Moodle Project site. This essay allows the scholars to demonstrate their learned skills and apply their knowledge to future interviews and career goals. Furthermore, the essay will be a method of measurement for evaluating the REU curriculum design.

Summary

This paper describes effective strategies that were implemented in the summer 2022 to improve the status of an existing grand challenges scholars program at its institution. By implementing new innovative strategies, first- and second-year engineering students expressed more interest in applying their technical knowledge in engineering to engineering grand challenges research to complete their Talent competency in the GCSP. Efforts such as the research and the entrepreneurship series and the fall and spring symposiums generated over 250 engineering students that were intrigued by the grand challenges scholars program. Additional funded REUs were awarded to 23 new undergraduate scholars and 4 high school students that are currently taking engineering courses at the prescribed institution.

References

[1] National Academy of Engineering. 2008. NAE Grand challenges of Engineering. http://www.engineeringchallenges.org/.

[2] C. M. Vest, "Context and challenges for twenty-first century engineering education". *Journal of Engineering Education, 97(3), 235-236, 2008*.

[3] J. M. Lakin, Y. Han and E. Davis, "First-Year Students' Attitudes towards the Grand Challenges and Nanotechnology", *Journal of STEM Education, 17(3), 70-76, July-September, 2016.*

[4] H. M. Manitzas Hill, J. Zwahr, and A. Gonzalez, III, "Evaluating Research Self-Efficacy in Undergraduate Students: Experience Matters", *JoSoTL*, vol. 22, no. 1, Mar. 2022.

[5] M. Borrego, M. Mastronardi, H. Choe, and R. Hartman, "The Impact of Undergraduate Research Experiences on Participants' Career Decisions," *Journal of STEM Education: Innovation and Research*, vol. 22, no. 2, pp. 5–12, 2021.

[6] J. O. Shanahan, E. Ackley-Holbrook, E. Hall, K. Stewart, and H. Walkington, "Ten Salient Practices of Undergraduate Research Mentors: A Review of the Literature," *Mentoring & Tutoring: Partnership in Learning*, vol. 23, no. 5, pp. 359–376, Oct. 2015, doi: https://doi.org/10.1080/13611267.2015.1126162.

[7] M. Syed *et al.*, "The Role of Self‐Efficacy and Identity in Mediating the Effects of STEM Support Experiences," *Analyses of Social Issues and Public Policy*, vol. 19, no. 1, pp. 7–49, Oct. 2018, doi: https://doi.org/10.1111/asap.12170.

[8] D. Parish, J. Lavelle and L. Martin-Vega, "Development and Implementation of an NAE Grand Challenge Scholars Program: A Case Study at North Carolina State University," in *Proceedings of 16th LACCEI International Multi-Conference for Engineering, Education, and Technology: Innovation in Education and Inclusion, Lima, Peru, July 19-21, 2018.*

[9] N. Balster, C. Pfund, R. Rediske, and J. Branchaw, "Entering Research: A Course That Creates Community and Structure for Beginning Undergraduate Researchers in the STEM Disciplines," *CBE—Life Sciences Education*, vol. 9, no. 2, pp. 108–118, Jun. 2010

[10] J. M. Lakin, A. H. Wittig, E. W. Davis, and V. A. Davis, "Am I an engineer yet? Perceptions of engineering and identity among first year students," *European Journal of Engineering Education*, vol. 45, no. 2, pp. 214–231, Jan. 2020, doi: https://doi.org/10.1080/03043797.2020.1714549.

[11] J. R. Morelock, "A systematic literature review of engineering identity: definitions, factors, and interventions affecting development, and means of measurement," *European Journal of Engineering Education*, vol. 42, no. 6, pp. 1240–1262, Feb. 2017, doi: https://doi.org/10.1080/03043797.2017.1287664.

[12] E. Wenger-Trayner & B. Wenger-Trayner, “Introduction to Communities of Practice - Wenger-Trayner.” Wenger-Trayner, 2015, https://wenger-trayner.com/introduction-to-communities-of-practice/.

[13] R. Adams *et al*., “A community of practice approach to becoming an engineering education research professional,” in *360° of Engineering Education: Proceedings of the 121st ASEE Annual Conference & Exposition, Indianapolis, IN, USA, June 15-18, 2014*.

[14] L. C. Li, J. M. Grimshaw, C. Nielsen, M. Judd, P. C. Coyte, and I. D. Graham, “Evolution of wenger's concept of community of Practice,” *Implementation Science,* vol. 4, no. 1, 2009.

[15] B. W.-L. Packard, *Successful STEM Mentoring Initiatives for Underrepresented Students – A Research-Based Guide for Faculty and Administrators*. Sterling, VA: Stylus, 2015.

[16] G. Crisp and I. Cruz, “Mentoring college students: A critical review of the literature between 1990 and 2007,” *Research in Higher Education*, vol. 50, no. 6, pp. 525–545, 2009.

[17] Qaqish, O., & Parish, D., “An Improvement of an Engineering Course that Presents and Promotes the NAE’s Twenty First Century Grand Challenges and Program,” in *2022 ASEE Annual Conference & Exposition, Minneapolis, MN, USA, June 26-29, 2022*.

[18] T. L. Strayhorn, *College students' sense of belonging: A key to educational success for all students*. New York, NY: Routledge, 2019.