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Bridging Futures Takes a Village: A Pre-College Collaborative Education and Research Approach to Broaden Participation of Underrepresented Population in STEM Career Pathways

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Olgha Bassam Qaqish, Ph.D. is a prominent figure in engineering education and research, currently serving as the director of the Engineering Grand Challenges Scholars Program (GCSP) at NC State University. With a diverse background encompassing education, research, mentorship, and innovation. Dr. Qaqish is a driving force in shaping the academic landscape.

She holds a patent for pioneering work titled, "Methods, Systems and Computer Readable Media for applying multi-push acoustic radiation force to samples and monitoring a response to quantify mechanical properties of samples," showcasing her expertise in applied engineering. She is also a respected author, having co-authored two textbooks. Her debut, "Algebra Essentials," emerged during her tenure teaching Mathematics at Wake Tech Community College, while her second publication, "Creating a Better World: Innovation, Ingenuity, and Engineering," serves as a cornerstone in first-year engineering courses at NC State.

In addition to her roles in curriculum development and instruction, Dr. Qaqish is deeply involved in research and mentoring. She serves as an instructor for core first-year engineering courses such as E101: Introduction to Engineering & Problem Solving and E102: Engineering for the 21st Century. Her commitment extends to undergraduate and graduate-level research courses, where she fosters an environment of innovation and discovery. She established the study abroad program for E101 for Quito, Ecuador for Spring 2024 and is now the program director for the study abroad program for E101 for Prague, Czech for Spring 2025.

Dr. Qaqish's academic journey reflects her dedication to learning and excellence. She earned her Bachelor of Science in Biomedical Engineering from Boston University, followed by a Master of Science in Biomedical Engineering from NC State University and UNC-Chapel Hill. Her academic pursuits culminated in a Ph.D. in Educational research from NC State University, underscoring her commitment to advancing engineering education.

As the director of the Grand Challenges Scholars Programs and a First-Year Engineering Educator at NC State University's Undergraduate Academic Affairs - College of Engineering, Dr. Qaqish remains a steadfast advocate for academic and social achievement in engineering. She champions diverse educational strategies tailored to each student's unique strengths while nurturing areas of improvement, thus ensuring a supportive and inclusive learning environment for all aspiring engineers.

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Abstract:

This case study examines the integration of an Early College High School (ECHS) with the Grand Challenges Scholars Program (GCSP) at a prominent R1 public institution in the United States. The collaboration aims to empower K-12 students from underrepresented minority (URM) groups by engaging them in research to prepare them for successful careers in engineering and computer science. These URM students include first-generation college students and individuals from diverse racial, ethnic and gender backgrounds.

The GCSP, endorsed by the National Academy of Engineering (NAE) in 2009 and supported by over 90 institutions worldwide, equips undergraduate students to tackle Grand Challenges of the 21st Century. The program adopts a holistic approach to preparing scholars, emphasizing social consciousness, hands-on research skills, multidisciplinary knowledge, entrepreneurial experiences, and a global perspective. Since its establishment in 2013, the GCSP chapter at the university has mirrored the program’s broader success. In 2022, the university’s chapter launched the GCSP Research Experience for Undergraduates (GCSP-REU), which provides intensive mentorship and research opportunities to over 20 undergraduate engineering students. The GCSP-REU specifically targets students from marginalized populations and those without prior research experience; thus catalyzing their future successes [1].

The ECHS aligns with similar principles, focusing on holistic education to address the NAE Grand Challenges. It is dedicated to developing URM students by integrating project-based learning, problem-based inquiry, project management, and research skill into its curriculum. The ECHS and GCSP share core values and objectives, making their partnership a strategic effort to increase participation in engineering higher education and provide students with the support necessary for research success.

In the summer of 2023, this collaborative vision came to fruition with the launch of a joint research program. The inaugural ECHS cohort, consisting of four high school students, took part in a five-week research program alongside the GCSP-REU scholars. This initiative aimed to prepare these high school students for undergraduate engineering studies, while fostering interdisciplinary and inter-institutional collaboration. The program’s initial success was evident in its ability to challenge stereotypes and facilitate meaningful interactions between high school students and undergraduate scholars.

Feedback from the first cohort in 2023 prompted improvements for future iterations of the program. Program leaders applied the engineering design cycle to enhance participation and diversity, resolve logistical issues, strengthen support mechanisms, and ensure sustained growth. Additionally, ECHS students who were not part of the summer program were given the opportunity to join District C Teamship, a business problem-oriented internship established by the ECHS. This experience contributed to refining program dynamics and improving student engagement. In subsequent iterations, the program expanded to include eleven ECHS students working across various research labs on campus. This development highlights the program's growing success in advancing engineering education and research among URM groups. In summary, this case study illustrates a successful collaboration between ECHS and GCSP at an R1 institution to enhance diversity and inclusion in engineering and computer science fields by developing an innovative research program that prepares URM students for future success in these fields.

Background:

In recent years, government officials, educators, and industry leaders have expressed concern about the lack of diversity and inadequate training of professionals in Science, Technology, Engineering, and Mathematics (STEM) fields. This issue carries significant implications for economic sustainability, scientific advancement, and national security [2]-[4]. In the United States, the underrepresentation of minority groups in STEM remains a persistent challenge. Specifically, the STEM education system is predominantly Caucasian, with underrepresented minority (URM) students defined as being non-male and/or from Black/African American, American Indian, Alaskan Native, Hawaiian Native, Pacific Islander, and Hispanic/Latin(x) backgrounds [5]. These students may also be first-generation college students and come from low socioeconomic backgrounds [6]-[8].

Data from the National Center for Education Statistics (2021) underscores these disparities: in the United States, Caucasian students earned 56% of all Bachelor's degrees in STEM fields, while Hispanic/Latin(x) students earned only 18%, Black/African American 9%, American Indian or Alaskan Native 0.4%, and Hawaiian Native or Pacific Islander a mere 0.2% [4]. These percentages are starkly misaligned with the growing diversity of the United States population, where Hispanic, Black, American Indian and Pacific Islander populations represent 19.5, 13.7%, 1.3% and 0.3% of the population, respectively [9]. The consistent inequality in STEM education has led to numerous efforts at reform and interventions aimed to address these challenges [10].

Efforts to rectify these disparities have primarily focused on improving the academic preparedness of URM students. Pre-college initiatives are designed to expose URM students to essential STEM curriculum in mathematics, science, and physics, while also providing mentorship and facilitating social integration to enhance students' perseverance in STEM fields and develop strong STEM identities [2], [6], [11]-[14]. By equipping URM students with the

necessary skills and confidence, these programs seek to empower them to pursue STEM careers, ultimately addressing the systemic barriers that have historically hindered their progress and development.

Introduction

This paper introduces a novel approach to addressing these challenges by integrating a STEM-focused Early College High School (ECHS) with the Grand Challenges Scholars Program (GCSP) at a leading R1 public and predominantly white institution (PWI). By leveraging the strengths of both programs, this initiative seeks to empower URM students and bridge the gap between secondary education and advanced STEM research opportunities. This case study illustrates how collaborative, tailored pre-college research opportunities can be designed to achieve this goal for URM students. The partnership aims to cultivate a more inclusive and diverse pipeline for STEM professions, ultimately contributing to a workforce that is more equitable, innovative, and excellent.

The GCSP is a research-based program for undergraduate students, inspired by the National Academy of Engineering's (NAE) fourteen Grand Challenges. GCSP is designed to equip engineering students to become well-rounded, cultured, informed, and curious problem solvers for the 21st century. Throughout their time in GCSP, scholars focus their research on topics in one or more of the four pillars of the Engineering Grand Challenges: Security, Health, Sustainability, and Joy of Living. The program offers a range of opportunities to ensure scholars' involvement encompasses the five core competencies: talent, entrepreneurship, multidisciplinary, multicultural, and social consciousness [15].

Overview of the Early College High School

ECHS programs have gained popularity since their inception in 2002, largely due to support from the Bill & Melinda Gates Foundation [16]. These programs are particularly appealing to URM populations because they reduce financial and time barriers associated with higher education. Evidence suggests that students who participate in ECHS programs are more likely to earn college degrees, accumulate less educational debt, and enter their careers sooner [16].

The prescribed institution is a small public school that is in partnership with the higher education institution described previously. ECHS students engage in an accelerated education program that offers honors courses designed to prepare them for college-level rigor. During their first two years, students complete their required high school requirements and then progress to university courses. In the subsequent two to three years, students take university courses, participate in internships, and engage in hands-on research. These students are enrolled at the prescribed university as non-degree seeking students. Being enrolled at the university means that these students have an established students account, which gives them access to university

resources (i.e. reserving library books and rooms, university email accounts, etc). Successful students can graduate with up to 60 college credit hours. This award-winning, nationally recognized ECHS program, as a whole, is dedicated to bringing underserved populations, including first-generation college students, into STEM disciplines and the prescribed institution reflects these trends. Currently, the prescribed ECHS serves a student population of 295, with 66.78% identifying as racial and/or ethnic minorities, 60.68% as first-generation college students and 31.53% from low socioeconomic backgrounds.

The ECHS's deliberate and strategic efforts to enhance diversity and engagement are reflected in the curriculum that introduces students to the critical Grand Challenges for Engineering. The school holds holistic educational principles through practicing concepts included in Inquiry-Based Learning (IBL), such as Project-Based Learning (PBL) and Problem-Based Inquiry (PBI), and the development of project management and research skills. Established conceptually in 2010, PBL and PBI are instructional approaches that cater to the individualism and multiculturalism of a student body. When students have the options to work on relevant, real-world problems in groups over a period of time, a more diverse population is able to develop a deeper, more impactful, engaging, and well-rounded education when compared to traditional standardized learning approaches [17]. PBI and PBL often require team-based work, however the community of practice established is more influential than teamwork alone [18]. The institutional structure that shares the body of knowledge towards the Grand Challenges allows students to create value in collaboration with their learning community. These educational approaches provide a framework that empowers marginalized students and fosters their exposure to, and engagement in STEM fields.

High School and University GCSP Collaboration

The connection between the prescribed ECHS and the university GCSP programs was evident, due to the similarity in their values, and the focus on the NAE's Grand Challenges was a driving force behind the partnership established in 2022. ECHS students wanted hands-on, real-world projects, and GCSP offered an avenue to mentor the students in research skills and introduce them to research faculty at the university level. Eleven ECHS students interested in collegiate-level research applied for a summer research-based internship, with four selected to join the inaugural cohort of researchers. The demographics of the inaugural cohort consisted entirely of male students, with 50% being first-generation college students. The students participated in a modified segment of the GCSP-REU program, which allied for peer-mentoring relationships with more seasoned researchers. This design was instrumental for early research immersion and introducing the students to the vital Community of Practice (CoP) for Engineering Education [18].

The initial collaboration between the GCSP and ECHS demonstrated significant potential. To build on this success and to ensure sustainability, ECHS leadership developed a project aimed at improving the research experience for future cohorts. This initiative was facilitated through District C Teamship, a framework implemented by the ECHS with a mission to provide equitable access, rigorous coaching, and a modern approach to internships for students. The Teamship teaches students to work in diverse teams to solve business problems across various fields. The program pairs four students with a business partner, where the company presents a business problem to the student group. Students are then coached to identify the root issue, develop possible solutions, and test these solutions. They present their findings and recommendations to the partnering business, incorporating feedback from community stakeholders, school partners, and parents.

Between the first and second cohorts, District C Teamship students were assigned the task of improving research opportunities for high school students drawing on feedback from the initial cohort. This project enabled students to apply their problem-solving skills to enhance the research experience for future participants. Some proposed strategies include creating an advertisement, streamlining the application process and enhancing program branding for greater visibility. One group suggested establishing a website and social media channels to directly promote program engagement to the target audience. Other recommendations included increasing crowdfunding efforts to boost the student stipend and to encourage greater participation. The ECHS' leadership adopted these suggestions to strengthen research involvement within the ECHS and GCSP partnership. As a result, the program was rebranded at the high school level as "Howling Scholars". Funding this program was an important catalyst for its success. Individual students received a $1,000 stipend upon the completion of their participation, totalling $4,000 for each summer cohort consisting of four students. Initial iterations of this program were funded by independent community stakeholders who established an endowment. Future iterations of the program are sustainable due to the endowment, generating an interest of $4,000 annually that can then be used to support the longevity of this program.

Initial findings from this cooperative highlight the benefits of increasing participation among URM populations in engineering. Of the four students in the initial cohort, 75% of students chose to continue their education at the partner institution, and all four opted to pursue undergraduate engineering degrees. This success underscores the potential impact of such programs on student outcomes. This partnership's scalability is evident, as participation in the second cohort for the year 2023-2024 increased 150%, with a total of ten students. This growth suggests a promising trend and the potential for broader, more impactful results as the program continues to expand.

Challenges to Overcome

In addition to increasing participation, several challenges emerged during the program. According to qualitative data obtained through informal interviews with the ECHS leadership, a common issue among students, particularly those from URM backgrounds, was a lack of confidence, which often led to hesitancy in participation. Imposter Syndrome and deficiencies in time-management and organizational skills frequently required additional support. Some students also exhibited a tendency to prioritize speed over quality, highlighting a need for reinforced PBI and PBL methodologies, as well as an emphasis on mastery-based learning approaches. To address these challenges, the curriculum was adapted to include introduction to research courses, providing students with foundational skills and confidence early in their academic careers. Personalized recruitment efforts within the small high school environment also positively impacted students' confidence in applying to the program early in their academic career.

Initially, securing research faculty mentors proved challenging. Collegiate faculty and staff volunteered to host the high school researchers. The faculty mentors were not compensated financially for including the four high school researchers in the 5-week research experience. There was no financial cost to the faculty to host these students, but the implicit cost of contact hours required for mentoring them may have been an impacting factor.

There was also initial reluctance from research faculty mentors. This may be due to preconceived notions that high school students might be underprepared for collegiate laboratory settings and participating in quality hands-on research. These sentiments were understood through indirect data measurement obtained through conversations with potential research faculty mentors. To overcome this, ECHS leadership involved students in first-year engineering courses, encouraging them to interact with faculty and make a strong impression. The integration of the Grand Challenges and engineering design cycle early in high school resulted in improved preparedness and performance in these settings, even compared to their collegiate counterparts. Positive performance in these courses facilitated strong faculty connections, and the positive experiences of early research program cohorts were shared within the university, helping to alleviate some doubts among professors and open more opportunities for future cohorts.

Implementation Insights

In 2023, the first cohort of four high school students was mentored by a teaching faculty mentor, from the GCSP director's network. This initial faculty mentor did not have an already established lab infrastructure to host the high school researchers, which presented a challenge. This situation led to a heavy programming burden on the GCSP director and coordinator to onboard the high school students and provide technical guidance without labmates. Identifying ideal faculty members for mentoring the ECHS students was key to ensuring sustainability and success for the program. We strategically chose mentors that had established research labs that would provide peer mentoring and a CoP for the incoming ECHS students. Leveraging existing

lab infrastructure for professional, technical skill, and community development was ideal for removing additional burden to those facilitating the program, both at the ECHS and university levels.

The faculty mentors' preparation and training played a critical role in creating an inclusive, effective research environment. For example, mentors tailored their feedback to meet students at their developmental stage. They focused on practical skills like poster presentations, writing for research, and hands-on laboratory experimentation. One participant highlighted the value of these experiences: *"This REU was significant in me feeling confident enough to pursue future research. I was introduced to how research works, and now feel confident that I can make quality posters and writings in my future research"* [19].

Participating university faculty mentors in the program also participated in recognized mentoring training, such as those offered by the Center for the Improvement of Mentored Experiences in Research (CIMER) to strengthen faculty engagement [20]. This provided a larger repertoire of skills to mentor the students and combat common occurrences including imposter syndrome in underrepresented populations [21]. Previous research highlights that positive mentoring experiences significantly enhance perseverance in engineering education by fostering retention, academic success, confidence, and professional skill development among students. All of these factors also influence engineering identity and research self efficacy [1]. In addition to facilitating interactions with strategically trained faculty mentors, these ECHS REU students are mentored by more senior researchers in their respective research labs, and within the GCSP-REU program, where various levels and fields of students have been collaborating for five weeks prior to the ECHS joining the team. This structured, tiered mentoring approach lessens the burden on any one member and expands the community of practice each student has. It has already proven effective in previous GCSP-REU cohorts and could serve as a model for scaling in similar initiatives [1].

In reflection on program implementation, it is essential to harness the perspectives of the student participants. Their experiences directly reflect the program's impact and areas for improvement. The following feedback from students in both cohorts 1 and 2 highlights the transformative role of the program in fostering confidence, providing mentorship, and creating pathways for futures in the STEM field. A first-generation student from cohort 1 described their experience in the program as pivotal to their growth as a researcher, stating: "*My favorite part of the REU program was getting to work on professional level equipment and present my research professionally. It was an incredible experience to be treated like a scholar that was researching important things. It really benefited me to get to present the research especially, as I got to make and present my own poster"* [19].This sentiment underscores the importance of hands-on opportunities and professional research communication opportunities in building students' confidence and competence in research.

Additionally, students noted the significance of mentorship in navigating the complexities of research and professional academic environments: *"Having great mentors really helped me feel confident in professional settings. They critiqued our posters, helped with our writings, and taught us how to work in a lab. They also helped get us access to incredible tools, such as the HPC supercomputer"* [19]. Similarly, students from racial and gender minority backgrounds in engineering highlighted the program's role in fostering a sense of belonging and expanding their professional network: "*The mentorship I received in the REU Program gave me the confidence to excel in places where I would feel out-of-place otherwise and gave me a sense of community that is very much needed as a high school student in a college environment. The encouragement and continual support I was given from my mentors reminded me that I was capable of doing beyond what I had first imagined and was something I still appreciate to this day"* [22]. These reflections not only validate the program's approach, but also emphasize the importance of mentorship, community and supporting underrepresented students in STEM. The students' ability to connect with mentors and leverage university resources demonstrates the potential for well-structured programs to bridge systemic gaps in access to research opportunities.

Summary

In summary, this case study illustrates a unique and affordable solution for broadening participation of URM students in STEM related research at the university level through collaboration between an ECHS and a Grand Challenges Scholars Program at a major public research institution. Geographic proximity and integration of practices between the ECHS and the collegiate institution played a key role in the founding of the program, but future work can extrapolate this success to other situations. The aforementioned model tightens the gap and creates a bridge between pre-college students and collegiate STEM research. Implementation of the developmental model requires financial support, through crowdfunding, alumni giving, and grants, as well as mentors at the high school and collegiate level for infrastructure establishment and sustainment. Through customized curriculum and research experiences this collaboration can be a strong mechanism to enhance inclusivity and diversity in the STEM pathway, contributing to a more equitable, innovative, and excellent workforce.

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