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Building the Energy Workforce Pipeline: A Scholar-Mentorship Model for Pre-College Research

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Genesis Alvarez

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(Work in Progress)

Abstract

A university-led Scholar–Mentor program at George Mason University (GMU) extends a summer camp on clean energy into a sustained, year-long, research-based experience for high school students. Through this program, students engage in research projects and are mentored by faculty, graduate students, and professionals from leading power and energy organizations, including Google, Northern Virginia Electric Cooperative (NOVEC), and Hispanics in Energy Virginia Chapter (HIE-VA). The program is structured around a three-tier mentorship model that integrates faculty guidance, near-peer technical coaching, and industry-informed perspectives, bridging early STEM exposure with workforce preparation.

This Work in Progress paper presents the program's architecture, implementation strategies, and initial outcomes. A mixed-methods evaluation framework was developed to assess changes in students' technical confidence, communication skills, and sense of belonging within engineering communities. Preliminary findings, along with ongoing assessment efforts, are discussed to inform iterative program refinement.

By articulating both the program design and its assessment strategy, this work offers a replicable model for institutions seeking to build sustained pre-college research pipelines aligned with future energy workforce needs.

Keywords

Academia– Energy Engineering Education; High School Research; Industry Collaboration; Mentorship; Pre-College Engineering Education; Research Mentorship

Introduction

Early exposure to authentic engineering experiences is a critical factor influencing students' interest in and pursuit of employment in science, technology, engineering, and mathematics (STEM) pathways and their formation of engineering identity [1]. As energy systems evolve to incorporate renewable resources, advanced nuclear technologies, and digitalized grid infrastructure, the demand for a technically prepared workforce continues to grow.

Developing a sustainable and inclusive energy workforce requires educational pathways that extend beyond traditional undergraduate recruitment strategies. Pre-college programs play a key role in shaping students' perceptions of engineering careers. However, many outreach initiatives are short-term and lack sustained engagement, thus limiting their long-term impact on career trajectories. The 2025 George Mason University (GMU) High School STEM Summer Camp, *Lunar Microgrids: Engineering Power Beyond Earth*, served as the entry point for this study. The camp delivered a one-week, project-based experience integrating earth–lunar microgrids with renewable and nuclear energy systems.

Through hands-on labs, team-based design projects, and industry engagement, the program established baseline measures of students' technical confidence, communication skills, and interest in energy careers. Industry partners included Astrobotic, Corscale Data Centers, Dominion Energy Virginia, Elevate Energy, Google, Hispanics in Energy (HIE-VA), Northern Virginia Electric Cooperative (NOVEC), PATHIRED, SHINE, and Virginia Nuclear Energy Consortium.

Bridging the gap between introductory outreach and sustained research engagement is a key opportunity to strengthen the engineering workforce pipeline. This paper presents a work-in-progress initiative, led by GMU in collaboration with Google, HIE-VA, and NOVEC, to expand a clean energy summer camp for high school students into a structured, year-long research engagement. The program connects young scholars with faculty mentors, graduate student coaches, and industry advisors to support their authentic research experiences that address current energy challenges.

Five top-performing students from the summer camp were subsequently selected into a funded scholar cohort, forming the foundation of a 12-month Scholar-Mentor pilot program. In this extended phase, Scholars engage in research activities, receive technical mentoring, and present their work at workshops. These experiences provide sustained exposure to real-world engineering contexts, reinforcing the relevance of their research and supporting continued growth beyond the initial summer program.

The Scholar-Mentor model embeds mentorship, project-based learning, and identity-focused support within a long-term program designed to develop students' professional and technical skills, while fostering a sense of belonging within engineering communities.

This paper describes various aspects of the pilot program, including the program architecture, research themes, mentorship framework, and evaluation plan. Findings from early implementation and planned assessment activities will serve to refine this program.

Background and Motivation

Pre-college engineering programs are effective in broadening students' participation in STEM and strengthening their early interest in engineering careers. Project-based learning and mentorship help students stay interested in engineering by engaging them in real-world problems and providing guidance from experienced mentors. These experiences help students build confidence, develop skills, and better understand engineering careers [2], [3]. Mentorship is also a critical factor in supporting students' motivation in STEM pathways, particularly when near-peer and role-model interactions reinforce belonging and the formation of professional identity [4].

Recent studies highlight the importance of sustained engagement beyond short-term outreach interventions. While summer camps and workshops can spark initial interest, long-term mentorship and research opportunities provide students with deeper exposure to engineering practices and foster their skills in communication, problem solving, and collaboration [5], [6]. Our perspective is that programs that integrate research experiences at the pre-college level positively impact students' confidence, career awareness, and readiness to pursue STEM majors.

Investing in sustained pre-college engagement is not only an educational priority, but also a strategic approach to addressing long-term workforce needs in the energy sector. National workforce organizations emphasize the need for educational models that build technical competencies while cultivating systems thinking and professional skills [7]. These findings are consistent with broader K-12 engineering education literature that emphasizes authentic problem-based learning and mentorship to strengthen STEM enthusiasm and identity formation [8]-[10].

Despite these insights, relatively few programs extend pre-college research engagement beyond short-term experiences. The Scholar–Mentor model seeks to address this gap by combining sustained mentorship, authentic research, and identity-focused support within a structured year-long framework that also aligns with emerging energy workforce needs. This program is equipping students with industry-relevant skills and career insight while engaging them in meaningful work addressing modern energy challenges.

Program Architecture and Cohort Structure

The new Scholar–Mentor program evolved out of a clean-energy summer camp program. Summer camp participants applied for the year-long program. The application evaluated their interest, academic preparation, and commitment to research activities. The pilot cohort consists of a small group of five scholars, so that students can receive individual mentorship and close supervision of their research progress.

The program follows a phased structure. It begins with orientation and research onboarding, followed by topic exploration, guided research execution, and culminates with dissemination activities. During the orientation phase, Scholars participate in introductory workshops covering research ethics, literature review strategies, and technical communication. These sessions establish foundational skills necessary for engaging in research; they also foster cohort cohesion among participants.

Throughout the academic year, Scholars engage in online meetings with faculty and graduate mentors to discuss progress, troubleshoot challenges, and receive technical guidance. Meetings are structured around their project milestones, such as proposal development, data collection checkpoints, and draft report reviews. This ensures continuous progress and accountability.

The program will conclude with a dissemination phase, in which Scholars present their work through poster presentation sessions, written reports, or conference submissions.

Research Themes and Technical Scope

The Scholars engaged in research projects selected by GMU that align with current energy system challenges, emphasizing the interdisciplinary integration of power engineering, data science, and sustainability. Selections were based on faculty expertise, industry relevance, and feasibility for high school researchers. The projects chosen also had to have sufficient technical depth to support authentic inquiry. The faculty mentors ensured that research tasks were appropriately sequenced, enabling students to contribute meaningfully while progressively building technical competence.

The following research topics were developed:

- **AI-Based Dissolved Gas Analysis for Transformer Predictive Maintenance:** The student analyze dissolved gas analysis (DGA) datasets to detect internal transformer faults using ratio-based diagnostics and AI-assisted validation. The project introduces the student to IEEE's DGA interpretation standards, gas ratio calculations, and the use of generative AI as a diagnostic auditor, so they can compare traditional fault classification with AI-generated insights.
- **Detecting False Data Injection Attacks on Power Grid Data Integrity:** This project examines False Data Injection Attacks (FDIAs) on digital power grids using real data from PJM Interconnection. It develops a two-layer detection framework combining error metrics and an Isolation Forest model to identify coordinated attacks on voltage, frequency, and power flow.
- **SMR-Based Load Shifting for Data Center Integration:** The student models the integration of Small Modular Reactors (SMRs) as dedicated power buffers for hyperscale data centers. Using spreadsheet-based load simulations, the students evaluate grid relief and reliability under peak demand conditions, including redundancy analysis and AI-assisted validation of load-sharing strategies.
- **AI-Based Wind Turbine Blade Design Optimization:** The student applies optimization and modeling techniques to evaluate wind turbine blade geometries, exploring relationships between aerodynamic performance and energy production.

A summary of research themes and associated learning outcomes is provided in Table 1.

Table 1. Scholar Research Themes and Learning Focus

Research Theme	Technical Focus	Skills Developed
AI-Based Dissolved Gas Analysis for Transformer Predictive Maintenance	DGA ratio diagnostics, IEEE standards, AI validation	Data analytics, fault diagnosis, standards interpretation
Detecting False Data Injection Attacks on Power Grid Data Integrity	False data injection and data dropout simulation	Cybersecurity awareness, forecasting evaluation, error metrics
SMR-Based Load Shifting for Data Centers	SMR cluster modeling and peak demand mitigation	Energy modeling, reliability analysis, systems thinking
Wind Turbine Blade Optimization	AI-assisted aerodynamic modeling	Optimization, engineering design reasoning

While facing real-world engineering challenges by engaging in these projects, all Scholars are developing skills in data analysis, literature synthesis, simulation, and technical communication.

The Mentorship Framework

The Scholar–Mentor model consists of three tiers designed to support technical learning, professional development, and identity formation. Scholars connect with faculty mentors, graduate student near-peer mentors, and industry advisors, each contributing complementary forms of guidance and support.

Faculty mentors provide research direction, ensure academic rigor, and guide Scholars in developing research questions and methodological approaches. Through regular meetings and feedback cycles, faculty mentors help students connect their project work to broader engineering concepts and societal energy challenges.

Graduate student mentors serve as near-peer coaches, offering day-to-day technical assistance and modeling effective research practices. Their proximity in age and experience allows Scholars to ask questions more comfortably, fostering confidence and reducing barriers to engagement. Near-peer mentoring interactions include code reviews, troubleshooting sessions, literature discussions, and rehearsal of presentations. All of these provide structured opportunities for skill development and reflection.

Industry advisors offer context and insight into professional practice, emerging technologies, and workforce expectations. Through guest talks, project feedback, and informal discussions, advisors help Scholars understand how research connects to real-world engineering challenges. These interactions reinforce career awareness and provide role models that broaden students' perceptions of engineering pathways.

Together, the three mentorship tiers create a layered support system that promotes both technical growth and psychosocial development. The model emphasizes belonging, confidence, and professional identity formation, aligning with the literature that highlights mentorship as a key factor in sustaining students' engagement in STEM pathways.

Assessment and Evaluation Framework

To evaluate program impact, a mixed-methods assessment framework was developed focusing on Scholars' technical confidence, research skills, communication abilities, and sense of belonging in engineering environments. Evaluation instruments included student reflections documented in their research milestones, as well as a mid-year survey and an end-of-program survey at key stages of the program.

The mid-year and post-program surveys consist of Likert-scale items designed to measure changes in students' self-efficacy, understanding of engineering research processes, and perceptions of mentorship effectiveness. Survey statements will assess the Scholars' confidence in conducting research tasks, their ability to communicate technical ideas, and their awareness of engineering career pathways.

The survey will be deployed following the completion of the students' major research milestones. Descriptive statistics will be used to analyze responses and examine trends in the Scholars' research confidence, technical skill development, and perceptions of mentorship. The findings will also be used to inform iterative refinement of the Scholar–Mentor model.

Survey Instrument Design

To evaluate outcomes of the first cohort, online surveys will be administered at mid-year and at the conclusion of the program. A five-point Likert scale (1 = strongly disagree to 5 = strongly agree) will be used to assess changes in confidence, technical and professional skills, research capabilities, communication abilities, and perceptions of mentorship. This paper reports mid-year results.

The survey includes the following representative items:

1. I am confident in my ability to analyze technical problems related to energy systems and engineering research.
2. I feel comfortable explaining my research methods and results to both technical and non-technical audiences.
3. I see myself as belonging to an engineering or energy-related academic and professional community.
4. My participation in the program increased my interest in pursuing engineering or energy-related majors in college.
5. The research project helped me understand how engineering concepts apply to real-world energy challenges.
6. Faculty mentorship supported my understanding of research design and technical rigor.
7. Graduate mentorship increased my confidence in problem-solving and professional communication.
8. Industry mentorship clarified workplace expectations and career pathways in the energy sector.
9. I feel more prepared to participate in future research, internships, or technical projects.
10. The final presentation improved my professional communication skills.

Survey results will be combined with rubric-based capstone scores and mentor interview data to strengthen conclusions about changes in confidence, communication abilities, and sense of belonging.

Mid-Year Survey Outcomes

To provide a quantitative snapshot of mid-year outcomes, Table 2 presents item-level survey results mapped to key workforce development dimensions.

Table 2. Mid-Year Survey Results by Survey Item and Outcome Construct (n=5)

Question No.	Outcome Construct	Strongly Agree (%)	Agree (%)	Total Positive (%)
Q1	Technical Confidence	20%	80%	100%
Q2	Technical Communication Skills	40%	40%	80%
Q3	Sense of Belonging	60%	40%	100%
Q4	Career Interest	80%	20%	100%
Q5	Applied Understanding	60%	20%	80%
Q6	Faculty Mentorship	80%	20%	100%
Q7	Near-Peer Mentorship	40%	40%	80%
Q8	Industry Mentorship	20%	40%	60%
Q9	Career Readiness	60%	40%	100%
Q10	Professional Communication Skills	40%	40%	80%

Note: Each survey item is reported individually and mapped to a corresponding outcome construct. Percentages are based on a small cohort (n = 5) and reflect a mid-year assessment conducted approximately seven months into the one-year program.

As shown in Table 2, mid-year survey results (n = 5), collected approximately seven months into the one-year program, indicate strong early progress across key workforce dimensions. All participants (100%) reported positive gains in technical confidence (Q1), sense of belonging (Q3), career interest (Q4), and career readiness (Q9), with particularly high levels of strong agreement for career interest (80%). Applied understanding also improved, with 80% reporting stronger connections between engineering concepts and real-world energy challenges (Q5). Communication outcomes were positive but more varied, with 80% indicating improvements in both technical and professional communication (Q2, Q10). Mentorship emerged as a central strength: faculty mentorship received 100% positive responses (80% strongly agree), while near-peer mentorship was similarly strong (80%). Industry mentorship, though positive (60%), showed comparatively lower ratings, suggesting an opportunity for future strengthening in the second half of the program.

Discussion and Replicability

The Scholar–Mentor model demonstrates the potential of sustained, research-based engagement to strengthen pre-college engineering pathways beyond traditional short-term outreach programs. The diverse research themes explored in the pilot project highlight the model's flexibility in supporting interdisciplinary inquiry. The span of these projects, transformer predictive maintenance, false data injection attacks on power grid data integrity, wind turbine blade optimization, and SMR-enabled data center integration, allows Scholars to engage with authentic engineering challenges while developing competencies in data analysis, modeling, and technical communication. Collectively, these experiences reinforce the connection between classroom learning and real-world energy system applications.

Early observations suggest that the layered mentorship structure supports both academic and psychosocial development. Faculty guidance promotes research rigor, graduate student mentorship facilitates day-to-day skill development, and industry engagement provides context for real-world engineering practices. Several Scholars have progressed toward conference-style paper and poster presentations, indicating growing confidence in research dissemination and professional communication.

In addition to student outcomes, the implementation of the program highlights several practical considerations. These include the importance of manageable cohort sizes, clearly defined milestones, and structured communication channels between mentors and Scholars. Workshops and milestone-based progress tracking have been particularly valuable in maintaining engagement and supporting steady research advancement.

The Scholar–Mentor framework can be adapted and replicated by institutions with varying levels of resources. Key features supporting knowledge transferability include near-peer mentoring, modular research themes aligned with faculty expertise, and integration of professional development activities. Institutions seeking to establish similar programs may tailor research topics to local strengths while preserving the mentorship structure.

Ongoing assessment of this work-in-progress will further inform GMU and industry partners about the program's impact and scalability. Future iterations will include expanded cohort participation, longitudinal tracking of Scholars' academic trajectories, and deeper industry engagement to strengthen workforce alignment.

Conclusion

This paper presents a Scholar–Mentor model designed to extend pre-college energy education into a sustained research experience for high school students. By integrating faculty guidance, near-peer mentorship, and industry engagement, the program provides Scholars with authentic research opportunities that support technical skill development, professional growth, and confidence in pursuing engineering pathways.

The pilot implementation demonstrates the feasibility of combining mentorship and research within a structured year-long framework that aligns with contemporary energy challenges. Early observations indicate that the model supports Scholars' engagement in research practices, strengthens communication skills, and fosters a sense of belonging within engineering communities.

Emerging approaches in pre-college engineering education emphasize sustained engagement and identity development as key mechanisms for strengthening the workforce pipeline. This pilot program addresses these challenges and establishes a foundation for ongoing assessment and iterative refinement.

Future work will incorporate end-of-program survey findings, complementing the mid-year assessment, as well as expanded cohort participation and longitudinal tracking of Scholars' academic trajectories. The Scholar–Mentor framework offers a replicable model for institutions seeking to build sustained pre-college research pipelines aligned with evolving energy workforce needs.

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