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Board 376: REU Site: Lowering the Carbon Footprint through Research in Propulsion and Power Generation

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Abstract: The purpose of this poster will be to present results from the Research Experiences for Undergraduates Site at Penn State focused on low-carbon power and propulsion technologies. In the REU program, cohorts of 16 students per summer work at Penn State with faculty members, graduate student mentors, and research groups across the college of engineering related to propulsion and power generation, while also engaging in multiple professional development activities, including workshops, industry site visits, lab tours, and conference activities. Research topics of the students include combustion, additive manufacturing, fluid dynamics, materials, and heat transfer research. Simultaneously, engineering education research is being conducted on the students undergoing the research program, answering overarching research questions about the development of academic self-concept and how and when REUs can best influence undergraduate students to pursue graduate school. This poster will introduce the REU and the structure of the program and will also discuss findings from the first cohort of students from Summer 2023, which have been analyzed from the theoretical lenses of engineering identity and academic self-concept theory. Because of our grounding in theory, we intend for our REU model and the educational research studies performed to serve as a "sending context" in which other programs can consider designing REUs intentionally with experiences designed through educational theory to undergraduate students consider graduate school at the most beneficial time in their academic careers.

Introduction and Motivation: Gas turbines are a key strategic industrial sector that represents a major employer in the United States. The gas turbine industry also has an enormous opportunity for future growth in both aviation and power generation applications [1], where there is a strong push towards reducing the carbon footprint. To reduce CO_2 in aviation, there is an emphasis on hybrid-electric aircraft, which requires gas turbines to produce power much differently than conventional propulsion for flight. In the case of power generation, the onset of renewable energy sources is rapidly expanding; however, gas turbines are still required to provide electricity during peak hours and when renewable sources are not available. While gas turbines have been in existence for numerous years, there is still much research to be done. Improvements in thermal efficiencies continue to be a driver for research because of the significant impact that increased efficiencies have on the reduction of CO_2. Improvements by one point in efficiency for turbines in the US adds $7 billion of economic benefit and is the CO_2 equivalent to removing two million cars from the road [3]. Additionally, the use of gas turbines to replace coal power in the US could result in over a 50% reduction in CO2 output with no loss in generation level or reliability [4], [5]. In addition, it is more critical than ever to develop a diverse workforce for this field. The Department of Defense is increasing the requirements of suppliers, such as gas turbine manufacturers, to diversify their workforce. As such, our proposal aims to excite a diverse group of engineering students through the latest engineering technologies to develop new solutions that will lead to more efficient, low-carbon turbines.

Overview of the REU Program in Year 1: Participants were recruited through a nationwide application process spanning the semester prior. The faculty mentors were solicited in the same time period, and oriented to best practices in undergraduate mentorship in order to set clear expectations on the faculty involvement in mentoring. Similarly, all graduate students involved with the program took the CIMER Entering Mentoring training hosted at Penn State through a different REU. The REU provides travel and housing funds. As a brief overview of the 10-week program, the summer started with a "Gas Turbine Boot Camp" designed to introduce students to the specialized facets of the industry, how gas turbines fit into current and future energy production in the U.S., and affiliated research areas to which they would be contributing. Topics for this boot camp included principles of gas turbine operations and efficiency, combustion, aerodynamics, and manufacturing. Throughout the ten-week program, students underwent structured professional development and independent research projects under the guidance of Penn State faculty and graduate students. As examples, project topics and project names include those in Table 1. The professional development opportunities for Cohort 1 included several facets of technical communication training, preparing for graduate school, and attending a professional society organization conference related to the topic, and visiting and presenting research to key industry stakeholders. Students also tour other research laboratories at Penn State, engage in bi-weekly check-in lunches where they report out to each other how their projects were progressing, and have a chance to network informally with other faculty mentors and students involved in the REU program. Students also had the opportunity to take part in several informal social community-building activities, including a hike and potluck/picnic, which were well-received and helped build community immediately at the beginning of the summer.

Table 1: Example Topics and Project Titles for REU Projects

Topic	Project Title
Turbine Aerodynamics and Heat Transfer	Comparing Advanced Gas Turbine Temperature Measurement Techniques
Materials Science	Inconel® 718 Processed Via Laser-Directed Energy Deposition
Machine Learning/Control	Control of Combustion Instability using Reinforcement Learning Data-driven near-wall turbulence models for film cooling flows
Fluid Mechanics	Impact of Particle and Ice Ingestion on Axial Compressor Performance
Combustion	Impact of Combustor Nozzle Design on Combustion Instability
Additive Manufacturing	Topology Optimized Design of Heat Exchanger Fins for Additive Manufacturing Effects of Metal Additive Manufacturing Print Directions on Component's Thermal Conductivity
Sensing and Instrumentation	Impact of 5-Hole-Probe Head Design on Flow Measurement Quality

Educational Research:

While most engineering education research seeks to understand undergraduate preparation for industry careers, few engineering education researchers (notable exceptions being the work of Crede and Borrego [6-8] and Berdanier [9]) rigorously seek to understand the pathways by which undergraduate students choose to pursue a graduate degree. To date, none have characterized these pathways within the subdiscipline of gas turbine technology, propulsion, and power generation. While research confirms that in general—undergraduate research experiences are critical to introduce undergraduate students to solving academic research problems and academic career trajectories [6,10-11], to date no researchers have sought to determine the optimal time in an undergraduate's trajectory to introduce research, or which characteristics of the research experiences are more or less important to students from various backgrounds. Grounded in academic literacies theory[12] and academic self-concept theory [13], [14], which propose that the skills and mindsets required to thrive and have a sense of belonging in academic settings are developed through exposure to, practice of, and socialization in disciplinary expectations and norms, the research questions to be answered through the course of the evaluation plan include: *What are factors governing optimal time to introduce research to undergraduate students to encourage them to pursue graduate school? What characteristics of REU experiences are most critical in encouraging students to pursue graduate study? How do these vary given other factors (e.g, gender, race, institutional type, impact of prior research experiences?)* Educational data were collected through qualitative and quantitative methods. Three surveys were distributed to participants over the course of the summer and into the fall semester comprising several established and validated skills related to engineering identity and research self-efficacy: A pre-test occurred during the orientation "Gas Turbine Boot Camp", a post-test occurred in the last week of the REU, and a follow-up survey was sent mid-Fall semester to ascertain the longevity of the learning gains noticed from the post-survey. Three interviews were conducted throughout the summer to assess whether and how student development progressed. All interviews were conducted by a graduate student researcher to aid in rapport with the undergraduate students, were transcribed, and are analyzed in other work.

Of note, there are several quantitative metrics that had significant changes between the pre-survey and the second post survey related to both engineering identity [15] and research self-efficacy [16]. Twelve of the 30 statements in the engineering research identity scale showed significant changes; 28 of 40 items on the research self-efficacy scale showed significant changes. These findings, supported by qualitative data analysis methods informed through academic self-concept theory, are submitted to the Educational Research Methods division for ASEE 2024. As a highlight of qualitative findings to date, some main themes arising from the interview series with participants pertained to increased research interest and confidence, particularly oriented toward future graduate research programs; technical interest and confidence; presentation skill development; and technical communication competencies. These self-identified areas of growth align with our initial goals and structure of the program, which provides some formative evaluation of the programmatic outcomes.

Future Work and Recommendations: In future work, the second cohort of the REU will run in the summer of 2024. Lessons learned from administrative logistics will help to optimize the experience further for the next cohort of students, and the elements of the program that enhanced student experience, success, and learning will be retained and prioritized for the upcoming cohort as well. Additional focus will also be on social cohort development, perhaps leveraging more structure at the beginning of the program to ensure all participants feel like core members of the community from the start.

Lessons learned from this context include the following suggestions to other programs involving undergraduate research:

1. Formative educational research throughout the summer also provided an "ear" for potential problems brewing, such that the leadership team could intervene in projects before they went awry; a graduate student researcher was an ideal liaison between undergraduates and project PIs
2. We strongly suggest the requirement that all graduate students working with undergraduates undertake formal mentor training to ensure that undergrads have an optimal experience.
3. It is essential that –even more than achieving technical research objectives—the goal of the REU program is for students to have positive experiences with research.
4. A dedicated staff member whose job is to be a student liaison and plan/coordinate and facilitate REU events is a critical addition to the leadership team.

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