

Developing Diverse Leaders through Peer Teaching and Undergraduate Research: A Work in Progress

Prof. Mohamed Razi Nalim, Indiana University-Purdue University Indianapolis

Dr. Razi Nalim is Chancellor's Professor of Mechanical Engineering at IUPUI, where he directs the Combustion and Propulsion Research Laboratory and helps lead the Transportation and Autonomous Systems Institute. He has extensive experience in higher education and professional practice – in industry, academia, and government. He has administered research, sponsored work, graduate programs, international initiatives, accreditation, and financial aid, working with the faculty and administration of two major public university systems and their urban and flagship campuses. He has published well over a hundred technical papers, and received 7 patents, supported by over \$12 million in external grants from NASA, NIH, NSF, Rolls-Royce, and others. He pioneered research in novel pressure-gain combustion systems. He also pioneered project-enhanced active learning in gateway STEM education, with federal grants for pedagogic research and student training. He previously led research and development at two small companies, and he founded a new start-up to commercialize his research. He is an Associate Fellow of AIAA, and he has served overseas as Fulbright Scholar (twice) and NATO AGARD Scholar.

Ms. Danka Maric, Indiana University-Purdue University Indianapolis

Danka Maric is a Research Associate at the STEM Education Innovation and Research Institute (SEIRI). Her research interest center around how psycho-social factors interact with student learning and promoting diversity and inclusion in STEM education. She has expertise in quantitative research methodology and has developed a special interest in measurement during her time at SEIRI. She also works on faculty development through several of SEIRI's initiatives. This includes acting as the grant facilitator for the SEIRI Seed Grant program and supporting STEM faculty on STEM education research projects.

Mr. Mohammadhossein Jamshidnejad, Indiana University-Purdue University Indianapolis

Graduate Mechanical Engineering student interested in novel propulsion technology. Experience as a student liaison for research of an Engineering Innovation and Leadership program. Other related experience includes teaching assistantship for undergraduate and graduate level courses.

Dr. Sharon Miller, Purdue University

Sharon Miller, PhD, is an Associate Professor of Practice in the Weldon School of Biomedical Engineering at Purdue University. She received a BS degree in Materials Science and Engineering from Purdue University and MS and PhD degrees in Biomedical Engineering from the University of Michigan. Her educational efforts focus on biomedical engineering discipline-based educational research, including design self-efficacy, project-based learning, critical reflection in ethics, and high-impact practices.

Lauren Christopher, Indiana University-Purdue University Indianapolis

Dr. Lauren Christopher attended Massachusetts Institute of Technology, where she received her S. B. and S. M. in Electrical Engineering and Computer Science in 1982, specializing in digital signal processing and chip design. She worked at RCA's David Sa

Christine Krull, Indiana University-Purdue University Indianapolis

Eric W Adams, Indiana University-Purdue University Indianapolis

Shahrzad Ghadiri, Indiana University - Purdue University Indianapolis

Richard Vernal Sullivan, Indiana University-Purdue University Indianapolis

CLIFF CAMPBELL, Indiana University-Purdue University Indianapolis

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Abstract

The ‘Navy Engineering Innovation and Leadership’ (NEIL) program was launched at an urban engineering college at Indiana University – Purdue University Indianapolis (IUPUI) to provide leadership and research training to undergraduate students who are interested in civilian careers with the US Department of Defense (DoD). Selected engineering and computing students are being engaged in structured activities to develop and refine leadership skills. Our work-in-progress highlights how NEIL implements leadership training and how we assess leadership skill development. The program includes effective recruitment of underrepresented (UR) students, redevelopment of organizational leadership (OL) courses toward leadership training of engineering and computing students, mentoring of near-peers in academic learning and student activities by NEIL scholars, DoD-oriented student-led undergraduate research, and faculty-led educational research. The program capitalizes on established educational infrastructure. Most NEIL scholars are hired to assist in teaching challenging material through Peer-Led Team Learning (PLTL) and simultaneously enrolled in OL training courses. Notably, the percentage of women and UR minority student participants well exceeds their representation in targeted majors when compared with the general population in the college and with national metrics.

Introduction

This work-in-progress paper reports on a leadership and innovation skills development program supported by an ongoing 3-year grant from the US Office of Naval Research (ONR). The paper shares both practice and research. The program aims to have a significant impact on the success and careers of 60-70 students at a non-military urban engineering college, especially women and underrepresented students. The college, the Purdue School of Engineering & Technology in Indianapolis, has historically had a substantial number of recent engineering graduates employed by a nearby DoD base, the Naval Surface Warfare Center (NSWC) facility at Crane, Indiana.

The DoD and many employers seek skilled engineers who are highly innovative and are strong leaders in the workplace [1], and has developed leadership competency models specifically for its civilian workforce. In 2019, the 38th Marine Commandant’s Planning Guidance emphasized the combination of leadership with innovation, saying “For the Marine Corps, meaningful innovation is not just having great thoughts and concepts rather, it is about translating great thoughts and concepts into action.” [2]. However, many engineering and computing degree curricula, including at this institution, require neither any leadership training nor research experience that enables innovation (other than the practice of design). From a broader perspective, experience that increases professional formation as engineers is known to be a key factor in student success [3]. Extra-curricular reinforcement of interest and application of curricular learning also tends to support the completion of engineering degrees and thus availability of potential workforce [4]. Engineering students are more likely to find collegiate and professional successes when leadership skill development is implemented early and repeatedly during their learning [5, 6].

The authors were led to the present effort by (a) the opportunity to address DoD interest in both leadership and innovation skills, (b) the college's prior positive experience with peer mentoring and with undergraduate research, and (c) the quoted literature on factors enabling student success. Thus, a proposal was developed to provide engineering innovation and leadership (NEIL) skills and knowledge to students from diverse backgrounds through training activities and DoD networking opportunities. The resulting program for undergraduate students is built on an existing partnership between the college and the NSWC installation. This partnership had previously focused mainly on faculty research collaboration and graduate training for NSWC employees. The program also built on an existing peer-led team learning (PLTL) program that hires academically accomplished students to serve as near-peer mentors in challenging courses they had already passed. PLTL mentors facilitate small group activities that reinforce and apply key concepts to explore thought-provoking problems. Improved pass rates and retention rates due to PLTL [7-9] persist even among students who are less quantitatively prepared than their peers [10] as well as among students from underrepresented groups [11, 12]. A key PLTL benefit is that peer leaders also gain increased content knowledge and better success in higher-level classes and increased confidence to pursue STEM careers [13]. PLTL and other interventions have shown a strong effect on student persistence and success in courses with historically lower success rates indicated by D or Fail or Withdraw grades (DFW) [14].

Program Design

This program is designed to meet U.S. DoD interest in fostering a diversified, elite US STEM workforce. The grant supporting the program requires a large share of funds to be paid to participating students, and thus limiting the funding usable for research. The program design seeks to build on the college's existing infrastructure and the experience of faculty members directing the program. Generally proven approaches are used for improving student success and NEIL skills, but in untried combination. Where possible, the program relies on existing organizational structure, educational and advising frameworks, enterprise software, and learning management tools.

Recruitment & Timeline

The program is designed to onboard students at any stage of undergraduate study in ten engineering and computing majors in the college, seeking to maximize impact on multiple cohorts within the grant period. The activities planned for selected participants in the program design is shown in Fig. 1, indicating the full NEIL program activities for sophomore through senior years, and a 'pre-NEIL' program for 1st year (freshman) students. The proposed target was to enroll 70 NEIL scholars over a 3-yr period. For comparison, during the program period to date, the headcount of students enrolled in these majors has varied in range of 665-826 (not including freshmen year). The dollar amounts shown in the figure represent early budgeting and advertising, and have since increased to respond to market conditions and college practices. The program was launched in 2021 with a leadership and advisory structure, and online tools to communicate with enrolled and potential scholars, and with faculty supervising research.

Sophomore-Senior Years: NEIL scholars are selected competitively from among rising sophomores, juniors, and seniors and awarded a base scholarship in each regular semester of participation. The scholars accept to undertake a combination of activities that must include each

of the following, based on their class year: (a) one semester of PLTL or peer mentoring work for each participation year accompanied by a course in organizational leadership, (b) one session of Navy-priority area research or internship, and (c) regular Navy-oriented career development activities in each semester.

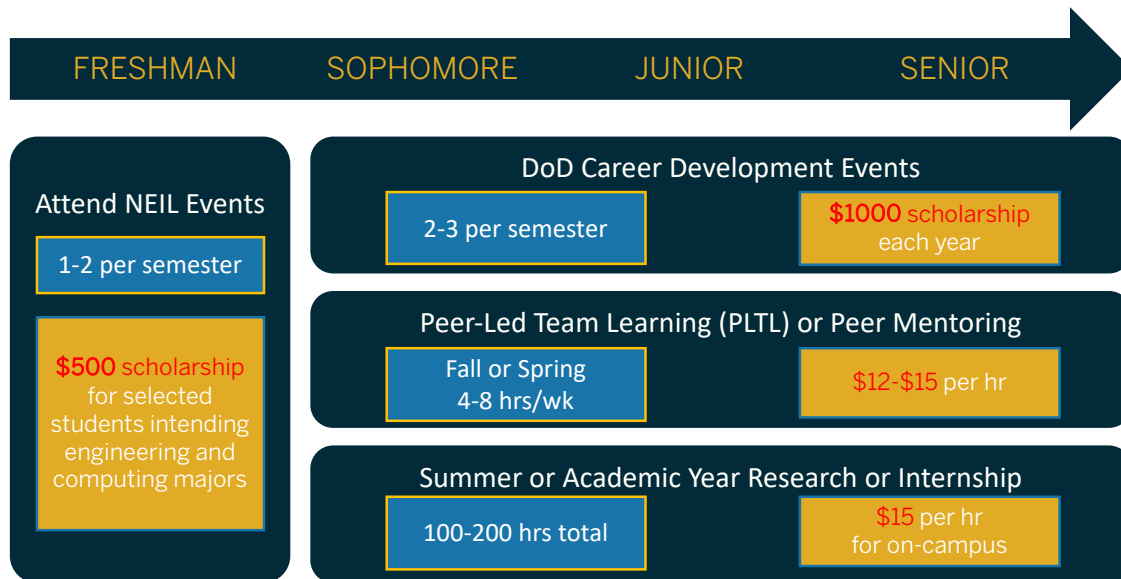


Fig. 1 NEIL Program Design for Engineering and Computing Undergraduates

Freshman Year: To encourage interest in the program in earlier years of the grant, freshman students who qualified to be directly admitted to their major and expressed interest in the NEIL program were onboarded and required to participate only in career development events in the year, which included presentations by senior students and by NSWC personnel. Consistent with college practice, a supplemental scholarship was provided. As a part of the college's recruitment of diverse students, the NEIL program was advertised to freshman students during a summer program that precedes the freshman year. Special outreach was made to UR and women students, who are encouraged to formally apply for the NEIL program upon starting their sophomore year.

Instructional Approach

The instructional approach is built on a combination of peer-mentoring, leadership training, undergraduate research with a leadership role, and networking with NSWC engineers and scientists. The program has a minimum GPA requirement of 2.5, which was carefully set to ensure that participants can qualify for research and teaching activities, while also allowing access to the program for all students who may thrive in the program activities.

Focusing on retention in engineering [15], particularly in the early years [16], the college and its campus have implemented PLTL and also provided both training and research opportunities for faculty members in other best practices, such as universal design for learning (UDL) and project-based learning [16]. PLTL leaders interact with diverse students and adapt different approaches to learning [17], relearning the subject matter more deeply. Teaching is a leadership skill of any professional and requires training to ensure effectiveness [18]. The OL courses were redesigned to provide NEIL scholars extended leadership training as they worked in PLTL or other peer mentoring roles, as well as taking leadership roles in research projects.

PLTL and Peer Mentoring

PLTL is an instructional approach that provides an environment for students to work in teams to engage in problem-solving under the guidance of a 'peer leader'. A 'peer leader' is an undergraduate student who assists instructors in teaching challenging subject material to students by leading active and collaborative learning [19]. They serve as role models and are selected because they have recently completed the course. Research indicates that not only does PLTL benefit students in the study groups, but the leaders as well. PLTL leaders demonstrate greater proficiency in subject content, and report having increased confidence in entering science-related careers after graduation [20, 21]. The NEIL program requires one semester session of PLTL or peer-mentoring in each year, which would give those entering as sophomores up to three peer-mentoring sessions. PLTL is assigned by matching courses needing this intervention with students who have already performed well in those courses. All PLTL leaders are paid an hourly wage for their work contribution to the college's teaching program. NEIL scholars who do not qualify for the college's limited number of courses offering PLTL positions are encouraged to explore other peer mentoring interests, and they are required to take OL coursework in a special section. For example, NEIL scholars who are active in a student organization (such as a National Society of Black Engineers student chapter) may choose to mentor junior students in their group in navigating their path to college success.

Leadership Training

Peer mentoring work, including PLTL, is accompanied by enrollment in the 3-course OL sequence "Leadership Seminar for Engineering & Technology Student Leaders", which is beyond the required plan-of-study for engineering and computing majors. There is no additional tuition cost for this instruction. These OL courses were developed for peer leaders to reflect on (a) leadership traits related to peer mentoring and research/innovation as prompted by deeper content learning during peer experiences, and (b) initiative and creativity when working in unpredictable circumstances.

The first two leadership seminar courses had been developed previously and implemented for a few years for PLTL mentors. The third leadership seminar course was developed specifically for the NEIL program to focus on deeper reflection of leadership traits related to research, innovation, and creativity as prompted by experiential-based learning during peer experiences. The courses build on activities as a student leader in PLTL, peer mentoring, research, and/or STEM diversity outreach. Students reflect on their experience through a series of metacognitive reflection prompts modeled after research conducted by Olsen and Burk, 2014 [22]. Cognitive reflection assignments were introduced in the second and third courses, and NEIL career module started its work using DoD resources for some of the courses.

The use of reflection as a learning tool is a well-documented cornerstone of leadership education and development. Leadership learning studies specifically advocate reflection as an effective method in promoting continuous learning and developing a realistic understanding of one's own leadership competencies [18, 23, 24]. Activity along with reflection enables students to better connect leadership principles and strategies to professional practice [22]. NEIL scholars will have a framework that allows them to map their experiences and learning in the program to the DoD's Leadership Competency models. The total student workload for the semester is

approximately 50 hours, which includes 8 hours of in-class training, leading 15 class meetings of 75-minutes each, preparation for each class, and a comprehensive end-of-semester reflection.

Undergraduate research

NEIL research projects are sought each semester from faculty, the research is reviewed to make sure it aligns with the STEM goals of the program. Typical projects have broadly focused on ‘sensors & sense-making from sensor data’, and ‘operational endurance of machines and humans’, which are selected from stated Navy priorities. Within these priority areas, the range of research assignments are quite broad, and they include: machine learning & artificial intelligence, nanotechnology sensors, 3D printed sensors, human kinematic movement, battery technology, engine technology, and fuel cells. NEIL scholars have a leadership role in their projects, rather than being one of a large team, and they typically meet with their faculty supervisor each week. They are required to produce a poster after 1-2 semesters that may be followed by a conference paper. The assessment of the undergraduate research component of the NEIL program is in the early stages; it will be the focus of future publications.

Career Development

The NEIL program arranges career development events each semester that all NEIL scholars must attend, usually bringing NSWC scientists, engineers, and recruiters to the college to speak to NEIL scholars about DoD-related careers, and various DoD scholarships. Scholars who have completed or made substantial progress in research projects are required to make poster presentations at these events. NEIL scholars are also given the opportunity to reflect on their experiences, including leadership training. Additionally, accomplished scholars visit the NSWC installation to present their work to a wider audience, tour facilities, and connect with students from other universities at a special Navy event, usually in the summer.

Program Implementation and Challenges

Recruitment & Graduation

The program has faced multiple distinct challenges during its three operational years. Extra-curricular work is generally a challenge on an urban campus where only a small fraction of undergraduate students reside on campus, with many students commuting while working part-time or full-time, and with family responsibilities and financial needs. This was expected by the team, and the financial resources of the grant were deployed in ways commensurate with expected needs and prior practices. The first unexpected challenge was that its launch in 2021 during the COVID-19 pandemic hampered recruitment, as social networks diminished and digital channels of communication with students were over-extended. However, after the success of a small initial group in 2022 and increases in stipend amounts and wage rates, the program gained better traction and has now enrolled nearly sixty students as limited by the available budget. The second unexpected challenge was a major campus administrative reorganization that is currently underway, essentially transferring the college (and the NEIL program) from one university to another. This will require all student payment mechanisms and budget authority to change. This reorganization has also reassigned some NEIL program faculty leaders to new duties, and led to significant staff turnover, which exacerbated typical bureaucratic bottlenecks, especially in disbursement of scholarships through financial aid accounts.

The current number of participants has been carefully limited to best provide the largest number of participants with the full NEIL experience within the available budget. By the end of its second year the program had enrolled a total 58 participants, including 39 currently active NEIL scholars, and 19 graduated NEIL scholars. This does not include freshman students enrolled to participate only in career development activities, as a preparation to apply to the program later. NEIL applications solicited from sophomore-senior students require an essay related to the NEIL program goals and an interview. NEIL scholars were selected by a committee that considered their applications holistically as well as meeting the minimum 2.5 GPA. Ethnicity and gender were not explicit criteria for selection. Notably, the percentage of women and underrepresented minority student participants well exceeds their representation in targeted majors when compared with college and national metrics, with 43% being UR students, and 30% women students. Whether this reflects program recruitment efforts or other factors requires additional research. The career development of the 19 NEIL scholars graduated has not yet been tracked to evaluate program impact. However, at least 4 are known to have enrolled in graduate programs, indicating an interest in pursuing a research-oriented career, while at least 3 others have begun a professional career in research and development (as distinguished from more typical engineering practice). The career choices of graduates will be studied in more detail as the program concludes in 2024.

PLTL and Peer Mentoring

In the third year of the program, 41 of the NEIL scholars have already participated in PLTL, acting as peer mentors in challenging engineering or computing classes, such as thermodynamics and electric circuits. These NEIL scholars have impacted hundreds of other students who have likely had improved academic success through the assistance of these peer leaders.

Leadership Training

The third OL course was developed for peer leaders to reflect on (a) leadership traits related to research/innovation as prompted by deeper content learning during PLTL experiences, and (b) initiative and creativity when working in unpredictable social and global circumstances. Cognitive reflection assignments were implemented in the second and third semester courses. In Fall 2022 implementation of an NEIL career module was launched in all three courses. In Spring 2024 a new section with approximately 10 NEIL scholars are taking their first OL course with the goal of serving as peer leaders in student organizations (instead of PLTL). This is being taught by a graduated NEIL scholar who is now working in industry, and is an important role model as a veteran prior to college studies and being identified as an underrepresented minority engineer.

Career Development

In conjunction with the DoD partner, career development events were held at the college each semester, with presentations by NSWC personnel and posters by NEIL scholars who have progressed in or completed their research. NSWC recruiters usually present an overview of the DoD career and scholarship, internships, and career opportunities. An in-depth Q&A session is held to encourage strong interaction between NSWC personnel and students. NEIL scholars also reflect on their development of leadership and innovation skills, in a panel format. NSWC personnel usually tour some of the college's labs where NEIL scholars and their faculty supervisors show and talk about their projects.

Initial plans for visits by NEIL scholars to the NSWC installation were thwarted by pandemic-era restrictions in place until 2023. Eventually, in the summer of 2023, a selected group of NEIL scholars presented their projects at an NSWC event attended by students and faculty from regional universities reporting on various DoD-supported projects. A similar visit is planned for 2024.

Sustainment

It was originally intended for the college to support students to continue PLTL and research until they graduate, specifically those enrolled during the grant as sophomores and juniors. This intent is now subject to funding allocations during the campus reorganization. The program is attempting to provide all enrolled students with a complete NEIL experience while planning for contingencies.

Research on Program Effectiveness

The impact of student leadership training and undergraduate research on skill development is being assessed through educational research. The program's evaluator is complementing this research by tracking diversity in student representation and examining which aspects of the program contributed to their skill development. Goals include the investigation of a) student leadership skill development throughout the NEIL program and b) the impact of research experiences on development of students' scientific innovation and discovery. For the present work in progress, we focus on the investigation of student leadership skill development.

NEIL Scholar Leadership Development

Leadership development is important to ensure engineers are prepared to adapt swiftly to change and to lead multi-disciplinary teams in highly technical areas. These leadership skills can also allow disruptive technological advances in the US, supporting the DoD's goal of "first to field" [25]. The program aims to develop undergraduate students who reach self-actualization, which means they understand the need for continual personal refinement in their leadership skills as they develop as professionals [6].

Methods

NEIL Scholar competencies of leadership and navigating change are measured using a mixed-methods approach using both a leadership survey and a focus group evaluation. Specifically, the leadership survey instrument [26] measures leadership development in four domains: individual leadership abilities, interdependence of engineering, society, and economy, teaming and peer work, and adaptability. The leadership survey is administered when the NEIL scholars join the program prior to any OL coursework and then again after they complete a peer leader experience. Students were asked to indicate how frequently they engage with behaviors pertaining to each domain on a 4-point Likert scale from *1(rarely)* to *4(almost always)*. Three items from the adaptability domain were reverse coded before final calculations. The focus group evaluation typically happens after at least one year of program participation. Participants are asked a series of questions that assess their program experiences and what aspects of the program impacted their development the most.

Preliminary Findings & Significance

The current survey sample size does not allow for inferential analyses, thus only descriptive data was examined from the survey. At both timepoints, student responses were above midpoint on the 4-point scale, indicating relatively frequent leadership behaviors at baseline. Small increases were seen in domains related to interdependence of engineering, society, and economy ($M_{pre} = 3.30$; $M_{post} = 3.33$), teaming and peer work ($M_{pre} = 3.62$; $M_{post} = 3.69$), and adaptability ($M_{pre} = 3.23$; $M_{post} = 3.37$). Scores in individual leadership abilities were unchanged at $M = 3.08$ at pre- and post-test. Though survey results from this small initial sample were neutral or modestly positive, triangulating these results with qualitative focus group outcomes suggests potential for overall program impact as the program grows and more data is collected.

In the focus group, students reported increased confidence/self-efficacy in leadership skills through their NEIL experiences. Namely, they expressed elevated confidence in task delegation, navigating unfamiliar situations unsupervised, taking initiative, facilitating teamwork in others, and sharing novel ideas. Students largely attributed this growth to being PLTL leaders, although other NEIL activities were noted. A few students shared feeling inspired by their NEIL experience to take on leadership or mentor roles external to the program. As student participation continues and our sample increases, we plan to triangulate survey and focus group results and explore gender/racial differences in development to make firmer conclusions about program impact on specific groups.

The overall proportion of female students (30%) and UR students (43%) among NEIL scholars is higher than baseline, which was operationalized as proportions among all engineering (17.5% female; 15% UR) and computing majors (19% female; 15% UR) at the program's start. This important finding is consistent with reported participation of women and UR students as PLTL leaders. The underlying factors that attract a higher proportion of women and UR students to PLTL and NEIL programs requires further investigation.

Conclusion

The NEIL program has enrolled a substantial number of engineering and computing students to build on their classroom learning to become strong leaders with research skills, taking advantage of paid research and peer-leading opportunities as well as special courses in organizational leadership. Women and underrepresented minorities applied for the program and were enrolled in numbers significantly higher than the general student population, under uniform selection criteria. Through DoD career development experiences, strengthened OL coursework, and hands-on research opportunities, NEIL scholars advance their innovation and leadership skills. The team continues to assess the impact of the program on the preparation of undergraduate students for engineering and computing professions, especially for careers in the DoD.

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