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Insights from the NanoEnvironmental Engineering for Teachers (NEET) Graduate Course on Teachers' Self-Efficacy in Teaching Engineering (Evaluation)

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Introduction

Teacher professional development programs ensure educators are equipped with the necessary tools to meet the diverse needs of their students. As demands shift toward a more hands-on approach to learning, courses tailored to enhancing pedagogical skills in such areas become valuable. As such, teacher professional development programs and courses that focus on teaching engineering with real-world problems emerge as catalysts for transformative teaching practices. In the context of this study, we delve into a 3-hour graduate course entitled NanoEnvironmental Engineering for Teachers (NEET) offered free of cost at Rice University, Arizona State University, Yale University, and the University of Texas at El Paso under the Nanosystems Engineering Research Center for Nanotechnology-Enabled Water Treatment (NEWT). The NEET class is designed for AP Environmental Science, Environmental Systems, Biology or Life Sciences, and K-12 STEM teachers to learn about water sustainability and engineering design through project-based learning (PBL).

Purpose of the study

This paper investigates the impact of the NEET class, a graduate course, on teachers' self-efficacy in teaching engineering. NEET, centered around project-based learning (PBL) and engineering design activities, aims to increase teachers' knowledge of engineering concepts and the usage of PBL through water sustainability topics. The primary focus of this study is to assess the effectiveness of the course in enhancing teachers' self-efficacy in teaching engineering concepts. By analyzing participants' survey data from four different university campuses over a six-year period, the paper seeks to provide comprehensive insights into teachers' self-efficacy after participating in the NEET course curriculum. Participants received the course curriculum through multiple instructors who utilized diverse instructional modes during their enrollment.

Literature Review

Project-Based Learning

Project-based learning (PBL) has gained widespread recognition as an effective pedagogical approach in engineering education [1], [2], [3]. The fundamental principle of PBL in engineering involves engaging students in real-world, hands-on projects to deepen their understanding of engineering concepts. Research indicates that PBL not only enhances students' technical skills but also fosters critical thinking, problem-solving abilities, and teamwork [2], [4] - [8]. Educators who incorporate PBL in their teaching practices contribute to the development of well-rounded and competent students who can then become engineers and other competent professionals [5], [9].

Self-Efficacy in Teaching Engineering

Self-efficacy, as conceptualized by Bandura, refers to an individual's belief in their ability to successfully execute a specific task [10]. In the realm of education, teaching self-efficacy refers to teachers' beliefs about their abilities to carry out their professional duties [11]. These beliefs impact teachers' motivation and performance and also affect their students' outcomes [11]. In the context of teaching engineering, self-efficacy plays a pivotal role in educators' confidence and competence in delivering engineering concepts in their classrooms.

Several studies have explored the relationship between teaching self-efficacy and instructional practices in engineering education [12] - [14]. Educators with higher levels of self-efficacy tend to exhibit more innovative and student-centered teaching approaches [11], [12]. Furthermore, evidence suggests that increased use of PBL is positively associated with self-efficacy and correlates with greater persistence, effort, and enthusiasm in teaching [15]. Understanding and enhancing teaching self-efficacy is essential for creating a positive and impactful learning environment in engineering education. PBL positively influences teaching self-efficacy by providing educators with concrete examples of applying engineering principles in real-world contexts [15]. The interactive nature of PBL contributes to the enhancement of educators' ability to effectively teach engineering concepts. The NEET class is designed such that it considers the research behind embedding PBLs with engineering design activities.

Context of NanoEnvironmental Engineering for Teachers (NEET)

NEET aims to increase the content knowledge of educators and empower them to implement rigorous project-based engineering activities on the topic of water sustainability in their classrooms. Participants discuss the need for diversity, equity, and inclusion in the K-12 space to promote student belonging in schools, understand how social biases can grow into stereotypes, and gain strategies to be aware of our privileges while teaching. As such, the course is designed with various goals in mind. For instance, it allows participants to think reflectively and critically about their current teacher practices. It improves their understanding of advanced placement and state standards. It facilitates the transformation of their teaching practices by exploring best practices in educational pedagogy. Moreover, by participating in the course, educators disseminate the Nanosystems Engineering Research Center for Nanotechnology-Enabled Water Treatment (NEWT) conducted at Rice University, Arizona State University, Yale University, and the University of Texas at El Paso. Finally, participants are able to incorporate project-based learning and engineering practices in their classrooms.

Throughout the program, participants are introduced to and engaged in the engineering design model, brainstorming techniques, and how to develop a problem statement. This knowledge enables participants to discuss designs and develop new products or ideas to address human-centered water issues. Working collaboratively in groups, participants first select an environmental science-related case study and then create or enhance a solution for their chosen issue, considering parameters such as accessibility, cost-effectiveness, diversity, equity, and inclusion. Case study topics include:

- *Atmospheric Water Harvesting*: Water is found in our atmosphere. However, extracting water content from the air, particularly in the driest locations, requires innovative engineering. Many techniques rely on passive or active cooling methods to generate a "dew" collected from parcels of air that have high humidity. Participants focus on improving techniques or developing an innovative design to draw water from the atmosphere.
- *Nanoscale & Biomimicking Antimicrobials*: There is a new generation of antimicrobial surfaces and coatings. Through this case study, the participants seek to address the problem of membrane fouling in water treatment systems and prevent the buildup of

resistant biofilms in public spaces, medical and food prep facilities, and medical implants.

- *Point of Use UV Sterilization*: Solar Disinfection (SODIS) is cost-effective and accessible. Participants focus on enhancing the reliability of harnessing the power of SODIS to remove specific contaminants from water, such as bacteria.
- *Public Hygiene and Sanitation*: Many areas lack water treatment systems or municipal sewage. Through this case study, the participants focus on finding solutions to bring sewage and water treatment systems to such areas.
- *Lead Crisis and Arsenic in Well-Water*: The presence of lead and arsenic in our water is a significant issue. The participants work on developing methods to detect and remove these contaminants from water, ensuring accessibility to communities in areas consistently impacted by these issues.

Methodology

Participants

The study involved elementary and secondary educators enrolled in the 3-credit graduate course entitled NanoEnvironmental Engineering for Teachers (NEET). Participants attended the course either in person, virtually, or in a hybrid format at one of the four university campuses that offered the course. In 2018, 2019, 2022, and 2023, the course was fully in-person; in 2020, it was virtual, and in 2021, it was in a hybrid format. Of the participants, 34 self-described themselves to be male, and 74 were female. Each campus had a different instructor, each possessing a unique teaching style and perspective. All NEET participants were invited to participate in the study; participation was voluntary, and informed consent was obtained from all participants

Instrument

To assess the impact of the course on teachers' engineering self-efficacy, data was collected using the Teaching Engineering Self-Efficacy Scale (TESS) [15], [16]. TESS is a validated instrument consisting of 23 items with five subscales: Engineering Pedagogical Content Knowledge Self-efficacy (KS), Engineering Engagement Self-efficacy (ES), Engineering Disciplinary Self-efficacy (DS), and Engineering Outcome Expectancy (OE) [16]. The TESS demonstrates high internal consistency reliability, with Cronbach's α ranging from 0.89 to 0.96 across the four factors [16]. These high-reliability coefficients indicate that the TESS consistently measures teachers' engineering self-efficacy with precision and accuracy. By utilizing the TESS in this study, we aim to comprehensively assess the impact of the nanoenvironmental engineering graduate course on teachers' self-efficacy across multiple dimensions of engineering education.

On the first day of the course, participants completed the TESS survey, providing baseline data on their self-efficacy in teaching engineering concepts. Throughout the semester-long course, instructors implemented project-based learning and engineering design activities related to water sustainability. Participants were actively involved in collaborative efforts, designing and building prototypes based on research from the nanoengineering center. Upon completion of the course, participants completed the TESS questionnaire again to assess any changes in their engineering self-efficacy levels.

Data Analysis

Pre-test and post-test scores on the TESS questionnaire were compared to determine whether there were significant changes in participants' engineering self-efficacy after completing the course. Statistical analysis techniques, such as paired *t*-tests and ANOVA, were employed to analyze the data and identify any significant differences. Moreover, the relative percent gained was also calculated by comparing the difference in mean scores between consecutive years and expressing it as a percentage of the initial mean score for each construct. This approach allowed for a standardized comparison of improvement rates across different constructs and over time.

This study adhered to ethical guidelines for research involving human participants. Confidentiality and anonymity were maintained throughout the data collection and analysis process, and participants were assured that their responses would only be used for research purposes.

Findings

Table 1 presents the overall changes in teaching engineering self-efficacy from 2018 to 2023 for all teachers across all campuses and modes of course delivery. The results indicate significant improvements in overall engineering self-efficacy as well as each subscale (engineering pedagogical content knowledge, engineering engagement, engineering disciplinary self-efficacy, and outcome expectancy) over the five-year period. The *p*-values associated with these changes are statistically significant, suggesting a meaningful enhancement in teachers' confidence and abilities to teach engineering concepts.

Table 1

Overall Changes in Teaching Engineering Self-Efficacy Utilizing Paired t-test from 2018-2023 (N=125)

Constructs	**Pre**		**Post**		*t*	*df*	*p**
	X	SD	X	SD			
Overall	4.54	0.85	5.55	0.45	-12.92	112	2.2E-16
Engineering Pedagogical Content Knowledge Self-efficacy (KS)	4.18	1.10	5.52	0.61	-13.491	124	2.2E-16
Engineering Engagement Self-efficacy (ES)	4.82	1.14	5.79	0.39	-13.49	124	2.2E-16
Engineering Disciplinary Self-efficacy (DS)	4.90	1.03	5.64	0.54	-8.58	119	4.2E-14
Engineering Outcome Expectancy (OE)	4.44	0.95	5.26	0.76	-8.97	121	4.4E-15

Additionally, a three-way ANOVA was conducted to investigate whether there were differences in engineering self-efficacy based on the location, year of the course, and gender of the participants. The analysis revealed no significant change in self-efficacy based on location ($F = 0.119$, $p > 0.05$), meaning participants had an increase in self-efficacy scores regardless of the location. However, the analysis revealed a significant difference in change in teaching self-efficacy based on year ($F = 0.041$, $p < 0.05$) and gender of the participants ($F = 0.0045$, $p < 0.05$). To determine where the significant difference was, we conducted a post-hoc Tukey HSD, which indicated no significant difference based on location. However, it revealed a notable difference in self-efficacy scores between female and male participants. Specifically, female participants scored, on average, 0.511 points higher than male participants, representing a statistically significant disparity. Regarding the year of participation, each year exhibited a significant difference in self-efficacy scores. However, subsequent post-hoc Tukey HSD analysis demonstrated that no specific year yielded better results than others.

Moreover, in consideration of the contextual data, we analyzed the relative percentage gain for each year and each construct, as detailed in Table 2. This analysis provides insight into the magnitude of improvement in teaching engineering self-efficacy across each year. The results presented in Table 2 have varying degrees of relative percentage gain for each construct and year, highlighting fluctuations in the rate of improvement in teaching engineering self-efficacy. By examining these relative gains, we gain a deeper understanding of the trajectory of change in teachers' confidence and abilities in teaching engineering concepts over the study period.

Table 2.
Teaching Engineering Self-Efficacy Scale Relative Gains by Construct and Year Regardless of Instructor and Location

	Relative % Gain					
	2018	2019	2020	2021	2022	2023
Engineering Pedagogical Content Knowledge Self-Efficacy (KS)	26	63	43	30	21	37
Engineering Engagement Self-Efficacy (ES)	17	33	30	15	19	35
Engineering Disciplinary Self-Efficacy (DS)	20	23	18	6	13	37
Engineering Outcome Expectancy (OE)	15	31	23	18	16	31
Overall	**21**	**40**	**30**	**18**	**18**	**34**

Discussion

The significant improvements observed in teachers' engineering self-efficacy over the six years across different instructors and modes of learning highlight the effectiveness of the program's curriculum in enhancing K-12 teachers' engineering pedagogy. These findings suggest that the structured approach to teaching engineering concepts utilizing project-based learning and real-world water sustainability issues, as implemented in the NEET class, has a profound impact on educators' confidence and abilities in teaching engineering concepts. Moreover, our findings suggest that female teachers have a higher self-efficacy score after participating in the NEET class. However, this finding should be considered cautiously because we had more female participants than males.

One possible explanation for improvement in self-efficacy is the emphasis on project-based learning (PBL) within the program curriculum. Research has consistently shown that PBL can lead to improved student outcomes by promoting active engagement, critical thinking, and problem-solving skills [2], [4]-[8], [14], [17]. By engaging educators in hands-on activities, discussions, and collaborative projects, the program fosters an experiential learning environment that empowers teachers to apply engineering principles in real-world contexts. When teachers learn how to implement hands-on project-based learning experiences for their classrooms, it positively impacts their students' engagement and, consequently, their own self-efficacy.

These findings align with previous research highlighting the positive impact of professional development programs on teachers' self-efficacy and instructional practices [14]. By equipping educators with the knowledge, skills, and confidence needed to teach engineering concepts effectively, the program not only enhances individual teachers' professional growth but also has the potential to influence student learning outcomes positively.

Although the results of the study are clear, some limitations should be noted. One such is the reliance on self-reported measures. The study design also did not account for potential confounding variables, such as prior experience in engineering education, individual teaching styles, or years of experience as a teacher.

Future studies could explore the extent of implementation of the activities introduced in the NEET course within K-12 classrooms. This could involve qualitative research methods, such as classroom observations or interviews with teachers, to gain insights into the integration of engineering concepts and pedagogical approaches into daily instruction. Additionally, longitudinal studies could assess the long-term impact of professional development programs on teachers' instructional practices and student learning outcomes.

Conclusion

The results of this study underscore the importance of structured professional development programs in enhancing teachers' self-efficacy in teaching engineering. By exploring the effectiveness of the NEET graduate course, this paper provides valuable insights for educational institutions seeking to empower their teachers with the necessary skills and confidence to integrate engineering education into K-12 classrooms effectively. We recommend that other educational institutions consider implementing similar programs prioritizing PBL and real-world case studies to enhance teachers' pedagogical skills and content knowledge in engineering education. By engaging teachers in experiential learning activities and problem-solving tasks, these programs can empower educators to effectively integrate engineering concepts into K-12 classrooms and positively influence student outcomes. Furthermore, we encourage teachers to actively seek professional development opportunities like the NEET graduate course to enhance their teaching abilities and stay abreast of current trends in STEM education. Participating in such programs can not only expand teachers' knowledge and skills but also foster a sense of confidence and efficacy in teaching engineering concepts.

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