BOARD # 275: NSF IUSE: Advancing Student-Centered Teaching for Disciplinary Knowledge Building in Engineering

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Shabnam Wahed, currently pursuing a Ph.D. in Engineering Education, is dedicated to revolutionizing the learning experience for engineering students beyond mere memorization. Passionate about elevating students' conceptual understanding, Shabnam directs her efforts toward refining the teaching and assessment methods for mastering fundamental and challenging engineering concepts. With a background in Electrical and Computer Engineering and a rich academic experience spanning six years, her overarching goal is to craft engineering learning environments and experiences in a way that intricately engages students on a cognitive level. In addition to her role as an engineer and researcher, Shabnam is an advocate and ally for fostering greater inclusion in STEM fields and beyond.

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Abstract

This NSF-funded project (DUE2215989) investigated effective instructional practices in middle and upper-level engineering courses to enhance student learning. Using a participatory action research (PAR) approach, we examined how exemplary faculty translate their teaching beliefs into practice within disciplinary contexts. Participants identified by department heads as outstanding instructors engaged in surveys, interviews, classroom observations, course consultations, and focus groups. Results highlighted commonly used student-centered strategies, including connecting content to real-life applications, encouraging peer interaction, using visual aids, and providing timely feedback. Innovative practices such as debates, "quiet" problem-solving, and intentional errors were also observed. Course consultations led to actionable recommendations, including diversifying teaching strategies, aligning materials with accreditation standards, and supporting team dynamics. A summer workshop further enabled faculty to reflect on and adopt these strategies. Future efforts will focus on scaling impact through cross-departmental workshops at an R1 land-grant institution's College of Engineering.

Background and Motivation

Middle and upper-level engineering courses are vital for students to master specialized knowledge and skills necessary for their chosen fields. Despite their importance, research on teaching methods in these courses has been limited [1]. These courses are recognized as particularly challenging and require innovative teaching strategies to enhance student learning [2]. This project, funded by NSF (DUE2215989) addresses these gaps by exploring effective instructional practices and fostering a sustainable community of practice to disseminate these methods across engineering departments.

The project's motivation stems from the need to align instructional practices with student-centered teaching which promotes active learning and knowledge building. Our key research questions were 1) what student-centered teaching methods are used by exemplary engineering faculty to promote knowledge building, and how do these align with their teaching beliefs, and 2) how can a sustainable community of practice spread these methods across departments to improve student learning? By addressing these questions, the project aims to meet the growing demand for producing workforce-ready engineers equipped with the skills and knowledge to thrive in professional environments.

Methodology

Research design

The study utilized participatory action research (PAR) methodology. It emphasizes the critical role of participants' insights and expertise. This approach was particularly well-suited for the study as it fosters the improvement of social practices by engaging participants in designing data collection processes, analyzing findings, and testing identified strategies in real-world settings [3].

Participants

Participants were drawn from ten departments within the College of Engineering, including Biomedical Engineering and Mechanics, Civil and Environmental Engineering, Industrial and Systems Engineering, Mining and Minerals Engineering, Computer Science, Electrical and Computer Engineering, Mechanical Engineering, Aeronautical and Ocean Engineering, Chemical Engineering, and Construction Engineering and Management. A total of 18 participants, with a maximum of two per department, were selected based on departmental recommendations identifying them as exemplary instructors.

Data collection

In alignment with the principles of PAR, data were gathered in multiple phases using multiple techniques, including classroom observations, survey, course documentation, focus group discussions, course consultation projects, and semi-structured interviews. Classroom data were collected using the Teaching Dimensions Observation Protocol (TDOP) developed by Hora and Ferrare [4]. It provided a structured framework for analyzing instructional practices. The Postsecondary Instructional Practices Survey (PIPS) [5], consisting of 24 items focused on diverse teaching methods, was also employed to ensure the collection of reliable and comprehensive data across varied classroom settings. Supplementary materials such as syllabi, lesson plans, and class notes further enriched the dataset. In the summer of 2023 and 2024, participants convened for a workshop where focus groups were conducted to collect data. During the workshop, we fostered participant engagement, encouraged idea-sharing for classroom student engagement, showcased various student-centered instructional practices in different departments, and established a foundation for inter-departmental collaboration. In Spring 2024, a course “deep dive” was conducted to better understand participants’ teaching practices, constraints and areas where our engineering education expertise can be a resource to them in terms of course planning or assessments. As part of this effort, graduate students enrolled in the a second-year PhD course, offered by the Department of Engineering Education at an R1 land-grant institution during Spring 2024, participated in a “Course Redesign Proposal” assignment. This assignment involved researching effective instructional strategies and conducting a detailed review of an existing course taught by faculty participants during the Spring 2024 semester. Students consulted faculty participants to gain insights and feedback, analyzed the gathered data to identify key themes, and developed targeted recommendations. Finally, they created a detailed redesign proposal leading to an enhanced design of the existing course. These redesigned efforts provided actionable strategies for improving student engagement, learning outcomes, and alignment with best practices in engineering education. Semi-structured interviews were another critical component of the study. These interviews focused on evaluating the overall project and participants’ experiences with it as well as examining the unique instructional practices identified during classroom observations. The questions provided deeper insights into each faculty participant’s teaching approaches and the underlying rationale for their methods. This contributed to a richer understanding of effective instructional strategies in engineering education.

Data analysis

The data analysis involved a multi-method approach, integrating quantitative data from classroom observations and surveys with qualitative insights from post-observation memos and course consultation projects to identify common instructional practices and tailored recommendations. To identify instructional practices reflective of common teaching approaches, the mean for each survey item was calculated. A threshold mean of 3.47, derived from the overall average, was established as the benchmark for identifying practices considered descriptive. From classroom observations, the frequency of each code was calculated by summing its occurrences across all faculty members. Then, the percentage of each code within its category was computed, providing insight into the most commonly used pedagogical strategies, instructional technologies, and teaching methods. Excel was used to develop a codebook focused on recommendations for course improvements drawn from consultation projects. These recommendations were categorized into themes such as teaching and learning activities, assignments and assessments, syllabus, course content and schedule, alignment of learning outcomes, reducing plagiarism, supporting functional team dynamics and time management, and other recommendations. Future analyses will include course documentation, focus group discussions, and semi-structured interviews to provide a comprehensive understanding of teaching strategies and their impact.

Preliminary Results and Discussion

The findings from this study highlight a broad spectrum of effective instructional practices and provide actionable insights for enhancing teaching and learning in middle and upper-level engineering courses. The Postsecondary Instructional Practices Survey (PIPS) revealed several core strategies consistently employed by instructors. These included guiding students through major topics, connecting course content to their lives and future careers, and crafting detailed syllabi that provided clear expectations. Immediate feedback emerged as a key practice which enabled students to quickly correct misconceptions. Additionally, instructors frequently acknowledged and built upon students' prior knowledge and created a foundation for deeper learning. Peer and instructor interaction were also emphasized that fostered collaborative and interactive learning environments.

Classroom observations offered further evidence of thoughtful course design and execution. Common practices among instructors included well-structured class introductions, consistent organization, and the strategic use of visual aids and technology. These elements contributed to clarity and student engagement. A recurring theme was the effort to connect theoretical content to real-world applications which not only motivated students but also reinforced the relevance of their learning. Beyond these shared practices, unique approaches were observed in some classrooms. For instance, the use of debate activities encouraged critical thinking and active participation. In some cases, instructors involved students in decision-making, such as scheduling presentations which promoted autonomy and accountability. Other distinctive strategies included integrating course content with other major-related courses, implementing "quiet" problem-solving sessions, and intentionally making mistakes or coding errors to teach problem-solving resilience.

The course consultation projects identified a range of tailored recommendations to enhance teaching practices and course design. Faculty were encouraged to adopt diverse teaching strategies such as field trips, scaffolded fill-in-the-blank activities, think-aloud problem-solving, peer teaching, and collaborative problem-solving sessions. These methods aimed to increase interactivity, reduce cognitive load, and boost student engagement. Recommendations for assignments and assessments included balancing grading between exams and homework, streamlining assignment types, incorporating conceptual questions into exams, and using feedback-driven homework systems to reduce student stress and improve learning outcome assessments. The faculty received suggestions to refine syllabi to include personalized sections, clarify learning objectives, provide detailed guidelines, and explicitly address diversity and plagiarism. Course content and schedules were another focus, with recommendations to adjust to integrate goal-setting and mentorship, incorporate industry perspectives, and emphasize collaborative learning. Finally, recommendations for aligning course materials and assessments with ABET accreditation standards and Fink's Taxonomy [6] ensured both the rigor and relevance of the courses. Faculty found these changes valuable in improving student engagement and meeting institutional and accreditation requirements.

The summer workshops served as a critical platform for sharing and reflecting on these findings. Participants discussed their experiences with the course consultation projects and expressed enthusiasm for implementing recommendations. For example, a Computer Science faculty member expressed plans to incorporate "fill-in-the-blank" assignments in upcoming courses that illustrated the workshops' tangible impact on instructional practices. The workshop sessions also highlighted instructors' shared teaching priorities, including building personal relationships with students, organizing course content effectively, motivating students, and connecting course material to real-world applications. The alignment between instructors' teaching beliefs and practices was evident in their consistent dedication to these priorities. For example, one instructor who valued high expectations and approachability incorporated frequent questioning, structured presentations, engaging facts, personal interactions, and external resources into her teaching. Besides, the workshops also highlighted key challenges participants faced in implementing good teaching such as managing administrative workloads, enhancing support for teaching assistants, improving recognition of teaching excellence in promotion and tenure processes, etc. The participants appreciated the opportunity to connect with colleagues from different departments, exchange insights, and explore versatile approaches for enhancing classroom engagement. Another key focus of the workshops was equipping instructors with strategies to effectively manage the challenges of transitioning from small to large class sizes. These discussions provided practical tools to maintain student engagement and ensure positive learning outcomes across varied educational contexts.

Conclusion

This NSF IUSE project has significantly advanced our understanding of effective instructional practices in middle and upper-level engineering courses. By documenting faculty beliefs and practices, the project provides a framework for aligning student-centered teaching with disciplinary knowledge-building. The findings highlight strategies for improving student engagement, fostering collaboration, and enhancing learning outcomes.

The project's impact extends beyond the immediate participants, with potential to influence teaching practices across engineering disciplines. Future efforts will focus on disseminating the findings through workshops, creating a repository of exemplary practices, and fostering institutional transformation to improve student learning experiences. To extend the impact of this grant beyond the funded timeline, we also plan to organize a series of workshops to share exemplary teaching practices used by our participants across the College of Engineering of this R1 land-grant institution. By addressing the dual demands of industry and academia for highly skilled engineers, this project contributes to sustaining the U.S.'s position as a global leader in innovation. Continued collaboration and knowledge-sharing among educators will ensure the long-term success and scalability of these transformative teaching practices.

Acknowledgement

This work is supported by the National Science Foundation under Grant No. 2215989. The opinions, findings, conclusions, and recommendations presented herein are those of the author(s) and do not necessarily represent the views of the National Science Foundation.

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