Lessons Learned: Exploring Effective Student-centered Instructional Practices in Middle and Upper-level Engineering

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Abstract

This lessons-learned paper delves into the realm of effective student-centered teaching practices within middle and upper-level engineering classes, with the primary goal of enhancing students' acquisition of disciplinary knowledge. The research is anchored by a central inquiry: what student-centered teaching approaches do exemplary engineering faculty employ to promote knowledge-building in their courses, and how do these approaches align with their beliefs about teaching? To address the research question, the study employed the participatory action research (PAR) methodology, which prioritizes the invaluable input and expertise of participants. A diverse group of participants renowned for their teaching excellence was selected from five departments. A total of ten participants were chosen, and data was collected using a variety of methods, including classroom observations, analysis of course materials, surveys, and focus group discussions.

Our observations across various courses have revealed common practices employed by instructors to foster effective learning environments. These practices encompass dynamic and diverse class introductions that utilize strategies like revisiting prior content, storytelling, and addressing student well-being to establish a strong foundation for the session. Throughout the class, instructors consistently maintained student engagement through techniques such as group activities, structured interactions, active problem-solving, and thought-provoking question-and-answer sessions. Visual aids and technology were integral in enhancing content delivery. Instructors also ensured the content was relatable by linking lessons to research findings, relatable examples, and familiar landmarks, grounding theoretical concepts in real-life relevance. Personalized support was a priority, with instructors offering targeted feedback to smaller groups and individual students, including one-on-one sessions for additional assistance. Some instructors introduced unique practices such as debate activities, involving students in decision-making processes, cross-course connections, and specialized problem-solving techniques. These diverse approaches collectively underscore the multifaceted strategies instructors employ to create engaging and effective learning experiences.

Another significant initiative undertaken in our study involved organizing a summer workshop that provided a platform for instructors to convene and engage in collaborative discussions regarding their teaching practices and their top five teaching priorities. During this workshop, we also deliberated on the preliminary findings from our data collection. The instructors collectively emphasized the importance of getting students engaged in the learning process. We identified several overarching categories of priorities that held relevance for all instructors, including the establishment of personal relationships with students, the effective organization of course content and class activities, strategies for motivating students, and the integration of course content with real-world applications. During the lightning talk, we will share a comprehensive overview of the study's research findings as well as the importance of student-centered teaching practices in engineering education.

Background and Motivation

The contemporary education of engineers remains a challenging domain, and a key area needing more focus on identifying effective teaching practices, particularly in middle and upper-level engineering classes. This lessons-learned paper, which emerged from an NSF-funded project (masked for review), explores student-centered instructional practices, with the primary goal of enhancing students' acquisition of disciplinary knowledge. The study aims to understand how instructors' philosophical beliefs influence their teaching practices. By grounding its understanding within specific engineering disciplines, this research provides not just generic insights but a subtle exploration of effective teaching practices within disciplinary boundaries. The motivation behind this paper stems from a crucial need to redefine and refine the pedagogical approaches within engineering disciplines, responding to the escalating demand for a workforce with both technical expertise and professional skills. This study explores the realms of student-centered instruction, aiming to uncover strategies employed by exemplary engineering instructors providing practical insights. Ultimately, it seeks to contribute to the ongoing dialogue on effective teaching practices, encouraging a shift towards an educational future where students actively engage in their knowledge-building journey.

Significant effort has been devoted to refining the concept of effective teaching and achieving pedagogical mastery [1], [2]. Over the last two decades, there has been extensive research on student-centered teaching, particularly in engineering. Active learning pedagogies, such as just-in-time teaching, case-based teaching, and collaborative learning, have gained prominence for engaging students in the learning process [3], [4]. However, Streveler and Menekse [5] argue for a more subtle view, urging researchers to consider disciplinary context, specific situations, learning objectives, and student types. Studies [5], [6], [7] emphasize the importance of a clear position on the nature of knowledge in STEM teaching, advocating for an understanding of disciplinary, curricular, and pedagogical content knowledge (PCK). They highlight the influence of instructors' beliefs on teaching practices, indicating the need for professional development to align beliefs with effective pedagogies [8], [9]. Recognizing a gap in generic formulations of student-centered teaching, the study aims to contribute by uncovering evidence of instructors synthesizing student-centered teaching with disciplinary knowledge, with potential contributions to the typology of effective teaching strategies. The study is anchored by a research question: what student-centered teaching approaches do exemplary engineering instructors employ to promote knowledge-building in their courses, and how do these approaches align with their beliefs about teaching?

Data Collection

To address the research question, the study employed the participatory action research (PAR) methodology, which prioritizes the invaluable input and expertise of participants. The PAR approach is best suited for this study because it actively improves social practices [10], involving participants in designing data collection, reflecting on data, and testing identified practices in their own contexts. A diverse group of participants was selected from five departments in the College of Engineering (COE) - Biomedical Engineering and Mechanics (BEAM), Civil and Environmental Engineering (CEE), Industrial and Systems Engineering (ISE), Mining and

Minerals Engineering (MME), and Computer Science (CS). Ten participants, two from each department, were chosen based on the recommendation of their department heads as exemplary instructors. Adhering to the tenets of PAR, data were collected using a variety of methods, including classroom observations, course documentation, surveys, and focus group discussions. Direct classroom data were collected using the Teaching Dimensions Observation Protocol (TDOP) proposed by Hora and Ferrare [11]. Since observational data cannot capture the full spectrum of classroom practices [11], it needs to be complemented by other data sources. The Postsecondary Instructional Practices Survey (PIPS) [12], comprising 24 items targeting diverse instructional practices, offered a valuable tool for collecting valid and reliable data from instructors with varied classroom practices. Besides, course documents such as syllabi, class notes, and lesson plans were collected to get insights into what participants consider valuable. Finally, in the summer of 2023, participants were brought together for a workshop where focus groups were conducted which is a time-efficient method of data collection. These multiple forms of data were collected for the purpose of triangulation in the research. In the workshop, participants worked with the researchers to use the analyzed data to build detailed case studies of how their teaching approaches combined a PCK focus with student-centered learning.

Results and Discussion

Lessons Learned from Classroom Observations

Our observations revealed common practices utilized by instructors to promote students' learning of disciplinary knowledge. These practices include dynamic class introductions, such as reviewing the semester schedule or starting with engaging stories and small talk, fostering a supportive atmosphere, and demonstrating concern for students' well-being. In one instance, an instructor built a sense of community by discussing a previous field trip and sharing details about upcoming events. Instructors also engaged in a discussion of the usefulness of office hours as a valuable resource in that they encouraged students across different departments to seek additional support when needed. Some instructors introduced unique practices to enhance the learning experience. These approaches included a debate activity in MME to discuss related risks, actively involving CS students in resolving project presentation scheduling issues, silent problem-solving and assigning tasks for collaborative MATLAB code development in BEAM, permitting multiple quiz attempts with detailed feedback in ISE, and emphasizing the relevance of lecture content to related courses in CEE. These varied instructional methods collectively highlight the multifaceted strategies instructors used to create dynamic and effective learning experiences, incorporating elements of active participation, critical thinking, collaboration, transparency, and real-world relevance across different engineering disciplines.

Throughout the class, student engagement was consistently maintained through various techniques. Techniques included the use of pre-made slides on tablets for problem-solving, seeking students' opinions on example posters, and facilitating small group discussions to encourage collaborative learning and idea exchange. Instructors often involved students by posing questions, actively maintaining their participation, and employing interactive methods such as hand-raising to ensure every student contributed. This commitment to diverse and inclusive engagement strategies reflected the instructors' dedication to fostering an interactive

and participatory learning environment across different disciplines. Additionally, instructors highlighted the pivotal role of visual aids and technology in enhancing the delivery of course content. The use of document cameras, overhead projectors, and slides served as powerful tools for illustrating key learning objectives, allowing students to follow along and actively participate. Instructors incorporated visual aids creatively, such as projecting homework assignments, introducing multimedia clips like MythBusters, and linking lessons to relatable examples and real-life relevance. The personalized support, including targeted feedback to smaller groups and individual students, further underscores the instructors' commitment to ensuring a comprehensive and tailored learning experience for all students.

Lessons Learned from PIPS

The findings of the PIPS survey highlighted a range of effective instructional strategies that instructors commonly utilized, such as designing activities that establish meaningful connections between course content and students' future endeavors. Providing immediate feedback during class engagement proved to be another impactful practice, fostering active learning and real-time improvement. Actively involving students through frequent question-based interactions and encouraging peer discussions during class sessions enhanced their grasp of course concepts. Ensuring well-structured class sessions with detailed notes contributed to effective note-taking and comprehension. Group dynamics were emphasized through collaborative small-group work, which promoted teamwork and diverse perspectives. Employing problem-solving structures that encouraged multiple solution approaches fostered critical thinking and analytical skills. The incorporation of assignments with small grading weights maintained consistent student engagement and motivation. These practices collectively contributed to creating engaging and effective learning environments.

Lessons Learned from the Summer Workshop

Another significant initiative undertaken in our study involved organizing a summer workshop that provided a platform for instructors to convene and engage in collaborative discussions regarding their teaching practices and their top five teaching priorities. During this workshop, we also deliberated on the preliminary findings from our data collection. The instructors collectively emphasized the importance of getting students engaged in the learning process. We identified several overarching categories of priorities that held relevance for all instructors; including 1) the establishment of personal relationships with students, 2) the effective organization of course content and class activities, 3) strategies for motivating students, and 4) the integration of course content with real-world applications. The alignment between instructors' teaching beliefs and their teaching practices was evident through their consistent dedication to teaching priorities. For instance, one instructor who emphasized the significance of setting high expectations and being approachable seamlessly integrated these principles into her teaching approach. She achieved this alignment through interactive strategies, including frequent questioning during lectures, structured PowerPoint presentations, incorporation of intriguing facts, personal interactions with students before and after classes, and the provision of external resources. Another instructor seamlessly integrated her teaching beliefs of conveying a love for teaching and building personal relationships into her practices by fostering a sense of community during a field trip, engaging

students in small group discussions, and accommodating a supportive community atmosphere in classroom. Another instructor who emphasized the significance of organization and transparency achieved this alignment through revisiting the semester's schedule, seeking student opinions on example posters. One instructor who believed that making class fun started the class with engaging introduction and introduced debate activities. These instructors' commitment to their teaching beliefs was evident in their classroom practices, creating dynamic and student-centered learning environments.

During the workshop, the instructors also talked about their concerns regarding implementing good teaching. These concerns include disparities in teaching assignments and heavier workloads, a need for increased support for both undergraduate teaching assistants (UTAs) and graduate teaching assistants (GTAs), a desire for assistance in managing administrative tasks related to teaching, and a call for more coordinated efforts in curriculum development and delivery. Instructors also expressed a perception that teaching is undervalued and not well-recognized in promotion and tenure/salary processes. Additional concerns involve the inadequacy of current teaching evaluation methods, a push for better recognition of inclusive teaching practices and quality online instruction, and a plea for increased attention to the specific needs of non-tenure instructional faculty groups. As a project team, we learned the importance of ongoing dialogue, collaboration, and adaptation in faculty development initiatives. The lessons learned for faculty developers as listed as below:

1. Recognize the importance of discipline-specific understanding in shaping effective teaching practices, emphasizing the need for tailored strategies within engineering disciplines.
2. Prioritize the alignment between instructors' philosophical beliefs and teaching practices to create dynamic and student-centered learning environments.
3. Encourage instructors to share and discuss their teaching practices in collaborative settings, such as workshops, to foster a community of learning and improvement.
4. Find ways to address concerns raised by instructors, including discrepancies in teaching assignments, recognition, and the need for increased support and coordination.
5. Emphasize top priorities for instructors as crucial elements for creating engaging learning environments and promoting disciplinary knowledge in engineering.

Conclusion and Future Work

The research sheds light on the dynamic and comprehensive nature of effective teaching practices in diverse engineering disciplines. By focusing on the practical manifestation of instructors' beliefs, this study adds valuable insights to existing literature on instructors' beliefs and practices in engineering education. It highlights the importance of discipline-specific understanding, contributing to the ongoing discourse on effective teaching practices. During the lightning talk, we will share a comprehensive overview of the study's research findings as well as the importance of student-centered teaching practices in engineering education.

Moving forward, the second phase of the project involves recruiting two participants from each of five additional departments within the College of Engineering (Electrical and Computer

Engineering, Aerospace and Ocean Engineering, Construction Engineering and Management, Chemical Engineering, and Mechanical Engineering). This expanded participant group will contribute to our extended data collection efforts, and they will be extended invitations to participate in our upcoming two-day summer workshop, with participation support facilitated through the NSF grant.

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