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Preparing Engineering Education Graduate Students for Research: Redesigning a Course in Developmental Theories and Engineering Thinking

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Abstract

Engineering education graduate students often lack familiarity with the educational theories and research methodologies necessary for rigorous engineering education research (EER). To address the issue, the course “Developmental Theories and Engineering Thinking” serves as a foundational course which provides the theoretical foundation necessary for students to understand learning processes and develop frameworks that inform engineering education research. Analysis of student work and prior syllabi revealed that the existing course structure inadequately prepared students to apply theoretical frameworks to their research contexts, thus calling for a redesign of the course. The redesign employed backward design, establishing the enduring outcome of helping students integrate learning theories with engineering epistemology to address contemporary challenges in EER. Key implementation changes included expanding the theoretical scope beyond traditional learning theories to explicitly incorporate engineering epistemology, emphasizing how engineering students construct knowledge and develop disciplinary thinking. Assessments were redesigned as interconnected assignments that progressively build students’ ability to synthesize learning theories, motivational theories, and engineering epistemology into a theoretical framework. Cooperative learning served as the primary instructional approach, with active learning strategies, including concept mapping, jigsaw learning, group investigations, and structured discussions, systematically integrated to facilitate deep learning and knowledge construction. Regular instructor feedback and peer review processes were embedded throughout the course to support continuous improvement. This systematic redesign demonstrates how backward design principles can address persistent challenge in graduate education, offering a replicable framework for instructors seeking to improve their course design in engineering education.

Introduction

Since the late 20th century, Engineering Education Research (EER) has been expanding globally as a distinct field of inquiry[1]. Unlike traditional engineering research which focuses on testing and experimenting with technical systems, EER investigates human learning and educational phenomena in engineering contexts, where multiple interacting factors influence outcomes and controlled experimentation is often impractical or impossible [2]. Researchers entering the field, whether graduate students or engineering faculty, must develop new competencies to conduct rigorous educational research[3]. The 2002 National Research Council report “Scientific Research in Education” established six guiding principles for rigorous educational research in response to widespread criticism of methodological rigor in the field[4]. The second principle – linking research to theory, addresses a persistent challenge in EER where theoretical frameworks are often treated superficially rather than as foundational to inquiry design. Engineering education communities have been encouraged to adopt these scientific and rigorous research practices to enhance the credibility and generalizability of the educational research[5].

Engineering faculty typically enter academia with little formal preparation in conducting engineering educational research. They come from a research environment characterized by clear, universally accepted methods, replicable experiments on static subjects, theories with concise and consistent structure. However, educational research presents a strikingly different landscape, one characterized by methodological ambiguity, inherent complexity of dynamic human subjects, and a plethora of learning theories. This contrast creates an overwhelming environment that leads to confusion and frustration[6]. Engineering education graduate students, transitioning from technical engineering backgrounds encounter similar challenges. Driven by commitment to student success and desire to improve educational outcomes, engineering educators increasingly pursue research into their own teaching practice[3]. However, without formal training in educational research methods and understanding of educational theories, many educators struggle to conduct rigorous, theory-driven investigations.

Graduate programs in engineering education typically include foundational courses that aim to prepare graduate students in conducting EER through socialization processes that develop educational research competencies. ENE 505 Developmental Theories and Engineering Thinking is designed to engage students with the educational theories and learning frameworks, including theories specific to how engineering students learn, and then guide them in building competency to select, analyze and construct appropriate theoretical frameworks in their own research. By systematically developing students' ability to understand, appreciate and realize the role of theories and theoretical framework in research, this course provides the conceptual infrastructure necessary for conducting rigorous educational research that meets NRC standards. However, intentional course design is essential to facilitate students' transition from technical engineering research to educational research, and to align with how engineering graduate students learn as experienced adult learners. This paper reports on the redesign of ENE 505 course, describing the redesign rationale, guiding principles, and implementation outcomes from both instructor and students' perspectives.

Literature review

Engineering Educational Challenge and Theoretical Framework

Engineering Educational Research (EER) has evolved into a distinct field of inquiry, propelled by efforts to improve engineering education quality and strengthen competitive advantage in technological innovation and engineering workforce development[7]. To achieve these aims, EER addresses problems fundamentally different from technical engineering challenges, centering on understanding how people learn engineering and how to prepare better engineers for the future of global engineering practice[8]. EER is largely applied social science research, drawing on a range of social science theories and methodological approaches to undertake investigations[9]. This epistemological foundation, however, creates significant tensions for engineering educational researchers who are trained as engineers.

This gap manifests as concrete difficulties when engineering faculty and engineering education graduate students transition into EER. Borrego's empirical study of boundary-crossing revealed five problematic features these emerging EER scholars encountered when learning rigorous educational research methods: (1) the open-ended nature of "why" or "how" research questions, (2) the need for theoretical frameworks, (3) use of qualitative or mixed methods, (4) difficulty defining and measuring educational constructs, and (5) the need for interdisciplinary collaboration [10]. Nearly a decade later, Streveler et al. found these challenges persisted, pointing to a critical gap that engineering education programs must address [11].

A theoretical framework provides the foundation for a study by drawing on relevant theories to address a research problem and guide research design [12]. The complexity of real-world educational phenomena necessitates the deployment of multiple theories, as individual theories can illuminate only particular dimensions of complex social realities [13]. By developing robust theoretical framework, engineering educational researchers gain essential tools to organize, explain, describe and interpret information across all stages of inquiry [12].

However, understanding the foundational role of theoretical frameworks in EER, rather than treating them superficially remains a persistent struggle. Rigorous educational research presents methodological challenges distinct from technical STEM research. Educational phenomena occur in complex social contexts where multiple variables interact simultaneously, making it difficult to control confounding factors [2] as well as identify the most salient factors amid the complexity. Theoretical frameworks offer essential scaffold for the research process by guiding the researchers in determining what to measure, how to operationalize constructs and which relationships to investigate. Without this understanding, researchers may be tempted to add theoretical frameworks merely as "veneer", a perfunctory section in the introduction or discussion, rather than letting the theory inform the entire research process [11].

These conceptual difficulties reflect fundamental differences in knowledge generation between disciplines. As newcomers to educational and social sciences research, engineering-trained scholars confront tacit practices and epistemological assumptions that differ markedly from engineering [7]. The challenge is not merely learning about theories but understanding how to integrate them meaningfully into the research. Grounding research in sound theoretical framework is identified as one of the most significant challenges for engineering education PhD students [11]. Meeting this challenge requires that PhD students understand and appreciate theories related to learning and learners' development that enable them to design theoretical frameworks leading to rigorous engineering education research. As trained engineers, many engineering education students struggle with reading and understanding educational theoretical articles and research, often finding the language, epistemological assumptions, and conceptual frameworks unfamiliar compared to their technical training.

This theory-practice gap underscores the critical need for foundational courses that provide students with opportunities to develop theoretical literacy and learn how to meaningfully integrate theoretical frameworks into research design. Such courses should honor students' engineering identities and epistemologies while scaffolding their development as educational researchers. The course "Theories of Development and Engineering Thinking" was designed to address this critical need, serving as a foundational course in our engineering education graduate program to prepare students to develop and apply theoretical frameworks to address contemporary challenges in EER.

Course Background and Motivation for Redesign

"Theories of Developmental and Engineering Thinking" is a required three-credit foundational course in the engineering education doctoral program, systematically introduces learning theories and educational research frameworks to the students. This course is also available as an elective course for students interested in teaching or educational research. This course occupies a critical position in the curriculum as it bridges students' engineering backgrounds and their emerging identities as engineering education researchers. The course aims to develop students' ability to understand, critique, and apply theories of learning and development to engineering education contexts.

Prior to redesign, the original course centered on five guiding questions: 1. How does learning occur; 2. Which factors influence learning; 3. What is the role of memory?; 4. How does transfer occur?; and 5. How should instruction facilitate learning?. Course topics spanned foundational learning theories and engineering-specific areas including design thinking, spatial reasoning and identity development. Students were required to engage directly with original works from seminal theorists including Dewey, Piaget, Vygotsky and others and contemporary works in EER. Assessments in the prior course included constructing annotated bibliographies, reviewing dissertations for theoretical frameworks, developing their own theoretical frameworks for EER and designing a theory-informed engineering learning activities.

To ensure the course continued to meet evolving program goals and understand student needs, a systematic instructional design analysis of prior course syllabus and semi-structured interviews with former students were conducted. Syllabus analysis revealed opportunities to strengthen constructive alignment by enhancing the coherence between learning objectives, instructional activities and assessment [14]. While the course title included engineering thinking, syllabus analysis pointed out that this component remained underdeveloped relative to general learning theories. The course focused primarily on foundational learning theories and general cognitive principles, engineering thinking was not defined explicitly and addressed sufficiently. Without clear conceptualizations of engineering thinking in the course, students lacked explicit guidance on how engineering students and engineers construct knowledge as a discipline or develop engineering habits of mind, a critical gap for preparing engineering researchers who must understand both general learning principles and engineering-specific epistemologies.

Beyond this content gap, instructional design analysis revealed that while learning objectives emphasized students' ability to apply theories to construct meaningful learning environments and developing theoretical framework for research, many instructional activities and assessments insufficiently scaffold students for achieving these objectives. Consistent with Streveler et al.'s findings that theoretical framework remains a persistent challenge for engineering education graduate students [11], findings from interview identified the need for more structured, progressive scaffolding to develop their competency in building theoretical framework for rigorous EER.

As mentioned above, students were required to engage with multiple seminal articles related to learning theories each week, these articles contained complex technical, psychological and philosophical terms. The reading materials while pedagogically valuable, create significant reading load as students grappled with unfamiliar vocabulary and epistemological assumptions across different disciplines. Thus, students suggested reducing the number of readings but maintaining depth by focusing on significant articles that make the learning more purposeful.

These findings indicated that while the course successfully introduced students to foundational learning theories, systematic redesign was necessary to address critical gaps in engineering epistemology integration, constructive alignment and theoretical framework scaffolding. A comprehensive redesign grounded in backward design and constructive alignment principles offered a pathway to transform the course into a more coherent, effective learning experience that would better prepare students to integrate theories with engineering epistemology and develop robust theoretical framework to conduct EER.

Theoretical Framework for Redesign

The redesign of the course, "Theories of Development and Engineering Thinking" employed backward design [15] as its guiding framework. This approach provides systematic, evidence-based process for creating coherent and student-centred learning experiences that are necessary for facilitating engineering graduate students' learning.

Backward Design

Wiggins and McTighe criticize traditional content-focused design for its lack of clarity in learning goals, where students achieving outcomes "by hope" rather than through deliberate instructional design [15]. In contrast, backward design represents a fundamental shift from traditional curriculum by inverting the typical design sequence. This approach starts with a clear description of learning outcomes, using these outcomes as the basis for subsequent curriculum planning [15]. The backward design process consists of three stages: 1. Identify desired results; 2. Determine acceptable evidence of learning; 3. Plan learning experiences and instructions. This sequential process ensures coherence and alignment among learning outcomes, assessments and instructional activities.

These desired results serve as educational objectives that indicate intended changes in students and function as criteria for selecting materials, outlining content, developing instructional activities and designing assessments [16]. When identifying desired outcomes, Streveler and Smith [17] adapted from Wiggins and McTighe [15], recommend distinguishing among three categories of outcomes: 1. Enduring outcomes (what learners should retain long after the course ends, serving as the driving force for the entire design); 2. Important-to-know outcomes (complementary building blocks needed to achieve enduring outcomes; and 3. Good-to-be-familiar-with outcomes (beneficial exposure that is not crucial to the learning experience). This categorization helps designers to focus design efforts on what truly matters and acknowledge that not everything is essential [17]. Determining valid educational outcomes requires instructors to possess not only disciplinary expertise but also an understanding of students' needs, prior knowledge, misconceptions and learning contexts [15]. Need analysis, the systematic examination of learners' requirements conducted through dialogue between instructors and students, provides critical input for formulating educational objectives [18] and designing aligned instructional and assessment activities.

The second step of backward design, determining acceptable evidence, requires educators to strategically identify the specific methods and tasks that will demonstrate whether students have achieved the identified learning outcomes [15]. Assessment tasks function as both evaluative mechanisms and pedagogical tools that support student learning. The evidence of learning must be deliberately crafted to target specific learning intentions and provide clear, convincing indicators of student understanding [19]. Acceptable evidence encompasses a continuum of assessment approaches, ranging from formative to summative assessments. Formative assessments are typically integrated into day-to-day class activities, characterized by an informal and iterative nature, and include non-graded methods for gathering feedback on student learning. Feedback is essential in diagnosing students' misconceptions and informing pedagogical adjustments throughout the course [20]. In contrast, summative assessments often occur at midterm or course end, constituting formal, performance-based evaluations that gauge mastery of learning outcomes upon course completion [21].

In the third stage of backward design, instructors focus on planning learning experiences and instruction that will prepare students to demonstrate the required knowledge, skills and understandings as identified in previous stages. When planning the teaching and learning activities, instructors need to consider learners' prior knowledge, misconceptions, and needs, designing activities that are both engaging and effective. While learning experiences should be thought-provoking and intellectually compelling, centering on big ideas that pull learners into meaningful work, this engagement must serve a clear educational purpose. Wiggins and McTighe caution against the common pitfall of designing activities that learners enjoy but that fail to advance substantive learning goals [15]. Instructors may draw upon an extensive corpus of evidence-based instructional strategies to inform pedagogical decisions regarding activity selection and implementation. For instance, systematic literature reviews such as Nguyen et al. have synthesized evidence-based instructional strategies that demonstrate efficacy in facilitating active learning and fostering student engagement while concurrently addressing implementation barriers, including student resistance [22].

Methodology in Course Redesign

Identify Desired Results

Before presenting the outcomes framework, we define the central ideas and core terms that shaped the redesign decisions. In this course, developmental theories encompass the broad range of educational theories explaining how individuals acquire knowledge and develop, organized into three categories: (1) learning theories that explain knowledge acquisition processes (behaviorism, social cognitive theory, cognitivism, constructivism); (2) motivational theories that explain the factors influencing learning (self-determination theory, expectancy-value theory, attribution theory), and (3) theories addressing individual variation based on developmental stages and cultural contexts (adult learning theories and multicultural education frameworks). The second core concept is engineering thinking, which encompasses the distinctive ways engineers learn and solve complex problems and includes multiple interrelated dimensions. Engineering thinking is grounded in engineering epistemology, the distinctive ways engineers construct knowledge and determine what counts as valid engineering knowledge. This epistemological foundation manifests in engineering habits of mind, a framework developed by Lucas and Hanson that identifies six core dispositions engineers employ: systems thinking, creativity, optimism, collaboration, communication and ethical considerations, which characterize how engineers approach making things work or making things work better [23]. Together, these developmental theories and engineering thinking concepts form the foundational knowledge structure of this course and shaped the identification of desired outcomes.

Following Wiggins and McTighe's backward design [15], the redesign process began by distinguishing between what students should retain beyond the course versus what they should simply know or be familiar with. The enduring outcome of the original course centered on 'developing theoretical frameworks related to the study and practice of engineering education' which positioned framework construction as the ultimate goal. However, critical reflection on the theory-practice gap revealed a misalignment. In this course, framework construction was not the enduring understanding we sought but rather evidence that students could demonstrate deeper comprehension. This insight led to framing the enduring outcome to emphasize that students would understand and apply developmental, learning and engineering epistemological theories as foundations for rigorous EER. This restructuring ensured that theoretical framework construction become an assessment of understanding rather than the understanding itself, fundamentally reorienting all subsequent instructional design decisions.

With the enduring outcome established, we next identified the important-to-know outcomes, the key understandings and competencies essential for achieving that lasting understanding. Analysis of previous course syllabus revealed that engineering epistemology which explained how engineers construct knowledge and develop disciplinary ways of thinking was underdeveloped, mentioned but never explicitly defined or systematically explored. These insights led to what students need to know: 1. Foundational and developmental theories and their roles in explaining knowledge acquisition in engineering education contexts and 2. Engineering epistemology as a distinct way of knowing that shapes how engineers learn and construct knowledge. We then identified what students need to be able to do at the end of the course, including 1. Critically analyze and evaluate theories within specific educational contexts, and 2. Synthesize multiple theoretical perspectives into coherent explanations that address engineering education challenges. Motivational theories were designated as good-to-know because they provided contextual breadth and supplement understanding of educational phenomena in EER. The identified desired outcome is summarized in Figure 1.

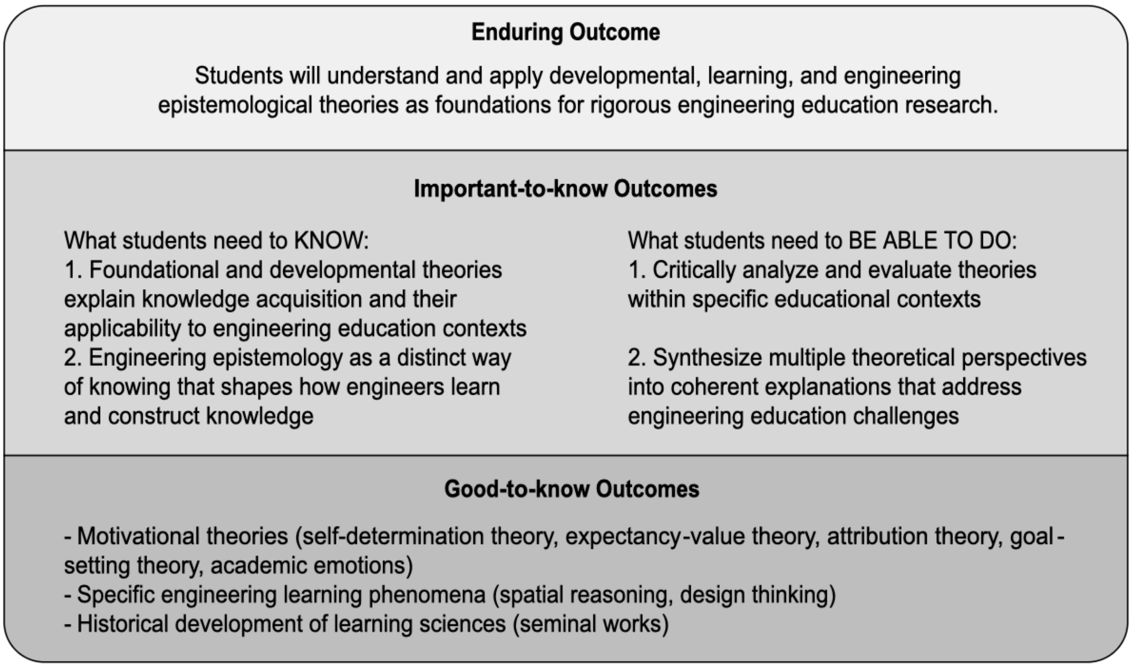

Figure 1. Identify desired results

Determine Acceptable Evidence

Having established the desired outcomes in Stage 1, Stage 2 of backward design focused on determining what evidence would demonstrate students' achievement of the enduring understanding. The redesign positioned the theoretical framework as the primary assessment that would reveal whether students truly understood theories as foundations for rigorous

EER. However, constructing a coherent theoretical framework demands deep theoretical understanding and synthesis abilities that develop progressively through structured support. Therefore, the assessment structure was redesigned and included progressive formative assessments, such as concept maps and reflections that build toward the summative theoretical framework.

Concept maps serve as ongoing formative assessments that require students to visualize their understandings towards developmental theories, learning theories and engineering thinking by identifying key concepts, articulating relationships among them and representing the hierarchical and lateral connections that constitute theoretical coherence [24]. Early concept maps focus on individual theoretical perspectives (behaviorism, cognitivism, social cognitive theory), while later maps require integration across multiple theories to provide the complete overview. The visual nature of concept mapping also makes students' thinking visible, revealing not just what concepts they recognize as important, but more critically, how they understand these concepts to relate. Research demonstrates that concept mapping enhances students' ability to compare complex readings and improves retention of material [25]. The use of concept map also allows instructors to identify misconceptions early and provide targeted feedback that clarifies student's misunderstandings. This assessment directly addresses both what students need to know and what they need to be able to do, providing formative evidence that guides instructional decisions throughout the semester.

Reflections provide formative evidence of students' understanding across all important-to-know outcomes. Structured reflections prompt students to articulate their evolving comprehension of how learning theories, motivational theories and engineering thinking relate to engineering education, while demonstrating their ability to critically analyze theories within the specific contexts of their own research interests and teaching philosophies. These metacognitive exercises enable students to examine their current understanding of theory's role in EER, potentially transforming their perspective from viewing theory as subsidiary application to recognizing it as foundational to rigorous inquiry.

The theoretical framework serves as the summative assessment that demonstrates students' achievement of enduring outcomes and important-to-know outcomes. The resulting framework provides evidence that students can understand educational theories and apply this knowledge through critical analysis, synthesis and contextualized application to engineering education challenges. Throughout this process, students receive iterative feedback from both peer and instructors and incorporate feedback into a final version that provides comprehensive evidence of the enduring understanding.

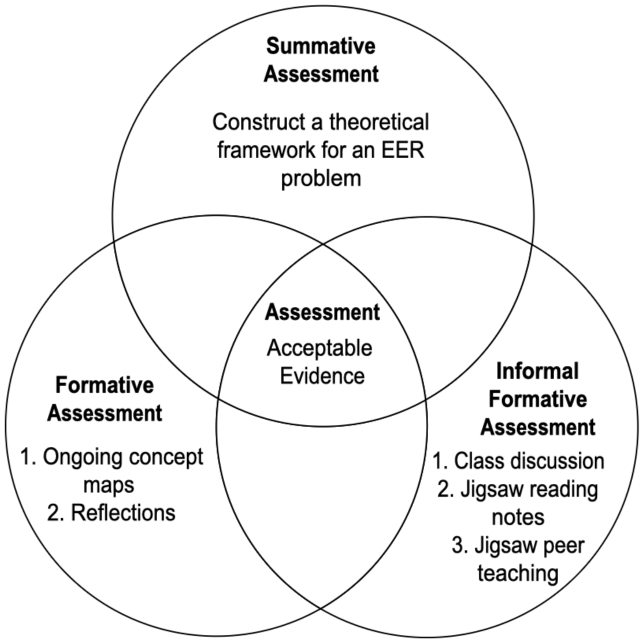

Figure 2. Determine Acceptable Evidence

Plan Learning Experiences and Instructions

Stage 3 focused on planning learning experiences and instruction to support students in reaching those outcomes. Critical analysis of the Spring 2024 course revealed students experienced cognitive overload from the volume of reading, while learning activities such as bibliography annotation did not translate into the deeper synthesis needed for theoretical framework construction. The redesign centers on active, cooperative learning experiences that deliberately scaffolded the progression from foundational knowledge building to sophisticated theoretical synthesis.

To address the theory-practice gap evident in the original course, the redesign incorporated cooperative learning [26] as the primary instructional approach. Cooperative learning's essential elements create conditions where students must actively engage with theories rather than passively absorb them. Through structured interdependence and collaborative discourse, students develop both theoretical knowledge and the synthesis abilities needed to construct a robust theoretical framework for EER.

The instructional design was informed by key characteristics of the target learners. Graduate students in engineering education are adult learners who bring substantial prior knowledge and experience and need to see immediate relevance to their own context (Knowles, 1978). Students enter the course with heterogeneous theoretical foundations, some possess strong engineering backgrounds but limited exposure to educational theories, while others have teaching experiences but are less familiar with EER. These learner characteristics directly shaped instructional decisions by leveraging students' diverse expertise as a learning resource rather than treating heterogeneity as a deficit.

The redesigned course employs five primary instructional strategies: concept mapping, whole-class discussions, jigsaw learning, group investigation and structured peer and instructor feedback. These activities are carefully designed to build progressively toward theoretical understanding and theoretical framework construction. The course begins by establishing students' understanding of epistemology and how different ways of knowing shape engineering education. Students read core chapters on major learning theories (behaviorism, social cognitive theory, information processing theory and constructivism), then creating individual concept maps that visualize their emerging understanding of each theoretical perspective. In class, students engage in discussions that emphasize critical analysis and how these theories apply to student learning.

Rather than requiring all students to superficially engage with numerous topics, jigsaw learning allows students to develop deep expertise with specific topics before teaching peers. This approach also addresses students' cognitive load by distributing the reading tasks among the group members. Students assigned to an expert group, read their assigned articles, prepare individual reading and comprehensive teaching notes or concept maps collaboratively for peer teaching. In the subsequent class session, students reorganize into jigsaw groups where each member teaches their theory to peers who studied different topics. Throughout the semester, two jigsaw learning cycles were conducted, covering topics on seminal educational theorists and motivational theories. At the end of each cycle, students conduct group processing through the plus-delta method to identify what went well in the process and what to improve in the next cycle.

Given the insufficient development of engineering thinking in the original course, the redesign incorporates dedicated instructional sessions that explore this concept through group investigation. Pairs of students collaboratively research specific types of engineering thinking (design thinking, systems thinking, problem-solving, empathy), examining how engineering thinking develops and manifests in engineering practice. Each student within the pair researches the topic and prepares notes before their collaborative discussion. During the discussion, students create visual organizers synthesizing their findings and present to the class, collectively building understanding of engineering thinking as a distinct way of knowing.

Integrated throughout the semester, four structured reflections prompt students to examine their developing understanding of theory's role in EER. These reflective practices create deliberate opportunities for students to step back from content acquisition and critically examine their own evolving conceptions, fostering a transformative shift from superficial engagement to recognizing theory as foundational in EER.

Instructional support for the theoretical framework assignment occurs in phases. The previous exposure to educational theories through planned instructional activities builds the foundational blocks students need to construct their own framework. Simultaneously, students are introduced to scholarly literature on theoretical frameworks (Varpio et al., 2020;

Magana, 2022), engaging in class discussion about what constitutes a coherent framework and analyzing examples from EER. Students identify research problems related to their interest and begin conceptualizing which theories might be relevant. After submitting initial framework drafts, students engaged in peer review where they provide feedback to improve each other's work. Instructor feedback sessions provide individualized guidance, and final class sessions create space for questions, clarifications and final refinements. This scaffolded process ensures students receive multiple opportunities to practice synthesis and application before final submission.

Discussion

This course redesign exemplifies the scholarship of teaching and learning (SoTL), which Boyer characterized as the systematic, scholarly investigation of teaching practices and their impact on student learning [27]. Rather than treating course design as administrative work, this redesign relied on SoTL principles by addressing a persistent concern in EER. As mentioned above, engineering graduate students consistently struggle to appreciate the importance of theories in EER and thus, having problems in constructing a coherent theoretical framework that guide their EER. Thus, this study redesigned the course by using Wiggins and McTighe's backward design [15] as the foundational framework. Critical analysis revealed that student difficulties in the course could stem from misalignment between course outcomes, assessments and instructions. When these elements are not systematically aligned, even motivated students cannot bridge the gaps through individual effort alone.

A prevalent challenge in conducting EER is students' tendency to apply theoretical frameworks mechanically, where students treat theoretical framework as superficial requirements rather than recognizing theories as foundational lenses that shape problem formulation, methodology and interpretation. This challenge could not be fully addressed when the original course design positioned framework construction as the learning outcome itself, enabling student to succeed by applying procedural template without developing genuine understanding. The backward design process addressed this challenge by necessitating a fundamental reconceptualization of the relationship between learning outcomes and assessment artifacts. In this redesign, theoretical framework is positioned as evidence of student learning that demonstrates their understanding of theories as foundational to rigorous research. This conceptual distinction reorientated all subsequent design decisions to focus on developing students' theoretical understanding.

The effectiveness of this redesign supports broader findings about backward design's capacity to address instructional misalignments that impede student learning while simultaneously transforming instructor practice. This transformation in instructor practice is consistent with documented benefits of backward design for teaching clarity and focus. Research demonstrated that instructors using backward design develop greater clarity about desired student achievements and improved understanding of how learning activities connect to learning standards, enabling them to focus on how instruction supports specific learning goals rather than simply covering content [28, 29]. Shifting from content-focused to outcome-focused course design exemplifies how backward design improves instructor professional practice, making pedagogical decisions deliberate, justifiable and improvable.

While this paper focuses on the design process rather than implementation outcomes, it is worth noting that backward design's benefits extend beyond instructional clarity to documented improvements in student learning. Research demonstrates that backward design enhances students' conceptual understanding over surface-level memorization [30], improves their ability to transfer knowledge to novel contexts [28], and develops critical thinking and analytical skills [31]. Students in backward-designed courses report higher engagement and more purposeful participation in learning activities, as the explicit alignment between outcomes, assessments and instruction helps them understand why specific activities matter [21, 28]. Preliminary feedback from students in the redesigned ENE 505 course indicates general satisfaction with the course structure and learning experiences, suggesting that the systematic alignment achieved through backward design positively influenced their learning. However, comprehensive analysis of student learning outcomes, including their development of theoretical understanding and ability to construct coherent frameworks, requires more rigorous investigation. A detailed examination of student perceptions, learning gains and the effectiveness of specific instructional strategies will be reported in a subsequent publication that analyzes implementation data systematically.

Conclusion

This paper demonstrates how systematic application of backward design can transform a foundational EER course to better develop graduate students' understanding of theories as foundational to rigorous inquiry. This systematic course redesign contributes to both the SoTL and EER by demonstrating how backward design addresses a persistent challenge in engineering education. The work illustrates that backward design functions not merely as a planning framework but as a methodological tool for diagnosing and addressing structural problems in course design. By documenting how backward design identified and addressed these misalignments, this work contributes to the scholarly knowledge base about effective course design in graduate level course, particularly for addressing the persistent theory-practice gap identified by Streveler et al. [11]. This paper also provides a replicable model for others seeking to address challenges in theory courses or foundational EER courses more broadly.

The significance of this work lies not in prescribing specific instructional strategies but in demonstrating that systematic, outcome-driven design creates coherent learning conditions necessary for implementation success. For engineering education community, this work models how backward design can function as a rigorous SoTL methodology for addressing persistent learning challenges, making course design scholarship that merits dissemination and peer critique rather than private instructional practice.

Finally, for higher education institutions, this work has implications for both resource allocation and professional development. The substantial time investment required for systematic redesign and its demonstrated value in producing conducive learning environments suggest that course design should be recognized and rewarded as scholarly work. Moreover, institutions should provide structured professional development in evidence-based course design frameworks, particularly backward design as foundational training for faculty. Such training would equip instructors with systematic methodologies for diagnosing and addressing pedagogical challenges, transforming course design from intuitive practice into deliberate scholarly inquiry.

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