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Broadening STEM Learning Opportunities for Future Mathematics Educators in Engineering (WIP)

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Introduction

Future mathematics educators in engineering play a critical role in transforming engineering education, supporting a shift from isolated mathematics instruction toward a more integrated and holistic approach. Mathematical knowledge is a fundamental component of engineering education, underpinning the mathematization processes and decision-making involved in engineering design [1]. In professional contexts, these processes do not occur in isolation; rather, they are closely intertwined with engineering knowledge [2] and broader societal contexts [3]. Despite this, mathematics instructors in engineering often emphasize algorithmic and mechanistic procedures [1], [4], with limited connections to engineering knowledge and minimal attention to relevant societal contexts [5], [6]. Such teaching practices may result in engineering students developing fragmented or unclear approaches to applying mathematical knowledge in both coursework and professional practice [7]. Thus, transforming mathematics education in engineering toward a more integrated vision requires that future mathematics educators engage in experiences that enable them to develop teaching practices that promote the integration of mathematical knowledge with engineering principles and societal considerations. However, knowledge about how to facilitate such experiences remains limited.

STEM education can serve as an approach that offers future mathematics educators the opportunity to foster a more integrated vision of teaching and learning. Integrated STEM learning experiences have been widely recognized as a way to "provide intentional and explicit support for students to build knowledge and skill both within the disciplines and across disciplines" [8, p. 5]. This approach also emphasizes the instructor's role, which extends beyond traditional lectures to facilitating learning that integrates multiple disciplines [9]. However, several approaches to STEM integration tend to underrepresent mathematics [10]. English [11] and Baker and Galanti [12] argue that mathematical modeling—particularly within the Models and Modeling Perspective (MMP) [13]—can serve as a vehicle for instructors to promote STEM integration in which mathematics plays a central role. However, these authors highlight that this approach generates challenges and therefore requires instructors to participate in experiences that contribute to the transformation of their teaching practices.

Doerr [14] notes that, although future educators possess valuable models that guide their teaching, modeling-based instruction requires substantial changes to these models in order to support student learning. For example, the instructor's role shifts from providing explanations and justifications to students to "putting the students in situations where they can interpret, explain, justify, and evaluate the 'goodness' of their models" [14, p. 77]. Lesh and Kelly [15] highlight that when teachers or future educators participate in modeling-based learning experiences, they have the opportunity to construct and refine their own models, enabling them to understand how students think during modeling activities. Thus, moving toward an integrated vision requires that instructors themselves actively participate in integrated, modeling-based learning experiences. Nevertheless, knowledge about how to design learning experiences that support future mathematics educators in engineering in modifying their models to foster integrated learning experiences remains limited, particularly with respect to the integration of societal knowledge.

Therefore, this work-in-progress (WIP) presents the advances and preliminary results of a study aimed at expanding STEM education preparation opportunities for future mathematics educators in engineering. Specifically, the research question guiding this study is: *How do future mathematics educators in engineering modify and adapt their models when participating in a STEM-integrated learning experience?*

Theoretical Foundations

This conference paper is derived from a broader study. In particular, for this WIP, the theoretical foundation is the MMP [13].

Models and Modeling Perspective

The MMP [13] emphasizes that the creation, adaptation, and application of mathematical models constitute a fundamental tool in the design processes that characterize engineering practice [16]. Accordingly, the MMP highlights the importance of engaging engineering students in learning experiences grounded in mathematical modeling, in which students are provided with opportunities to construct, revise, and extend their models [13]. Within the MMP, models are defined as "conceptual systems that are embedded in a variety of representational systems that provide the conceptual foundations for deeper and higher-order understandings of many of the most powerful ideas" in school mathematics and science curricula [17, p. 592]. In contrast to traditional instruction, in which problems are typically well-defined, include specific data, and prescribe step-by-step procedures, modeling-based learning experiences allow students to engage in processes of mathematization. These processes involve "quantifying, dimensionalizing, coordinatizing, categorizing, algebratizing, and systematizing relevant objects, relationships, actions, patterns, and regularities" [13, p. 5].When students and instructors participate in modeling experiences, they engage in iterative cycles of model construction, modification, adaptation, and extension, allowing them to progressively refine their conceptual understanding [18].

The MMP proposes six "Principles for developing thought revealing activities for students and teachers" [17, p. 591], also referred to as the Six Principles for Developing Model-Eliciting Activities [13]. These principles were adapted by Diefes-Dux et al. [1] to guide the design of modeling activities for engineering students. These principles ensure that such activities are designed to require students to construct models (Model Construction), work within authentic engineering contexts (Reality), engage in self-assessment from the client's perspective (Self-Assessment), document their modeling processes (Model Documentation), develop models that are shareable and reusable across contexts (Model Shareability and Reusability), and produce effective prototypes that can inform future modeling efforts or serve as templates for analogous situations (Effective Prototype).

These six instructional principles guide the design of modeling activities, such as Model-Eliciting Activities (MEAs) and Model Adaptation Activities [13]. These activities present real-world problems to be solved collaboratively by small groups of three to four students and require the construction of a mathematical model for a specific client. In addressing these problems, students move beyond merely obtaining a solution; rather, they "need to describe, explain, manipulate, or predict the behavior of the real-world system to support their solution as the best option for the client" [19, p. 247]. In addition, the six instructional principles have been shown to effectively support the design of integrated learning experiences. For example, English [11] based her work on the six instructional principles of the MMP to collaborate with teachers in designing interdisciplinary modeling problems. English highlighted that designing such experiences is a complex endeavor that often requires multiple iterative cycles of creation, testing, revision, and refinement, during which the instructional design principles proposed by the MMP serve as an effective guide for structuring and refining the design process.

The six instructional principles not only support the development of activities that reveal students' thinking but also actively elicit it. Specifically, "the descriptions, explanations, and constructions that students generate while working on them directly reveal how they are interpreting the mathematical situations that they encounter by disclosing how these situations are being mathematized" [17, p. 593]. These manifestations of thinking, which emerge as students articulate and share their ideas with peers, enable researchers to examine the interpretive systems of students, teachers, and researchers [20]. Thus, learning experiences designed according to these principles foster both students' model development and opportunities for researchers to investigate the conceptual transformations that occur throughout the modeling process.

Methods

This study employs an exploratory qualitative case study design [21] aimed at describing the problem-solving processes of future mathematics educators as they engage with an STEM integrated learning experience. For this study, a group of future mathematics educators was selected. Specifically, the participants were eight students enrolled in a master's program in mathematics education who expressed their interest in becoming instructors of mathematics courses for engineering students. With the objective of addressing the research question, an STEM Integrated Learning Experience based on mathematical modeling was designed.

Integrated STEM Learning Experience

The Designing Beams for Community Water Tanks: An Integrated Learning Experience (Design Beams ILE) was developed following the six instructional principles proposed by the MMP [1], which emphasize situating activities in authentic and realistic engineering contexts. This experience is situated in the context of addressing the water access needs of a low-income community. The Design Beams ILE was implemented in the participants' classroom over three sessions, each lasting 2.5 hours.

The Design Beams ILE was designed to engage participants with an engineering problem situated in a community context. The activity began with a contextualization phase using images and real-world information about a community project in which engineers and residents constructed cisterns with concrete and steel beams. The ILE then guided participants to examine the existing beams, which have a square cross-section reinforced with steel bars, and to consider community concerns regarding their load-bearing performance and the risk of steel corrosion. Participants were then asked to propose alternative beam geometries that maintained the original volume, incorporated procedures that could be applied to other situations, and considered natural fibers as reinforcement. Participants worked in small teams (two teams of three participants and one team of two participants) to develop presentations for the community, subsequently conducted scaled experiments to test their designs to failure, and revised their proposals based on the experimental results.

Data Collection and Data Analysis

Data were gathered through audio recordings of students' discussions, along with their presentations and written assignments completed during the learning experience. The recordings were fully transcribed, and the resulting data were organized by team. Data analysis followed the six phases of thematic analysis proposed by Braun and Clarke [22]. The study is currently in the data analysis phase; therefore, future plans will focus on completing this process In this WIP paper, we focused on presenting the preliminary results of one of the teams.

Preliminary Results and Discussion

The preliminary analysis allowed us to identify that the Design Beams ILE fosters participants' development as they progress through various processes of creating and modifying their models, integrating both disciplinary and societal knowledge.

One of the first findings was that the Design Beams ILE encouraged participants to actively engage in engineering design processes. They proposed initial improvements to the beam cross-sections, grounding their suggestions in geometric characteristics such as the number of edges and vertices of the shapes. Subsequently, participants had the opportunity to construct, test, compare, and evaluate their own designs, including scaled prototypes using materials that simulated steel beams and natural fibers. Through this iterative process, they considered potential enhancements to their initial proposals, not only by modifying the geometric shape but also by exploring different types of materials.

Another notable finding was that the Design Beams ILE encouraged participants to develop modifications and adaptations of their mathematical models. These processes included mathematization, encompassing dimensionalizing, algebraizing, and systematizing relevant relationships, patterns, and regularities [13]. For example, because the task required that the beams proposed by participants maintain the same volume as the original beams—so that communities would not require additional materials—participants initially relied on trial-and-error strategies. As they progressed in solving and evaluating their models, they identified and systematized their procedures, constructing algebraic expressions that allowed them to calculate cross-section dimensions more efficiently. This suggests that participants' problem-solving processes tend to evolve as they progress through the task and engage in self-evaluation

Finally, although the Design Beams ILE highlighted community members as clients, participants initially overlooked the social context in their design proposals. However, when constructing and testing their prototypes, they were able to recognize the challenges that community members might face in implementing their solutions. Subsequently, participants reflected on the social context of their designs and the importance of promoting such activities for engineering students. For instance, one participant noted that the activity "allows engineering learners to develop the capacity to design effective solutions to meet societal needs".

Preliminary Conclusions and Next Steps

Based on the preliminary results, this WIP provides evidence of the potential of the Design Beams ILE to engage future mathematic educators in experiences that promote the integration of mathematics with engineering in socially relevant contexts. Mathematical modeling served as a fundamental tool for participants to advance their problem-solving processes. The results also highlight that participants may initially overlook the relevance of the social context, focusing primarily on mathematical processes. Therefore, further analysis will be necessary to explore more deeply the critical reflections on context developed by the participants.

The next steps of this investigation involve expanding the analysis to include data from all participants and conducting a deeper examination of their problem-solving processes. This study contributes to the understanding of how future mathematics educators in engineering can be prepared with a more integrated and holistic vision of mathematics teaching.

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