Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #46986

BOARD # 262: IUSE: Propagation of the Concept Warehouse – an Educational Technology Tool to Promote Concept Based Active Learning

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IUSE: Propagation of the Concept Warehouse – an Educational Technology Tool to Promote Concept Based Active Learning

Several reports suggest there is an urgent need to greatly increase both the number and diversity of students graduating in STEM fields over the next decade [1, 2]. They recommend switching to teaching methods backed by research, like concept-based active learning. Concept-based active learning focuses on using activities to help students understand key concepts deeply, rather than just memorizing facts or algorithmically solving problems [3-6]. Studies show that pedagogies like concept-based active learning boost student engagement and achievement, help retain students in their program of study, and narrow the performance gap for underrepresented groups [7, 8]. However, the main challenge isn't proving that these methods work better than traditional teaching—it's getting instructors to actually adopt them [9]. This project aims to spread the use of the Concept Warehouse [10, 11], a web-based tool for concept-based active learning, in Mechanical Engineering (ME) programs. The tool was originally developed for Chemical Engineering (ChE) and includes over 3,500 *concept questions* which are short multiple-choice questions designed to engage students and assess their understanding of concepts. Concept questions typically do not require calculations but rather ask students to identify key concepts and apply them to new situations [12, 13]. The Concept Warehouse also contains concept inventories and more extensive instructional tools like inquiry-based activities and virtual laboratories [14-16]. Here, we present an update on the wide-range of project activities to extend earlier ASEE reports [17, 18].

The Concept Warehouse has grown significantly, now supporting over 1,700 faculty and 40,000 students. To support use in mechanical engineering, 856 new mechanics questions have been added .The team is working on developing a new Rigid Body Dynamics Concept Inventory to expand the current capabilities of the Dynamics Concept Inventory and has also created several adaptive learning modules for mechanics and material science [16]. Our approach to propagation has shifted from one based on diffusion of innovations [19] to a sociocultural approach [20]. Here, we identified the need for an ecosystems model to understand how the Concept Warehouse propagates within different, diverse settings and the ways that students use the Concept Warehouse to support their learning.

Our analysis has focused on both instructor and student learning. Drawing on Kelly [21], we conceptualize professional development as instructor learning, where knowledge and beliefs are interconnected. First, we have investigated the impact of introducing the Concept Warehouse on instructors' trajectories of practice, an innovative framework based on our ecosystem model to understand the role of contexts (including their institutions, courses, students, personal history and pandemic-related adaptations) in their use of the tool's multiple affordances [22]. While it is widely agreed that tools should encourage student-centered instruction, we contend that traditional models of tool adoption are overly simplistic. They often emphasize the diffusion of static tools, assume faculty remain unchanged, and prioritize strict fidelity of implementation. Instead, we propose that effective uptake requires acknowledging the complexity of the adoption process and designing tools alongside supportive structures that align with these nuances. Here, we introduce the concept of an instructors *trajectory of practice* – the unique ways that an instructor's repertoire of practice within their particular context develops and deepens over time [23].

In a second phase of analysis, we are investigating the perspectives instructors bring to their teaching and the resources they activate to shape these perspectives [24]. To interpret instructors' approaches to teaching broadly, and their interactions with educational technology specifically, we apply a theory of learning and epistemological development—namely, that of resources and frames [25, 26] as an alternative to the traditional focus on beliefs, which are often examined through a cognitivist lens as individual traits that "cause" behavior. In contrast, a sociocultural perspective emphasizes how instructional decisions are *co-constructed* through interactions between instructors and their social contexts, negotiated within specific systems of meaning. Framing, therefore, offers a way to understand decision-making as a dynamic process at the intersection of individual agency and social context, rather than as static beliefs that instructors carry into the classroom. Preliminary results indicate that how instructors frame their teaching directly impacts their use of educational technology. Consequently, fostering greater adoption of instructional tools necessitates addressing the underlying teaching frames that an instructor uses.

We also have studied students' conceptual and metacognitive learning processes through analysis of written explanations, think-aloud interviews, and survey data. Prior research has predominantly emphasized the regulatory dimensions of metacognition. We add to this research by studying epistemic metacognition to examine the relationship between epistemic metacognition and conceptual understanding in engineering statics courses across six partner universities [27]. Our analysis of 267 student responses to one specific concept question revealed greater diversity in students' epistemic metacognition than in their ability to answer the question correctly. Students employed varied epistemic metacognitive resources related to the nature and source of knowledge, epistemological forms, epistemological activities, and their stances toward knowledge. These resources typically aligned with one of two frames: a constructed knowledge frame that prioritized conceptual understanding and sense-making, or an authoritative knowledge frame that emphasized numerical and algorithmic problem-solving. Our team has analyzed 232 student responses and written explanations for a second problem involving friction and equilibrium [28]. Three different themes emerged as students explained their reasoning patterns: with the equation-based choice showing students overzealously applying incorrect equation-based reasoning. In addition, that group was very confident in their answer. We have also surveyed 510 students from a diverse range of two- and four-year institutions over multiple academic terms, gathering insights into their experiences with the Concept Warehouse in mechanics courses. Those findings are addressed in a separate ASEE paper [29].

In another study [30, 31], a "common questions" study was undertaken by faculty at seven diverse institutions, in which the participating faculty members agreed to deploy four common concept questions for Statics, and four for Dynamics (with one problem being common to both sets). Written explanations of approximately 2,000 responses were reviewed the results indicated that depending on the question, modality (in-class, out-of-class, etc.), and cohort, typically 25% – 75% of students who report the correct answer can provide an adequate justification. Similar to the above study, in cases in which students failed to justify a correct answer, the reasons can vary from applying physical reasoning that was not directly applicable, appealing to surface features or non-essential details (for example, inability to accept that 'given' parameter values can be specified as symbols, without actual numerical values), to expressing confusion. Another outcome of the study was that across all cohorts, women expressed lower confidence in their responses than men, even in cases when they outperformed men the problem response.

Using the Concept Warehouse as a foundation, we have spun off two artificial intelligence-based initiatives based on the work in this project, one centered on adaptive learning modules and a second centered on using machine learning to analyze student reasoning. Adaptive learning platforms are becoming increasingly prevalent. However, these systems typically focus on fostering declarative knowledge and procedural fluency, often neglecting conceptual learning. To address this gap, we have developed adaptive learning modules in mechanics and materials science to support individualized conceptual learning [16, 32-35]. The second project focuses on using generative artificial intelligence to automate students short answer written justifications of their answer choice to concept questions. Written explanations have been demonstrated to enhance student engagement and learning outcomes, offering valuable insights into student understanding for instructors and researchers [36-38]. However, the challenge lies in analyzing the substantial volume of text generated. To address this, researchers have turned to machine learning for automating feedback and grading, providing tutoring, and conducting advanced analyses of both short- and long-answer texts [39]. Recently, the use of Transformer-based large language models (LLMs) [40] in qualitative research has gained traction due to their generative capabilities, sparking interest among education and machine learning researchers in exploring their potential applications. In this project, we apply state-of-the-art Transformer LLMs—including T5 , GPT-3 , GPT-4 , and Mixtral-of-Experts to analyze student responses to concept questions in mechanics and chemical engineering thermodynamics [41-44].

As part of the propagation strategy, we have engaged in community building with the goal of supporting instructors in negotiating their technology use in their own practice [45]. Each semester during the project, we have hosted a virtual community of practice. Two major workshop efforts dedicated to the Concept Warehouse. In summer 2020, we first conducted a workshop at the 2020 Virtual ASEE conference, which drew participation from over 50 attendees. Later that summer, a series of two 4-hour summer workshops garnered over 270 applications, with more than 60 participants attending each live session. Applicants who were unable to attend synchronously were provided with access to workshop recordings. In Winter 2024, we delivered a three-day workshop to 22 two- and four- year university faculty members dedicated to concept-based active learning and the use of the Concept Warehouse. There was an overwhelming response from our call, with 179 applications completed. Twenty-one (21) out of 22 rated the summative question “Would you recommend this workshop to a colleague?” as “Strongly Recommend” and one (1) as “Recommend.”

Acknowledgements
We acknowledge the support from National Science Foundation (NSF) through grants DUE 1821439, 1821445, 1821638, 1820888, and 1821603. The opinions, findings, and conclusions are those of the authors and do not necessarily reflect the views of the NSF.

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