Board 418: Understanding Context: Propagation and Effectiveness of the Concept Warehouse in Mechanical Engineering at Five Diverse Institutions and Beyond – Results from Year 4

Dr. Brian P. Self, California Polytechnic State University, San Luis Obispo

Brian Self obtained his B.S. and M.S. degrees in Engineering Mechanics from Virginia Tech, and his Ph.D. in Bioengineering from the University of Utah. He worked in the Air Force Research Laboratories before teaching at the U.S. Air Force Academy for seven years. He has been at Cal Poly San Luis Obispo since 2006, where his research interests include aerospace physiology, engineering education, and rehabilitation engineering. During this time, he has done a professor exchange in Munich and started a study abroad program in Rome.

Dr. Milo Koretsky, Tufts University

Milo Koretsky is the McDonnell Family Bridge Professor in the Department of Chemical and Biological Engineering and in the Department of Education at Tufts University. He received his B.S. and M.S. degrees from UC San Diego and his Ph.D. from UC Berkeley,

Dr. Susan Bobbitt Nolen,

Professor Emerita of Learning Sciences & Human Development

Prof. Dominic J Dal Bello, Allan Hancock College

Dom Dal Bello is Professor of Engineering at Allan Hancock College (AHC), a California community college between UC Santa Barbara and Cal Poly San Luis Obispo. At AHC, he is Department Chair of Mathematical Sciences, Faculty Advisor of MESA (the Mathematics, Engineering, Science Achievement Program), and Principal/Co-Principal Investigator of several National Science Foundation projects (S-STEM, LSAMP, IUSE). In ASEE, he is chair of the Two-Year College Division, and Vice-Chair/Community Colleges of the Pacific Southwest Section. He received the Outstanding Teaching Award for the ASEE/PSW Section in 2022.

Dr. James M Widmann, California Polytechnic State University, San Luis Obispo

Jim Widmann is a professor and chair of the Mechanical Engineering Department at California Polytechnic State University, San Luis Obispo. He received his Ph.D. in 1994 from Stanford University and has served as a Fulbright Scholar at Kathmandu University

Dr. Michael J. Prince, Bucknell University

Dr. Michael Prince is a professor of chemical engineering at Bucknell University and co-director of the National Effective Teaching Institute. His research examines a range of engineering education topics, including how to assess and repair student misco

Prof. Christopher Papadopoulos, University of Puerto Rico, Mayaguez

Christopher Papadopoulos is Professor in the Department of Engineering Sciences and Materials at the University of Puerto Rico, MayagÃ¼ez Campus (UPRM). He earned B.S. degrees in Civil Engineering and Mathematics from Carnegie Mellon University (1993) and

Understanding Context: Propagation and Effectiveness of the Concept Warehouse in Mechanical Engineering at Five Diverse Institutions and Beyond – Results from Year 4

It has been shown that active learning strategies have a positive effect on student retention, engagement, and performance, and can reduce the performance gap for underrepresented students [1-8]. One form of active learning, concept-based learning, is used to “foster students' understanding of deeper concepts rather than just factual knowledge” [3]; the effectiveness of this approach has also been well established. Despite the evidence, many faculty continue to stress algorithmic problem solving without attending to student conceptual understanding. The biggest challenge to improving STEM education is not developing additional instructional practices, but finding ways to get faculty to adopt the evidence-based pedagogies that already exist.

A primary goal of our project is to propagate the Concept Warehouse (CW) into Mechanical Engineering (ME) and other disciplines, and to study how that propagation occurs. The CW is an online innovation tool that was initially developed for the Chemical Engineering community, and includes ConcepTests, Concept Inventories, and Instructional Tools. A portion of our work focuses on content development in mechanics, and includes statics, dynamics, and to a lesser extent strength of materials. We are also studying how different contexts affect the uptake of the CW within the mechanics community. Our IUSE project objectives are to:

1. Extend the use of the Concept Warehouse (CW) to Mechanical Engineering (ME) and grow by 50,000 student users from diverse populations. To achieve this objective, we will:
   a. Develop content [at least 300 new ConcepTests] for Statics and Dynamics.
   b. Continue development of ME research-based Instructional Tools (e.g., Inquiry-Based Activities and Interactive Virtual Laboratories) that help students develop conceptual understanding.
   c. Serve as a repository for Concept Inventories that can be used by ME (and other) instructors.
   d. Provide extensive learning analytics for users who wish to perform research, test or develop new Concept Inventories or ConcepTests, and/or use them to inform classroom instruction.
2. Investigate the propagation of the CW as it expands into ME, with a specific focus on understanding aspects of the educational systems that influence the propagation of the CW in five diverse institutional settings. Aspects of the educational systems include institutional context; instructor histories, beliefs and practices; student histories and practices; and the affordances and constraints of the technological innovation itself.
3. Conduct educational research on effectiveness of validated instructional practices across five diverse institutions. This research will identify ways to support engagement and conceptual learning of diverse populations of students, within the contexts of the educational systems (i.e., institutional contexts, instructor and student histories, beliefs and practices, and the innovation – the CW).

4. Promote and track propagation of the enhanced CW via targeted community building in ME. This will be accomplished through workshops, implementation of an Action Research Fellows Program, collaboration with professional societies in ME and outreach efforts to two-year colleges.
5. Continue to develop and refine a sustainability plan for continued expansion of the CW.

In the past year, we have focused on (a) analyzing extensive interviews with faculty members to investigate aspects of the educational systems that influence the propagation of the CW in five diverse institutional settings, (b) a multi-institutional "Common Questions Study" expanded from last year, (c) student metacognitive responses to complex concept questions, (d) machine learning of constructed responses, (d) continued development and review of concept questions, and (e) development of adaptive instructional tools.

Ecosystems Metaphor for Propagation

In this project, we use an ecosystem metaphor to understand the propagation of an instructional tool, the Concept Warehouse [9]. This metaphor reflects a socio-cultural perspective that is local, idiosyncratic, historic, and context- and climate-centered [10]. Using this metaphor we develop a model (Fig. 1) to address the ways a technology-based tool, the Concept Warehouse, propagates in diverse settings and to how students use the tool in their learning. The ecosystem model goes beyond previous research using the Diffusion of Innovations framework [11] which does not adequately account for the ways in which instructional and learning practices are socially situated within specific educational ecosystems, nor how those systems influence the ways in which practices are taken up by individuals and groups.

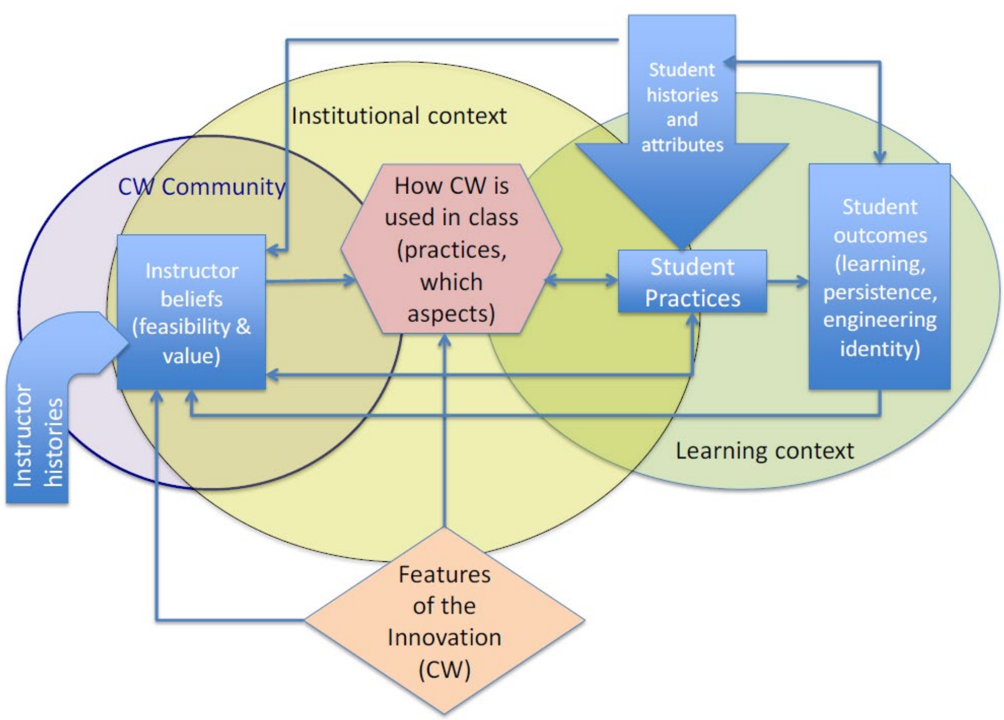

Figure 1. Model of the educational ecosystem for a single institution.

Educational ecosystems are complex, and changes in any aspect of the system lead to other aspects responding, often in unanticipated ways [12], [13]. Not only do initial decisions to use the tool reflect instructors' system-embedded goals and trajectories of practice, the ways in which they use and adapt the tool change the ecosystem, leading to new insights, learning, shifts in practice and even modification of initial goals.

Instructors Trajectories of Practice

We continue to analyze instructor interviews, focusing on 12 cases, all of whom participated in the Concept Warehouse Community of Practice (CoP). We have completed analysis that introduces the idea of an instructor's trajectory of practice, an alternative construct to understand the diverse ways that faculty utilize educational technology and student-centered instructional practices. This construct leverages our theoretical model [9] to understand the role of contexts (including their institutions, courses, students, personal history and pandemic-related adaptations) in their use of the Concept Warehouse's multiple affordances. Using a case study of five instructors, we compare use of the Concept Warehouse both before and after participating in professional development activities (workshops and/or a community or practice). These trajectories are tool-mediated where instructors gained understanding of student learning and assessment from their responses in the Concept Warehouse. They are also community mediated where the project's CoP provided extra-institutional support for deepening practice. Instructors use of the tool and interactions with the community depended on their instructional contexts. We argue a shift in perspective, valuing variability over conformity, is fundamentally needed to support diversity goals.

Common Questions Study

We have pursued a "4 question" research design in both statics and dynamics. In the design, we recruited instructors teaching at different institutions (8 instructors from 6 institutions for statics; 6 instructors from 5 institutions for dynamics). These instructors selected a common set of four conceptual questions that they agreed to deliver including explanation, confidence, and effectiveness follow-ups. The intent is for them to deliver the questions at the time and mode that best matched their content delivery and use of the tool (e.g., homework, in-class group, in-class individual). The effectiveness follow-ups were incorporated into the tool earlier in the grant and include two Likert scale items ("I understood what the question was asking" and "Trying to answer this question made me think deeply about the course material") with written explanations to each item following. After the third question, students were invited to complete a survey which was developed this Project Year. The survey contained 18 items focusing on practices and engagement, including cognitive engagement, emotional engagement, value, metacognition. A subset of these students was invited for interviews. We also developed and deployed an instructor survey.

Preliminary results from the study of four statics instructors [14] mentioned above were as follows:

- Across all four institutions, and independently of correctness of their answer, female students consistently reported lower confidence in their answers.

- In general, among students selecting correct responses, about one third to one half expressed reasoning that was considered ‘correct’. Nevertheless, many ‘incorrect’ answers contained portions of reasoning that suggested that some core ideas were being expressed, allowing for the possibility of further discussion to build understanding.

Student’s Metacognitive Responses to Complex Concept Questions

In a study on student metacognition conducted, a group of 250 students from six different higher education institutions were administered a concept question in statics. These institutions included a community college, a large public land-grant institution, and a university located in a primarily Spanish-speaking country. The students were required to provide their multiple-choice answer, an explanation for their answer, their confidence level, and their assessment of the question's clarity and how it helped them to think deeply about the course material. While most students across all institutions stated that they comprehended the question, less than half of them selected the correct answer. A few students expressed that the question was clear, but they were unsure of how to solve it. Many students pointed out that the conceptual nature of the question prevented them from using equation-based algorithms to arrive at a numerical solution, resulting in an absence of deep thinking. Some students believed that a question should have a numerical solution to be considered "real" engineering, while others thought that such questions helped to evaluate their conceptual understanding.

Machine Learning of Constructed Responses

In order to analyze the large number of student constructed responses to conceptually challenging questions in mechanics, we have initiated a collaborative effort with machine learning researchers. We have completed initial evaluation of large pre-trained generative sequence-to-sequence language models to automate the laborious coding process of student written responses. Adaptation of machine learning algorithms in this context is challenging since each question targets specific concepts which elicit their own unique reasoning processes. This exploratory work seeks to utilize responses collected through the Concept Warehouse to identify viable strategies for adapting machine learning to support instructors and researchers in identifying salient aspects of student thinking and understanding with these conceptually challenging questions. Initial work [15] explored T5-large and GPT3 transformer based Natural Language Processing (NLP) models. We are extending this work to study the use of NLP for linguistic justice. Linguistic justice is defined as equitable access to political or social life through language [16]. Through text summary and topic modeling utilizing machine learning tools like Box-of-Words (BoW) and latent Dirichlet allocation, we identify critical aspects of student narratives of understanding in written responses to mechanics and statics CTs. We seek to use machine learning to identify different ways students talk about a problem. Through this process, we hope to help reduce human bias in the classroom and through technology by giving instructors and researchers diverse narratives that include insight into their students’ histories, identities, and understanding. These can then be used to connect technological knowledge to students’ everyday lives.

ConcepTests in Statics and Dynamics

Since the beginning of our grant, there have been 342 ConcepTests developed for statics and 411 questions created for dynamics. Additionally, a subgroup of the Statics team developed 41 strength of materials questions. Currently, the teams are reviewing current questions for clarity, and plan to continuously improve the current questions. For some of the ConcepTests, students have provided their agreement with the statement "I understood what this question was asking", and "Trying to answer this question made me think deeply about course material", which will also be helpful in analyzing the quality of our ConcepTests.

Development of Adaptive Learning Modules

Leveraging work done for a different grant, we have been working on adaptive learning modules (ALMs) in physics, statics, and dynamics. These will be added to the Instructional Tools tab in the Concept Warehouse. As shown in Figure xxx, the modules start with a short video letting students know why the particular topic is important. We also try to highlight underrepresented engineers and scientists in these videos. Then, we provide content delivery, similar to what might be given in a flipped course. These are also interactive, with a few short concept questions embedded within them. Students are then given a ConcepTest to see how well they understood the content, and then depending on their answers, they will be given a specific Supplemental Instruction. These are short 2-3 minute videos to help correct any misconceptions. This prepares them for an Instructional Tool, which delves into the concept more deeply and often includes a predict-observe-explain cycle. Finally, a summative ConcepTest is given to see how successful the overall ALM was.

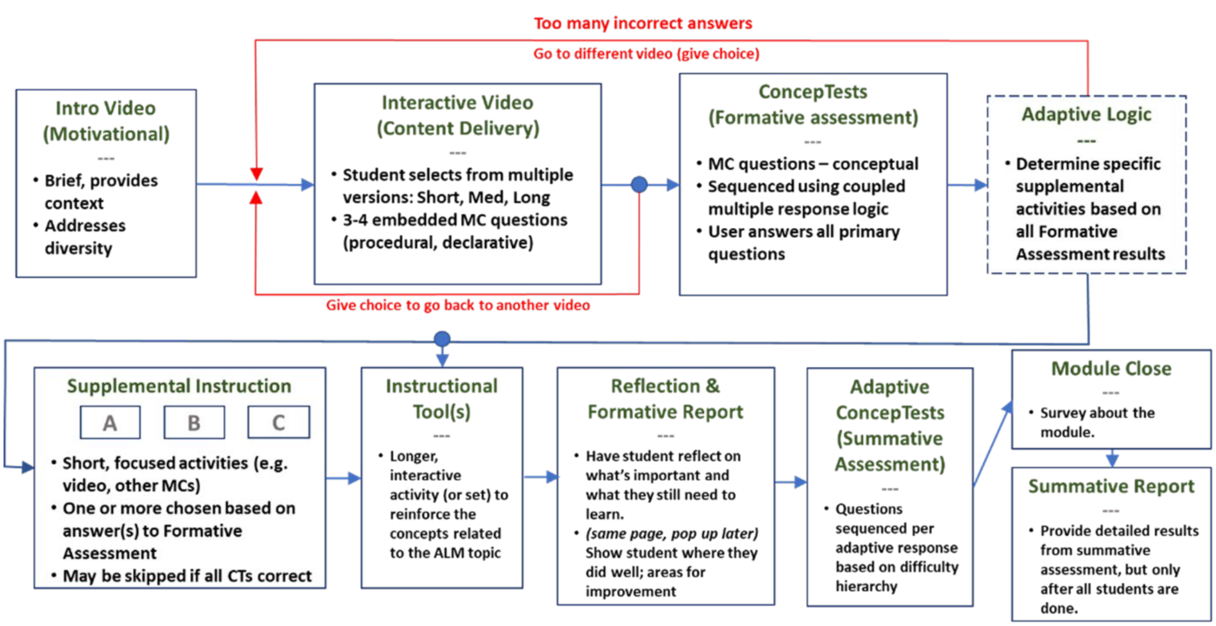

Figure 2. Flow diagram for Adaptive Learning Modules.

Conclusions

As our project reaches its end, we will focus on continued analysis of our instructor interviews, our common questions study and associated survey responses, and finalizing our ConcepTests and Instructional Tools. Our hope is to provide easily adaptable learning materials to mechanics faculty, as well as research into how and why educational innovations propagate in the engineering education community.

Acknowledgments

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

References

[1] National Research Council, Discipline-based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering, S.R. Singer, N.R. Nielsen, and H.A. Schweingruber, Editors. 2012: Washington, DC.

[2] Deslauriers, L., E. Schelew, and C. Wieman, Improved Learning in a Large-Enrollment Physics Class. Science, 2011. 332(6031): p. 862-864.

[3] Freeman, S., S.L. Eddy, M. McDonough, M.K. Smith, N. Okoroafor, H. Jordt, and M.P. Wenderoth, Active learning increases student performance in science, engineering, and mathematics. Proceedings of the National Academy of Sciences of the United States of America, 2014. 111(23): p. 8410-8415.

[5] Hake, R.R., Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. American Journal of Physics, 1998. 66(1): p. 64-74.

[6] Prince, M., Does active learning work? A review of the research. Journal of Engineering Education, 2004. 93(3): p. 223-231.

[7] National Research Council, Expanding Underrepresented Minority Participation: America's Science and Technology Talent at the Crossroads. 2011, National Academies Press: Washington, DC.

[8] Haak, D.C., J. HilleRisLambers, E. Pitre, and S. Freeman, Increased Structure and Active Learning Reduce the Achievement Gap in Introductory Biology. Science, 2011. 332(6034): p. 1213-1216.

[9] Nolen, S. B., and Koretsky, M. D. (2020, June). *WIP: An Ecosystems Metaphor for Propagation* Annual meeting of the American Society for Engineering Education.

[10] Engeström, Y. (2001). Expansive Learning at Work: Toward an activity theoretical reconceptualization. *Journal of Education and Work*, *14*, 133–156.

[11] Rogers, E.M., Diffusion of innovations. 2005, New York: The Free Press.

[12] Cheville, RA., 2019, "Pipeline, Pathway, or Ecosystem – Do Our Metaphors Matter?" Distinguished Lecture, ASEE

[13] Lord, S. M., Ohland, M. W., Layton, R. A., & Camacho, M. M. (2019). Beyond pipeline and pathways: Ecosystem metrics. *Journal of Engineering Education*, *108*(1), 32-56.

[14] Papadopoulos, C., Davishahl, E., Ramming, C., Batista Abreu, J., and Kitch, W. (2022, August), *Work in Progress: Context Matters: A Comparative Study of Results of Common Concept Questions in Statics at Several Diverse Institutions* Paper presented at 2022 ASEE Annual Conference & Exposition, Minneapolis, MN. https://peer.asee.org/41627

[15] Koretsky, M., Auby, H., Shivagunde, N., and Rumshisky, A. (2022, August), *WIP: Using Machine Learning to Automate Coding of Student Explanations to Challenging Mechanics Concept Questions* Paper presented at 2022 ASEE Annual Conference & Exposition, Minneapolis, MN. https://peer.asee.org/40507

[16] Nee, J., Smith, G. M., Sheares, A., & Rustagi, I. (2021). Advancing social justice through linguistic justice: Strategies for building equity fluent NLP technology. In *Equity and Access in Algorithms, Mechanisms, and Optimization (EAAMO '21), October 5–9, 2021, NY, USA.* ACM, New York, NY, USA 9