Understanding Context: Propagation and Effectiveness of the Concept Warehouse in Mechanical Engineering at Five Diverse Institutions and Beyond – Results from Year 1

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. Brian has taught in the Mechanical Engineering Department at Cal Poly, San Luis Obispo since 2006. During the 2011-2012 academic year he participated in a professor exchange, teaching at the Munich University of Applied Sciences. His engineering education interests include collaborating on the Dynamics Concept Inventory, developing model-eliciting activities in mechanical engineering courses, inquiry-based learning in mechanics, and design projects to help promote adapted physical activities. Other professional interests include aviation physiology and biomechanics.

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. He is Chair of the Mathematical Sciences Department, and Principal Investigator of the NSF S-STEM grant at AHC. He serves as Program Chair of the Two-Year College Division of ASEE, and Vice Chair/Community Colleges for the Pacific Southwest Section of ASEE.

Dr. Milo Koretsky, Oregon State University

Milo Koretsky is a Professor of Chemical Engineering at Oregon State University. He received his B.S. and M.S. degrees from UC San Diego and his Ph.D. from UC Berkeley, all in Chemical Engineering. He currently has research activity in areas related engineering education and is interested in integrating technology into effective educational practices and in promoting the use of higher-level cognitive skills in engineering problem solving. His research interests particularly focus on what prevents students from being able to integrate and extend the knowledge developed in specific courses in the core curriculum to the more complex, authentic problems and projects they face as professionals. Dr. Koretsky is one of the founding members of the Center for Lifelong STEM Education Research at OSU.

Dr. Susan Bobbitt Nolen, University of Washington

Susan Bobbitt Nolen is Professor Emerita of Learning Sciences & Human Development at the University of Washington. She earned her PhD in Educational Psychology at Pudue University. Her current research interests focus on student engagement in engineering practices and social interaction during learning activity, and their relationship to engineering identity and opportunity to learn. She also studies organizational learning in higher education systems.

Dr. Christopher Papadopoulos, University of Puerto Rico, Mayaguez Campus

Christopher Papadopoulos is Professor in the Department of Engineering Sciences and Materials at the University of Puerto Rico, Mayagüez Campus (UPRM). He earned B.S. degrees in Civil Engineering and Mathematics from Carnegie Mellon University (1993) and a Ph.D. in Theoretical and Applied Mechanics at Cornell University (1999). Prior to UPRM, Papadopoulos served on the faculty in the Department of Civil engineering and Mechanics at the University of Wisconsin, Milwaukee.

Papadopoulos has diverse research and teaching interests in structural mechanics and bioconstruction (with emphasis in bamboo); appropriate technology; engineering ethics; and mechanics education. He has served as PI of several NSF-sponsored research projects and is co-author of Lying by Approximation: The Truth about Finite Element Analysis. He is active in the Mechanics Division.

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 misconceptions and how to increase the adoption of research-based instructional strategies by college instructors and corporate trainers. He is actively engaged in presenting workshops on instructional design to both academic and corporate instructors.

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 it Nepal. At Cal Poly, he teaches the College of Engineering's interdisciplinary, industry sponsored, senior project class as well as course in mechanics and design. He also conducts research in the areas of creative design, machine design, fluid power control, and engineering education.

Understanding Context: Propagation and Effectiveness of the Concept Warehouse in Mechanical Engineering at Five Diverse Institutions and Beyond – Results from Year 1

Abstract

Several consensus reports cite a critical need to dramatically increase the number and diversity of STEM graduates over the next decade. They conclude that a change to evidence-based instructional practices, such as concept-based active learning, is needed. Concept-based active learning involves the use of activity-based pedagogies whose primary objectives are to make students value deep conceptual understanding (instead of only factual knowledge) and then to facilitate their development of that understanding. Concept-based active learning has been shown to increase academic engagement and student achievement, to significantly improve student retention in academic programs, and to reduce the performance gap of underrepresented students. Fostering students' mastery of fundamental concepts is central to real world problem solving, including several elements of engineering practice. Unfortunately, simply proving that these instructional practices are more effective than traditional methods is not enough to ensure widespread pedagogical change. In fact, the biggest challenge to improving STEM education is not the need to develop more effective instructional practices, but to find ways to get faculty to adopt the evidence-based pedagogies that already exist.

In this project we seek to propagate the Concept Warehouse (CW), a technological innovation designed to foster concept-based active learning, into Mechanical Engineering (ME) and to study student learning with this tool in five diverse institutional settings. The CW is a web-based instructional tool that we developed for Chemical Engineering (ChE) faculty. It houses nearly 3,000 ConcepTests, which are short questions that can rapidly be deployed to engage students in concept-oriented thinking and/or to assess students' conceptual knowledge, along with more extensive concept-based active learning tools. The CW has grown rapidly over the last four years (around 1,200 faculty accounts and 30,000 student users). We propose to expand use of the CW into mechanics and ME and thereby impact 50,000 students during this project. Although the current CW content is discipline-specific, the functions are generic and readily transferable to other engineering disciplines as content is developed.

To date, our Statics and our Dynamics Teams have developed 107 and 105 new ConcepTests, respectively. Question development and categorization has included a framework developed by Beatty et al. (2006), and includes utilizing Content, Process, and Epistemological Goals for each question. Beta testing with students is currently being conducted, and includes questions on both clarity and on educational effectiveness. Our goal is to create 150 ConcepTests in each subject by the time of the conference.

Twelve instructors from the partner schools have been recruited to help us study how context affects the adoption of the Concept Warehouse. These Phase I participants were asked to use the CW to deploy a Concept Inventory, and were then interviewed to examine the instructors'

perceptions of their institutional and learning context and their histories and beliefs. Phase II participants will be asked to deploy ConceptTests within their classrooms, and site visits will be conducted for additional interviews, classroom visits, and student focus groups. These will be used in conjunction with institutional context at five very different schools (a large research public university, a small private university, a 2-year college serving a large number of under-represented students, a large non-PhD granting public university, and a bilingual research university) to determine the conditions that are most supportive of adopting educational innovations.

Introduction

There has been a tremendous amount of work devoted to improving undergraduate STEM education. As a result, we now have extensive research showing that certain instructional practices, such as concept-based active learning, are more effective than traditional lectures for achieving a number of important learning outcomes. Concept-based active learning involves the use of classroom activities specifically designed to promote deep conceptual understanding (rather than only factual knowledge). Understanding fundamental concepts and the ways that concepts relate to each other is one of the key differences between experts and novices, and facilitates both information retrieval and problem solving. In addition to successfully promoting understanding of critical concepts, concept-based active learning methods have a number of additional benefits. Adoption of these methods has been shown to reduce the performance gap of traditionally underrepresented students, reduce failure rates and increase the retention of students in STEM programs (Freeman, 2014: Prince, 2004). While the educational benefits of concept-based active learning have been documented exhaustively, the adoption of these and similar evidence-based practices in undergraduate STEM programs has been slow (Henderson et al., 2015: NRC, 2012; Olson and Riordan, 2012). A key challenge now is to understand how to move educational theory into educational practice by promoting broader and more rapid adoption of these techniques.

The focus of this NSF-supported project is to better understand the diffusion of the Concept Warehouse (Koretsky, 2014), an online tool designed to foster students' conceptual understanding, into the mechanical engineering community. The Concept Warehouse (CW) is a repository of educational tools originally designed for chemical engineering instructors. It includes approximately 3000 multiple choice concept questions that can be used in variety of evidence-based instructional practices such as peer instruction (Crouch and Mazur, 2001) or just-in-time teaching (Novak, 2011). The CW also houses several concept inventories, validated instruments that can be used to assess students' understanding of critical scientific and engineering concepts. Concept inventories have several research applications and have been used extensively to examine the effectiveness of various teaching environments for promoting students' conceptual learning. Finally, the CW houses additional educational tools such as inquiry-based activities and virtual laboratories, all of which have been shown to improve student learning. This wealth of educational materials stored on the CW has resulted in broad adoption by the chemical engineering community, with over 1200 faculty and 30,000 student users to date. We now seek to expand this tool for use by mechanics instructors and to study its adoption by this community.

Project Objectives

The objectives of our IUSE project 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.

The current paper will focus on objectives 1 and 2; to achieve these objectives, we have formed a team from five diverse institutions: a large research public university, a small private university, a two-year college serving a large number of under-represented students, a large non-PhD granting public university, and a bilingual research university.

The Concept Warehouse

The Concept Warehouse (CW) was originally developed for use in the discipline of chemical engineering (Koretsky et al., 2014). The CW Project has two goals: (i) to provide content that decreases instructional barriers to help faculty implement concept-based active learning in class and (ii) to create of discipline-based community focused on concept-based active learning. It has been used extensively in chemical engineering and through the project reported here is also beginning to be used in mechanics related classes. Approximately 1,200 faculty have accounts and 30,000 students have used the tool in the *on line* mode. The CW is available to university faculty for free at http://cw.edudiv.org.

The CW provides three complementary functions: (a) a content repository, (b) an audience response system to deliver content in class or out, and (c) learning analytics that provide learning data to instructors and researchers. It is organized around two user interfaces – an instructor interface to find, author, and deliver content and a student interface for students to interactively respond. A video describing the CW is available at https://youtu.be/Nf5w0kG3asY. The data produced within the technology-based tool has been used for studies of student learning (Koretsky et al., 2016a; Koretsky, et al., 2018; Cao and Koretsky, 2018) and propagation of educational innovations (Friedrichsen, et al., 2017).

There are three content tabs available through the Instructor Interface: ConcepTests, Concept Inventories, and Instructional Tools. Once content is selected, the instructor can deliver it using the CW. Students then use a Student Interface to answer the questions or complete the activities. Some instructors may wish to use the content outside the response system provided within the Concept Warehouse, and may include ConcepTests on quizzes, homeworks, or as quick checks during class without recording student answers. The CW has export functionality to assist instructors in whatever implementation practices they choose.

Figure 1 shows a screenshot of a "ConcepTest" developed during this project as students would view it on their laptop. There is also a mobile student app which is formatted to optimize use on cell phones (Koretsky et al., 2014) ConcepTests are conceptual questions that have learners apply a core concept or set of concepts to reason through to the correct answer. They help students develop mastery of engineering concepts and help faculty and students identify the level of understanding. Figure 1 shows a multiple-choice question where the instructor has chosen the option to request that students provide a written explanation and a confidence rating.

There are also a set of concept inventories (CIs), measurement instruments developed to help instructors and researchers determine the extent of their students' conceptual understanding, available for summative assessment (as opposed to the ConcepTests which are typically used for formative assessment). Most of the CIs available on the CW have been developed and psychometrically tested according to validity and reliability criteria. In this project, we are also using the CW as a resource for development of new CIs, such as the Test of Representational Competence with Vectors (Davishahl et al., 2019).

In addition to ConcepTests and CIs, more extensive Instructional Tools are available to help students develop conceptual understanding. These include reflection activities (Koretsky, et al., 2016a) as well as activities pedagogically tailored to conceptual understanding such as Interactive Virtual Laboratories (Bowen et al., 2014) and Inquiry Based Activities (Prince et al., 2015; Self et al., 2016). Figure 2 shows an example of a simulation developed during this project that forms the basis of part an Inquiry Based Activity in dynamics.

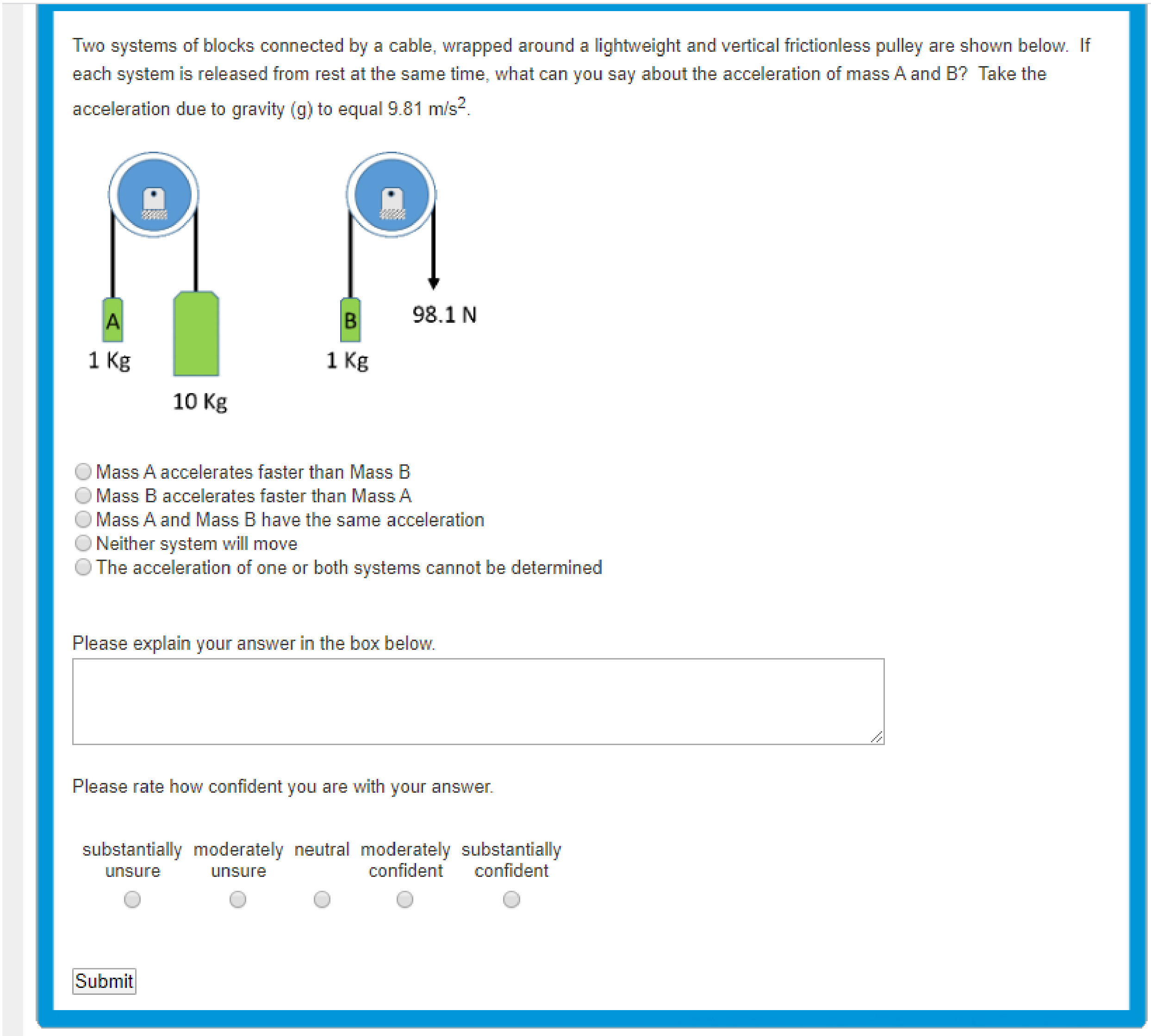

Figure 1. Screenshot of the Student Interface of a ConcepTest for Engineering Dynamics. The instructor has the option to request written explanations and confidence when assigning the question.

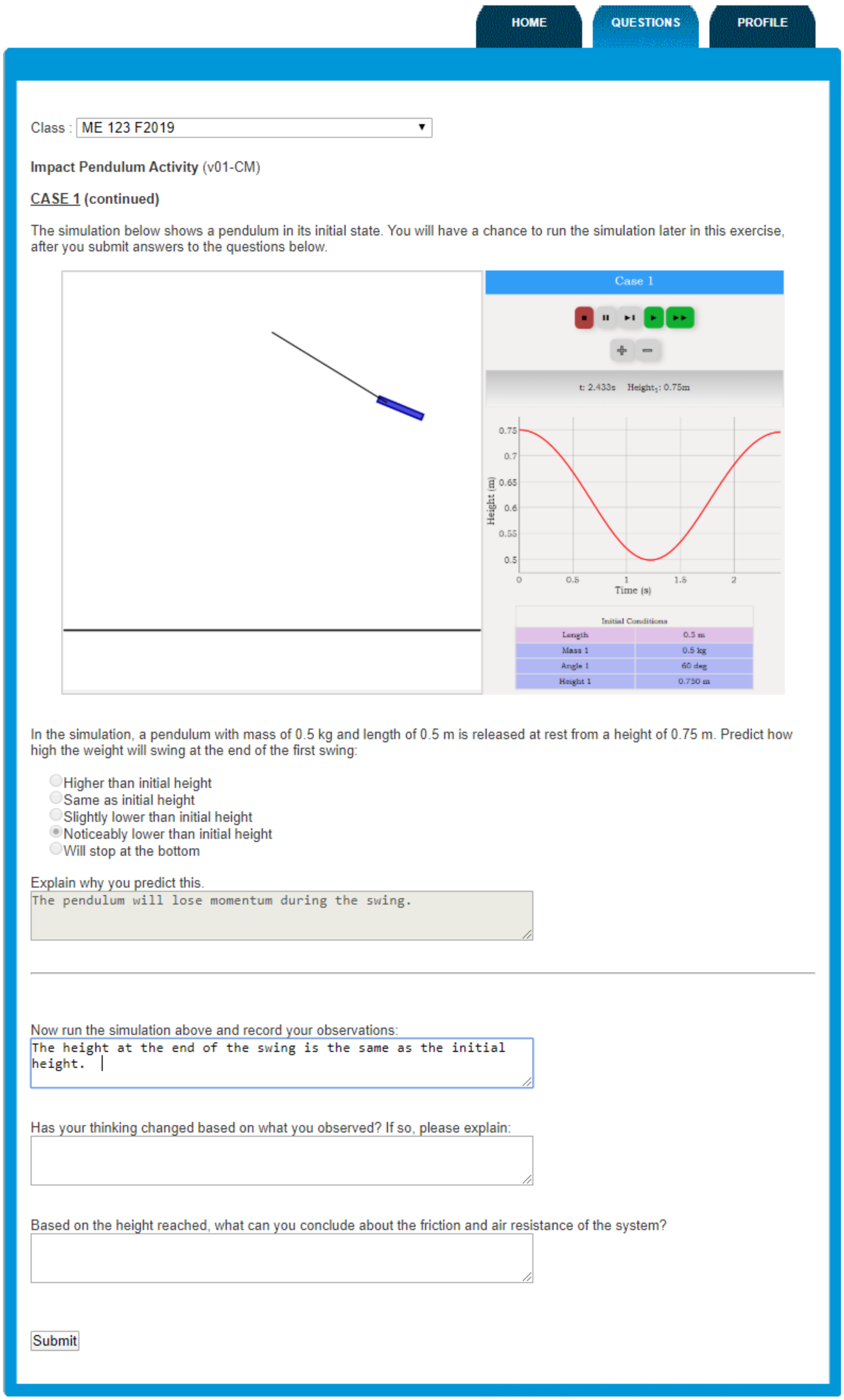

Figure 2. Screenshot of the Student Interface of an Inquiry Based Activity for Engineering Dynamics.

Development of ConcepTests in Statics and Dynamics

Two teams of researchers, one each for Statics and Dynamics, are generating the ConcepTest questions and Instructional Tools for the expansion of the Concept Warehouse. Team leaders recruited faculty from the Mechanics Division of the American Society for Engineering Education. Faculty were selected due to their interest and experience in using evidence-based teaching practices. Each team was given the task to develop approximately 200 ConcepTests and 4-6 Instructional Tools for each of the two mechanics courses.

In January of 2019 an in-person kickoff meeting was held at the campus of the lead institution to discuss the Concept Warehouse, development of ConcepTests, and for team building. During this interactive workshop, our Statics and Dynamics team members logged on to the Concept Warehouse and answered ConcepTests as if they were students, brainstormed topic lists for each of their courses and began developing their own ConcepTests. After the kickoff meeting, each team continued to meet virtually approximately once per month to work on developing ConcepTests and discussion question goals (see below). To date, each team has developed approximately 100 concept tests on a variety of topics and subtopics within each discipline. The process can be summarized as follows:

- Each team agreed on a list of topics and subtopics that are used to give a primary classification for each ConcepTest. In general, these topics align with the usual accepted topics for Statics and Dynamics, which often correspond with chapter headings in the standard texts.
- Because the teams were selected on the basis of experience in mechanics education, including use of concept-based instruction, each team member is bringing ideas and examples of what constitutes a "good" concept question for Statics and/or Dynamics.
- To maximize impact of the ConcepTests, team members were introduced to the idea of setting goals for each problem. Following Beatty et al. (2006), each ConcepTest is assigned a Content (C), Process (P), and Epistemological (E) goal. Development and refinement of the goal statements is still underway, and to date, many ConcepTests do not yet have goal statements assigned. Work on the categorization of Process and Epistemological goals is continuing.
- ConcepTests can further assess conceptual knowledge by embedding similar concepts in problems with different 'surface features', or by embedding distinct concepts in problems with similar surface features.
- Similar to items on concept inventories, ConcepTests are typically qualitative in nature, focusing on understanding ideas and requiring only minimal calculations.
- Unlike items on concept inventories, ConcepTests may or may not be designed to target an established misconception. Moreover, ConcepTests may be designed to have ambiguities or non-unique answers to promote discussion and debate among students in classroom situations.

We have spent considerable time discussing the goals mentioned above. Content goals establish the knowledge area addressed by the problem, and typically align with the chosen Topic, e.g., Particle Equilibrium. Process goals establish the procedures and skills that the problem is designed to help the student master (e.g., identifying an axis about which to sum moments). Epistemological goals have two senses: one is to establish a 'big idea' about 'what engineering is about' (e.g., the realization that a problem has multiple solution paths); a second is to establish a pedagogical goal (e.g., to elicit a debate among students regarding what is 'correct').

Some examples of ConcepTests follow:

(a) Multiple Correct Responses.

Figure 3 shows an example of a ConcepTest in which the answer depends greatly on assumptions made by the student. This type of problem can be posed either ahead of class or during a class meeting with the primary purpose of eliciting discussion among students since the answer to the problem depends on the assumptions made. These types of engaging pedagogies require high level thinking and can lead to deeper understanding of modeling principles. They also promote the understanding that in engineering there is not always a single correct answer.

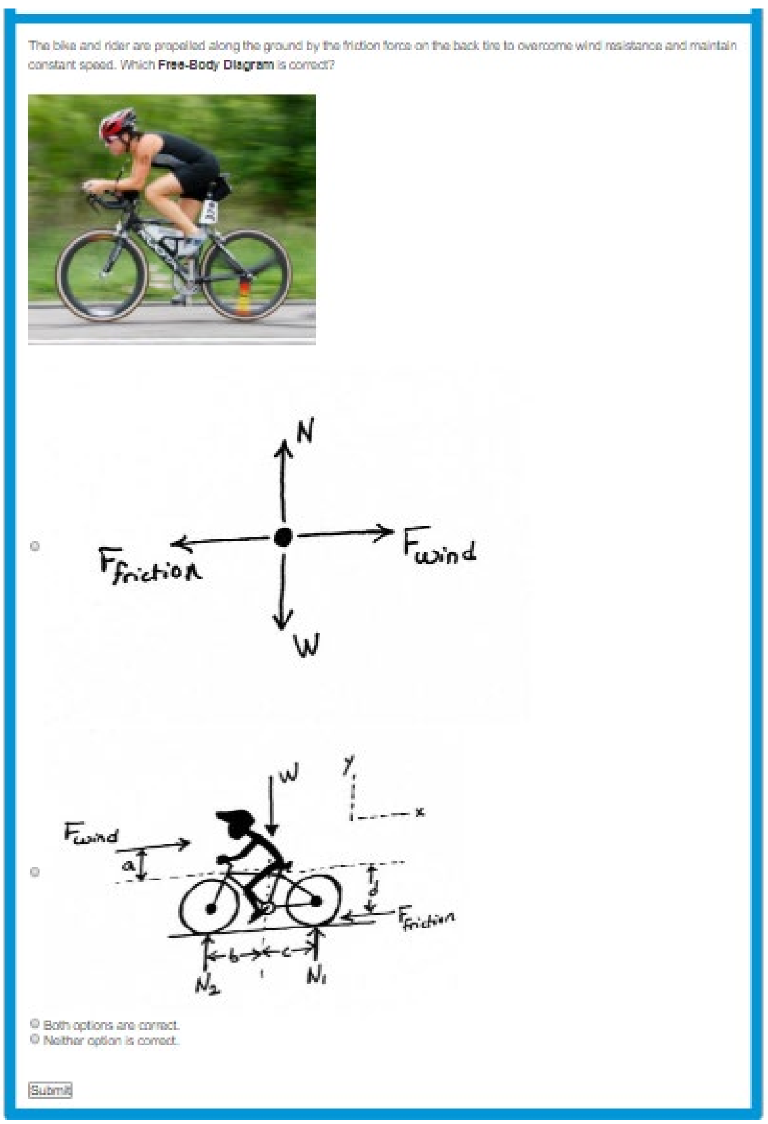

Figure 3. Example of problem intended to promote discussion by students

(b) Identifying Appropriate approaches

Often in mechanics, students have difficulty identifying appropriate approaches to solve problems. Figure 4 shows an example of a ConcepTest which is difficult to answer correctly if students do not have a firm understanding of the different equilibrium equations involved in statics. In this specific case, a student who does not realize that the sum of moments about any point must equal zero for equilibrium might answer that the Free Body Diagram (FBD) is possible.

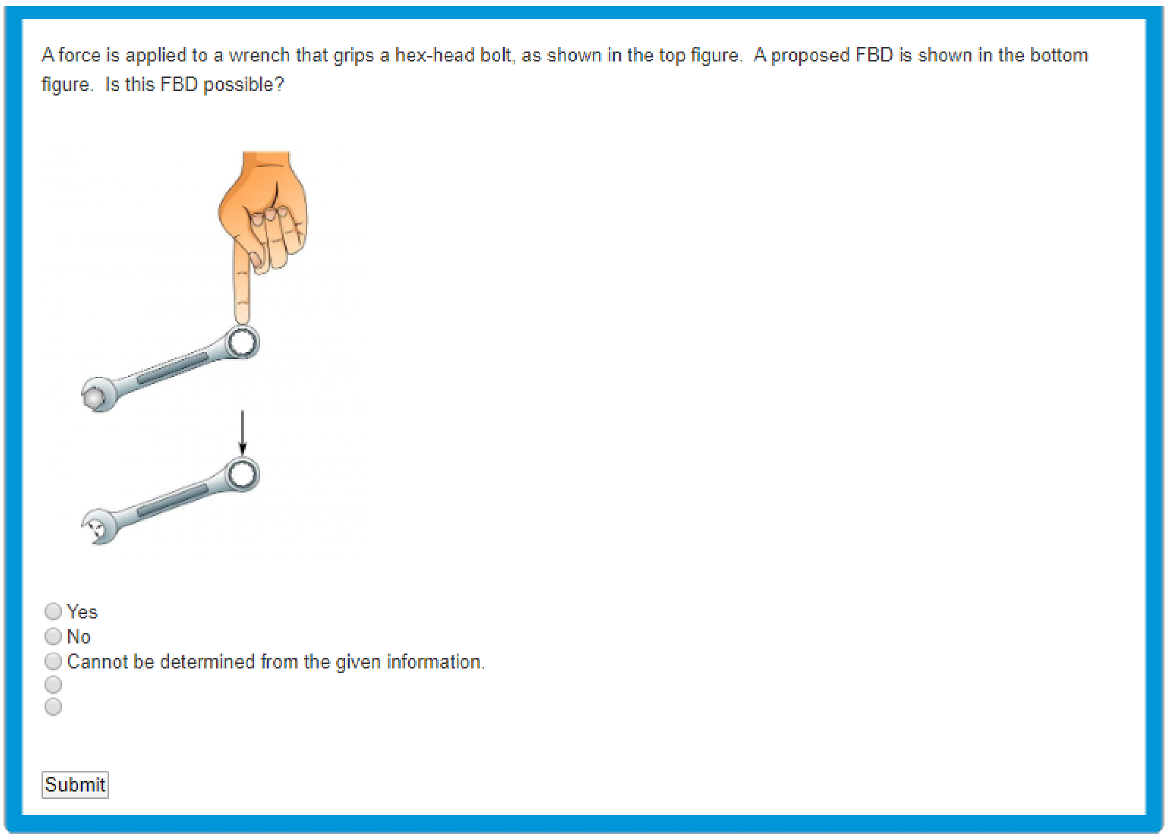

Figure 4. A ConcepTest that requires students to reflect on their approach

(c) ConcepTests that highlight new ideas in Mechanics

As students learn mechanics they are presented with new ideas and concepts that may be difficulty to learn and master. Figure 5 contains a problem that tests student understanding of a new concept in Statics, that of a two-force member. Identifying such members in a structure can greatly facilitate equilibrium analysis. Using this problem in class, an instructor can quickly ascertain how many students are understanding this idea using the CW or a different a classroom response system.

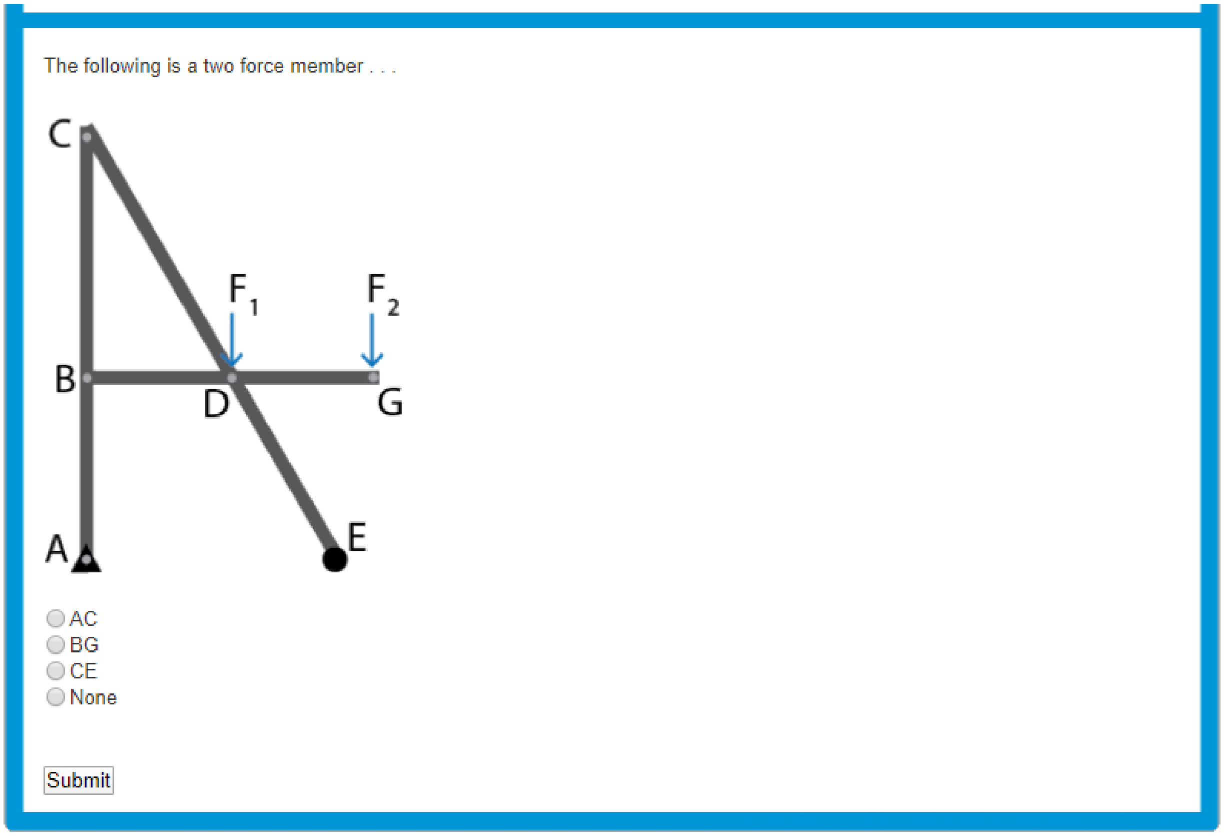

Figure 5. Problem that tests understanding of a new Mechanics Concept

(d) Problems that highlight common misconceptions

Perhaps one of the most powerful uses of ConcepTests is to require students to face and reconcile common misconceptions. Figure 6 is an example of a ConcepTest where students who have misconceptions of acceleration will often answer incorrectly. When discussing their answers with classmates, students often correct their own misconceptions. At this point, having a series of isomorphs may then be used to cement their new understanding of mechanics by asking questions about the acceleration vectors at point B, C and D.

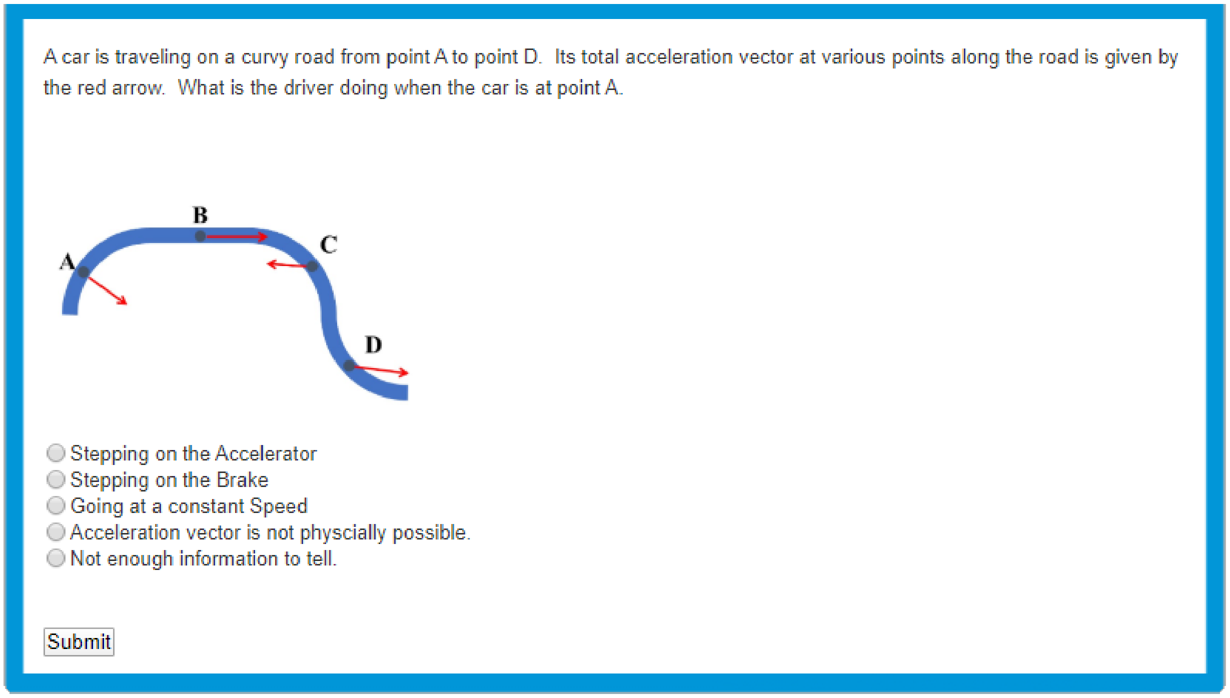

Figure 6: ConcepTest of common misconceptions.

Context Research

We ground our research in a situative theory of learning and motivation (Greeno, 2006; Greeno & Engeström, 2014; Nolen, Horn, & Ward, 2015). As shown in Figure 7, instructors' decision-making around whether and how to use CW in their classes is not solely dependent upon their knowledge of innovation efficacy (i.e., research evidence). Instead a variety of contextual factors may influence instructor decisions, including affordances of the innovation; institutional context, including values, student populations, class size, curricular structures, and formal and informal supports for teaching; and the learning context (e.g., class size, room configuration, length of term, technology environment). Different factors may be salient in different kinds of institutions and for instructors in different positions (e.g., tenured vs. nontenured). As implementation progresses, feedback from students, student learning data, and additional professional development are likely to play a role in ongoing use and adoption of the CW.

As reported elsewhere (Nolen and Koretsky, 2020) we have collected institutional data for our five partner institutions: a public comprehensive master's only institution, a public research institution, a public Latinx-serving institution, a small private institution, and a two-year college. These data include items such as engineering undergraduate enrollment, selectivity, class sizes, graduation rates, and faculty-student ratio. These data will help inform our investigation on how institutional context affects use of the CW.

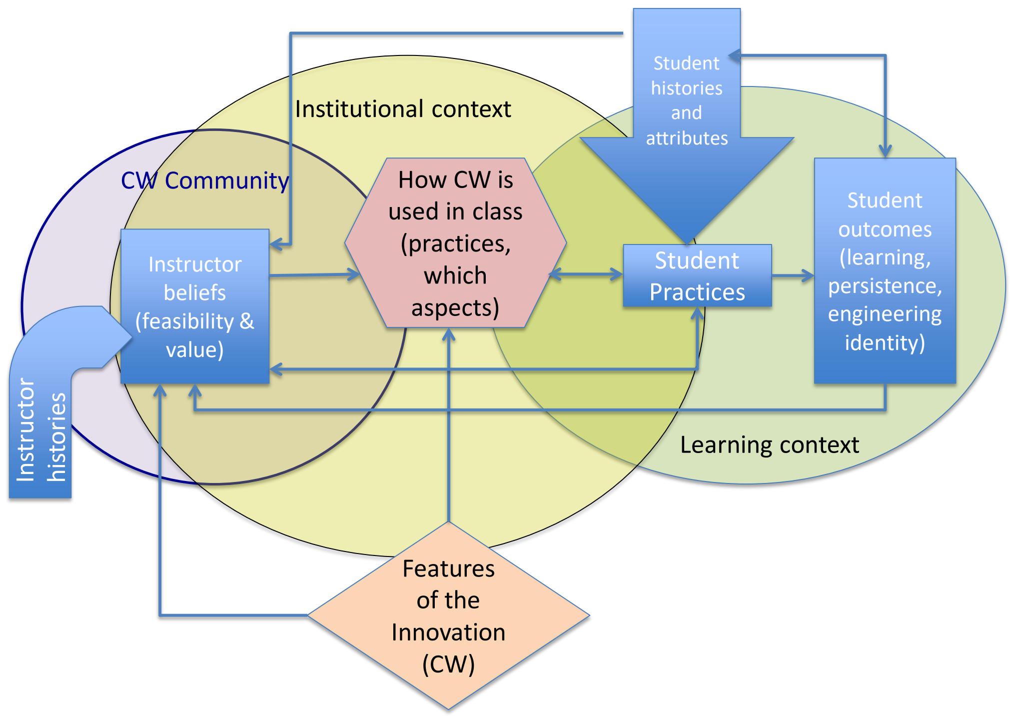

Figure 7. Model of the context of decision-making regarding the use of CW.

To study the role of these factors in the propagation of CW in Mechanical Engineering, we invited participation from instructors in five quite different institutions (e.g., public and private, 2-year and degree-granting, selective and nonselective enrollment) with different histories, missions, and student demographics. In the first wave of data, we have interviewed 12 instructors in Mechanical Engineering (including 5 females, 5 persons of color, 5 assistant professors, 4 tenured professors, two teaching faculty and one graduate student) who implemented pre- and post-test Concept Inventories. We asked about their institutional contexts, their views of CW and its future possible use in their courses, their current practices, and their student populations. Preliminary analyses revealed a number of themes across contexts and individuals that support the proposed model. Analysis is ongoing; we will also collect observational and interview data from instructors and students as additional aspects of the innovation are implemented this year, in addition to student learning data collected through the CW.

After the summer of 2020, we will have a critical number of questions for each topic in both statics and dynamics. This will facilitate having the Level 2 and Level 3 research participants as described above. We will be able to study how different instructors choose to use the Concept Warehouse, and the contexts that support their usage. Additionally, we will begin our Action Research Fellows program.

The purpose of this program is to support instructors to integrate use of the CW in their courses through action research (Koretsky, 2016b), that is, asking and answering questions about practice and collecting evidence in their own classroom to inform practice. We will adapt a similar program administered in another project (ESTEME@OSU Action Research Fellows). This program uses a cohort model and 11 Fellowships will be awarded two different years, starting

Fall 2020. At least two fellows each cohort will be recruited from 2-year colleges, and we will also target recruitment of faculty from underrepresented populations. Fellows will be supported in three ways: 1) participation in a community of instructors with similar goals to apply what research tells us about learning in the classroom; 2) partnership with a member of the project research team with expertise in education research and classroom practice to support research design, data collection and analysis; and 3) $2,000 financial support. The entire group will meet via video conferencing at least twice per term, and be encouraged to disseminate their results to the community at the ASEE or ASME Annual Meetings.

Conclusions

Our diverse, multi-institutional team is studying how context affects the uptake and use of an online educational tool, the Concept Warehouse. To date, our team has developed over 100 statics and dynamics concept questions and is in the process of creating instructional tools for the use in these mechanics courses. We have begun to disseminate our work through workshops (e.g., NETI, ASEE section meetings, and the upcoming ASEE National meeting), and will begin recruiting participants in our Action Research Fellows program. To date, we have interviewed twelve different instructors as part of our initial Level 1 research, where participants are simply asked to peruse the CW and give their students a concept inventory assignment. Level 2 recruitment has begun, where instructors are asked to more fully implement the use of the CW in their course.

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

Beatty, I., Gerace, Leonard, W., and Dufresne, R.J. (2006) “Designing effective questions for classroom response system teaching,” American journal of physics, vol. 74, no. 1 pp. 31-39.

Bowen, A. S., & Reid, D. R., & Koretsky, M. (2014), Development of Interactive Virtual Laboratories to Help Students Learn Difficult Concepts in Thermodynamics, Proceedings 2014 ASEE Annual Conference, Indianapolis. https://peer.asee.org/20317.

Cao, Y. and. Koretsky, MD. (2018) Shared resources: Engineering students' emerging group understanding of thermodynamic work. *Journal of Engineering Education* 107(4): 656-689.

Crouch, C. H., & Mazur, E. (2001). Peer instruction: Ten years of experience and results. American journal of physics, 69(9), 970-977.

Davishahl, E., & Haskell, T. R., & Davishahl, J., & Singleton, L., & Goodridge, W. H. (2019, June), Do They Understand Your Language? Assess Their Fluency with Vector

Representations Paper presented at 2019 ASEE Annual Conference & Exposition , Tampa, Florida. https://peer.asee.org/32675

ESTEME@OSU Action Research Fellows, 2016-2017. [accessed 2020 Mar 15]; Available from: http://stem.oregonstate.edu/esteme/action-research-fellows

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

Friedrichsen, D. M., Smith, C., & Koretsky, M. D. (2017). Propagation from the start: the spread of a concept-based instructional tool. Educational Technology Research and Development, 65(1), 177-202.

Greeno, J. G. (2006). Learning in Activity. In R. K. Sawyer (Ed.), *The Cambridge handbook of: The learning sciences.* (pp. 79-96). New York, NY US: Cambridge University Press.

Greeno, J. G., & Engeström, Y. (2014). Learning in activity. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences., 2nd ed.* (pp. 128-147). New York, NY: Cambridge University Press.

Henderson, C., Cole, R., Froyd, J., Friedrichsen, D. G., Khatri, R., & Stanford, C. (2015). Designing educational innovations for sustained adoption: A how-to guide for education developers who want to increase the impact of their work. Increase the Impact.

Keeler, J. M., & Koretsky, M. D. (2016). Surprises in the Muddy Waters of High-Enrollment Courses. Journal of Chemical Education, 93(11), 1830-1838.

Koretsky, M., Keeler, J., Ivanovitch, J. and Cao, Y. (2018) The role of pedagogical tools in active learning: a case for sense-making. *International Journal of STEM Education*. 5(1).

Koretsky, M.D., Brooks, B.J., and A.Z. Higgins (2016a). Written justifications to multiple-choice concept questions during active learning in class. *International Journal of Science Education*, 38(11), 1747-1765.

Koretsky, M., Bowma-Gearhart, J., Brown, S., Dick, S.T., Brubaker-Cole, S, Sitomer, A. Quardokus Fisher, K., Smith, C., Ivanovitch, J.D., Risien, J., Kayes, L.J. and D. Quick (2016b). Enhancing STEM Education at Oregon State University - Year 2. in *American Society for Engineering Education Annual Conference & Exposition*. New Orleans.

Koretsky, M.D., J.L. Falconer, B.J. Brooks, D.M. Gilbuena, D.L. Silverstein, C. Smith, and M. Miletic (2014) The AIChE Concept Warehouse: A Web-Based Tool to Promote Concept-Based Instruction. *Advances in Engineering Education*, 4(1).

National Research Council. (2012). Discipline-based education research: Understanding and improving learning in undergraduate science and engineering. National Academies Press.

Nolen, S. B., Horn, I. S., & Ward, C. J. (2015). Situating motivation. *Educational Psychologist, 50*(3), 234-247. doi:10.1080/00461520.2015.1075399.

Nolen, S. B. and Koretsky, M.D. (2020) WIP: An Ecosystems Metaphor for Propagation and Student Learning. *American Society for Engineering Education Annual Conference & Exposition*.

Novak, G. M. (2011). Just-in-time teaching. New directions for teaching and learning, 2011(128), 63-73.

Olson, S., & Riordan, D. G. (2012). Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics. Report to the President. Executive Office of the President.

Prince, M., M. Vigeant, and K. Nottis (2015) The Impact of Inquiry-Based Learning Activities on the Retention and Transfer of Conceptual Learning in Heat Transfer. *Chemical Engineering Education*, 49(1).

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

2016-2017 ESTEME@OSU Action Research Fellows. [cited 2017 Jan 4]; Available from: http://stem.oregonstate.edu/esteme/action-research-fellows

Self, B., J. Widmann, and G. Adam (2016). Increasing Conceptual Understanding and Student Motivation in Undergraduate Dynamics Using Inquiry-Based Learning Activities. in *American Society for Engineering Education Annual Conference and Exposition*. New Orleans.

White, R. M., & Brooks, B. J., & Koretsky, M. (2015, June), Development and Usability Testing of a Student Mobile Application for the AIChE Concept Warehouse Paper presented at 2015 ASEE Annual Conference & Exposition, Seattle, Washington. 10.18260/p.23854