2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering
Education for 130 Years
ASEE
Paper ID #39980

Board 76: Work-in-Progress: Threshold Concepts in Capstone Desgin

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Work-In-Progress: Written Reflection for Threshold Concepts in Capstone Design

Abstract

One approach to look at student learning is to identify “threshold concepts.” These are concepts that, once grasped, allow students to engage with the material in a fundamentally different way. First described by Meyer and Land [1], these concepts are transformative, irreversible, integrative, and troublesome. The process of mastering a threshold concept (TC) means traversing a liminal space during which the student is changed. Looking inward at our own capstone program, we identified three candidate TCs: (1) Complex engineering problems are best solved by teams working together. (2) A team can learn a lot from a prototype, even (especially?) when it doesn’t work. (3) The goal isn’t to find the right answer, but to learn a process by which a satisfactory answer can be found. Using data from periodic nationwide capstone surveys, combined with observation and review of capstone design literature, we then explore whether these concepts may be typical of all Capstone Design courses. During Fall 2022, students in a large multidisciplinary engineering capstone program were asked to complete periodic written reflections in support of proposed concepts 1 and 2, in order to explore whether written reflection may support student progress through these thresholds. Four times over the semester, students reflected on their individual project work as part of a team, and two to three times over the semester, teams reflected on what they learned from early-stage prototypes. This paper presents our rationale for identifying the three TCs, shares preliminary observations of student growth demonstrated in reflection assignments, and proposes next steps for facilitating student progress through these thresholds.

Introduction

A threshold concept (TC) enables students to engage with the course material at a deeper level. It is often characterized as “troublesome knowledge” [1] , and is not a simple fact or equation to memorize, but must be internalized. They also explain that a TC “represents a transformed way of understanding, or interpreting, or viewing something without which the learner cannot progress.” According to Cousin [2], the transformation that students experience involves “an ontological as well as conceptual shift […] becoming a part of who we are, how we see, and how we feel.” Meyer and Land identify several key characteristics of TCs to distinguish them from core concepts, which are important required knowledge, but do not represent a passage to greater understanding.

- Transformative: The way the student thinks about the subject, and often their identity as a practitioner, are changed.

- Irreversible: The student cannot un-learn the concept or return to an old way of thinking without significant effort.
- Integrative: The concept reveals the interrelatedness of other concepts.
- Troublesome: The concept is counterintuitive, requires integration of seemingly unrelated pieces of information, or is completely foreign to the student.

Since most universities' capstone design courses are designed to satisfy the "major design experience" portion of ABET's Curriculum outcome, they must, by definition, be "based on knowledge and skills acquired in earlier course work" [3]. Moreover, the learning in capstone design is not only related to discipline-based skills and knowledge, but something greater: the application and integration of that knowledge into the solution of a new problem, sometimes as part of a team. This represents the sort of experience students will have as engineers once they graduate and go on to work. Indeed, capstone design projects have evolved to prepare students for "design and practice" as a supplement to core curriculum focused on "theory and research" [4], and capstone is some students' first significant experience with open ended, experiential, team-based coursework. In the technical portions of the project, this is a manageable situation for most students. After all, they have been taking courses where they have to solve technically challenging homework and test problems, or complete intricate lab exercises. In the aspects of the project that surround and provide context for the technical portion, however, students tend to be less experienced. This includes challenges like identifying the correct problem to solve, working with teammates, defining the tasks required to complete the work and allotting time, determining when their solution is good enough to satisfy project requirements, budgeting, and balancing time/cost/quality tradeoffs. Paretti et al. [5] found that topics like independent learning, time management, interactions with colleagues and supervisors/clients, and teamwork were the areas most frequently cited as (1) being challenging for new engineers and (2) areas where their capstone experiences transferred over to help them navigate the challenges. In essence, capstone design is where individuals begin to undergo the transformation from students to engineers [6]. Capstone design represents the liminal space between being a student and being an engineer. This shift is significant, and observation seems to indicate that it is a gradual one with key steps along the way, so capstone design can itself be a threshold course in the engineering curriculum.

The idea of identifying TCs in engineering courses has been explored in the past [7]–[12]. In particular, Reeping et al. [7] conducted a thorough study of the use of TCs in Electrical and Computer Engineering (ECE), as part of a department-wide effort to redesign curriculum [10]. Reeping et al. differentiated between fundamental ideas and TCs, for example, contrasting a memorization of Ohm's Law with an understanding of why the relationship between voltage, current, and resistance is true. Of note in the work related to ECE curricula is that non-technical skills or professional skills received little attention in discussions of potential TCs. Reeping et al. noted that there has been work done to explore professional skills in contexts similar to TCs, but observed that the faculty discussion around big ideas in the context of curriculum redesign quickly shifted to focus on technical topics [10]. Another department-wide effort [8] yielded promising leads at identifying TCs using minute papers, but observed that while these were useful in identifying troublesome knowledge this alone is not enough to classify a topic as a TC. Similarly, at a course level, other authors have proposed TCs [9], [12], [13], but most of these, with the exception of problem-solving strategy outlined in [13], tend to identify difficult topics or skills rather than true TCs.

Looking Inward: Capstone Threshold Concepts at Rochester Institute of Technology (RIT)

This work began with an inward look at the concepts that our instructional staff believe are key to helping students progress through our capstone design course sequence. As part of our continuous improvement process, our staff gathers each semester to debrief on what students struggle with and what might help them progress. This meeting coincided with a campus-wide teaching circle led by the first-year writing program, which also has stakes in writing across the curriculum. The teaching circle focused on TCs in Writing Intensive general education classes, and much of our rationale for this work-in-progress paper came from that teaching circle's concept – to support faculty in identifying their courses' disciplinary influences, naming those disciplines' TCs, and redesigning the writing tasks in their courses to reflect those concepts, all in order to invite students into more explicit and better understandings of their academic and professional communities.

A regular part of every continuous improvement discussion is the fact that managing team projects challenging, and that teamwork troubles can get in the way of completing a design project. Faculty advisors regularly observe students unwilling to call out sub-par behavior by teammates in an effort to keep the peace, leading to workload imbalances and resentment. It is critical for each team member to understand the role they play on a project team, and how their work fits in with the work of the team as a whole. This individual accountability can be challenging on a project where some tasks require full-team participation, and others require only one or two team members.

Agile project management prioritizes rapid generation of working "prototypes" in order to gauge feasibility and provide a foundation for continued development. At our university, this way of thinking is a shift from the traditional waterfall approach to design, where prototyping does not happen until the design is fully detailed and vetted in simulation. For a capstone design course, where the projects are typically new every year, little is known about the work to be done; even the instructor is likely to lack the experience to forecast out one to two semesters into the future with any degree of certainty. In these scenarios, there is significant value in prototyping early in order to learn. While the concept of "prototyping to learn" is not strictly in keeping with the Agile principle to deliver working software, researchers have demonstrated that it can be adapted for hardware-based design projects [14], [15]. However, with what we believe is a waterfall-based mindset, combined with a grade-driven desire to get quickly to the "right" answer, students seem hesitant to build a prototype that they know is not likely to work. At our university, many teams put off building anything until their design is complete, despite encouragement from instructors to prototype early. This mindset holds teams back from learning critical pieces of information early enough to address issues.

Finally, an issue that we have struggled with since the inception of our capstone program is the competing interests between students who just want to work on a design and faculty who are trying to teach students a structured design process in the context of design projects. Feedback from course evaluations regularly points to what students view as burdensome overhead getting in the way of doing "real" project work, while faculty must work to hold students accountable for explaining the rationale behind their design decisions.

If we look at our own program and the concepts we routinely see students struggle with, we see a trove of complex and context-dependent problems that defy formal skills-based instruction. We propose to articulate the troublesome aspects of these themes and our own observations of our capstone program at our institution as three TCs for capstone design:

1. Complex engineering problems are best solved by teams working together.
2. You can learn a lot from a prototype, even (especially?) when it doesn't work.
3. The goal of capstone isn't to find the "right answer," but to learn the processes by which a satisfactory answer can be found.

These are not course learning outcomes: these are concepts that represent shifts in mindset. If they are indeed TCs, they will be transformative, irreversible, integrative, and troublesome.

1. <u>Complex engineering problems are best solved by teams working together</u>: The *transformative* element of teamwork is a shift in mindset to think about yourself as part of a team, rather than an individual working side by side with other individuals. This concept in and of itself is *integrative*. Students who grasp it are able to consider the skills, needs, strengths, and weaknesses of the team and see how they fit together to do more. This is also *troublesome*, particularly for students who have been trained to view schoolwork as something you do yourself, and grades as something earned by a person. Worse, students who have had poor team experiences might view teams as being detrimental to their education. On the other hand, once a person truly recognizes the value of teamwork, they are likely to prefer working with a team on a complex problem, making this *irreversible*.

2. <u>You can learn a lot from a prototype, even (especially?) when it doesn't work</u>: A student is *transformed* when he or she stops thinking about a prototype as "the final product," and starts thinking about it as "an opportunity to learn." The act of prototyping forces students to

reconcile differences between theory and reality. They also need to consider both design and testing, since prototyping to learn requires them to think strategically about which feasibility questions in their project can best be answered with a prototype versus analysis. A student who grasps this concept is also actively puzzling through multiple right answers (TC 3), which makes this *integrative.* Students sometimes find this *troublesome*, however, because typical engineering curricula and assessment models reward students when they get things "right," and learning from a prototype means approaching it with a sense of curiosity and acceptance of wrongness. Once students cross this threshold, they have experienced firsthand the excitement of making concrete progress, so it appears to be *irreversible*.

3. <u>The goal of capstone isn't to find the "right answer," but to learn a process by which a satisfactory answer can be found</u>: What is *transformative* about the design process is not the application of a series of process steps, but the idea that the process enables you to identify a local optimum among a series of acceptable solutions. There is a mindset shift from "I need to get the right answer" to "I'm looking for a good solution." The individual steps of a design process are not necessarily difficult, but the act of *integrating* the steps (resolving conflicting viewpoints, anticipating later impacts of early decisions, weighing equally viable options, etc.) cuts across discrete skills and enacts the need to be flexible and manage "the big picture." Similar to the prototyping concept, this is *troublesome* because students are often trained to think they will do well if they get the "right" answer–which makes this concept *integrative* as well in how it overlaps with TC 2.

Looking Outward: Are Capstone Threshold Concepts Applicable Elsewhere?

After looking inward at our own program, we looked outward to ask whether these TCs are applicable to *any* capstone program. The value of such a determination is that it could help capstone instructors focus their efforts toward guiding students through concepts that will enable them to engage with the course material at a deeper level.

The results of a decennial survey of capstone programs nationwide provides some insight into the topics that are addressed in capstone courses [16]. With 522 survey respondents from 464 different departments at 256 institutions in the most recent (2015) survey, these results represent a broad cross-section of capstone programs in US engineering institutions. Past surveys in 2005 and 1994 received 444 and 360 responses, respectively, and represent a similarly broad range of capstone courses. In 2015, respondents had the option to enter topics covered specifically in lecture in addition to topics covered by the team project or by individual assignments.

Common themes emerged, and are summarized in Table 1. Since these topics are most frequently covered, capstone instructors must generally feel that they are important. The topics themselves are not TCs, but they are a promising set of topics within which to look for TCs. Communication, elements of design process (planning/scheduling, concept generation, and decision making), and teamwork emerged as common themes. Communication is a topic that many students struggle with, and good communication enables success in nearly all other aspects of capstone design. It was identified by Capstone-to-Work researchers ([5], [6]) as a topic that students struggle with at work and one where they rely on their capstone experience to help them. We did not identify a TC directly related to communication, but this is an area for future exploration. Teamwork is a commonly taught topic in capstone courses, and was identified in [5] and [6] as a topic that proved to be challenging during the first three months of professional employment, and one which was supported by capstone. This supports our TC 1.

Table 1: Common topics in capstone courses, from three decennial capstone surveys [16]. (*Indicates response was in the top five for both lecture topics and overall course content)

Appears in each set of top 5 responses	**Appears in top 5 responses for ⅔ surveys**
Written/oral communication*	Teamwork
Project planning/scheduling*	Concept generation/selection
Engineering ethics (lecture topic only)	Decision making

In addition to instructional goals, many capstone programs (including the program that is the subject of this paper) involve the construction of a working prototype for a client. Prototyping is less common in Chemical and Civil Engineering, where working prototypes are impractically large for students to build, but most other programs require some type of build. Increasingly, capstone programs are exploring approaches to product development and design using an Agile methodology (e.g., [17]–[19]), which drives teams to prototype early, delivering functionality at a steady pace through the project. Underlying this is a desire to move students from paper design to prototype quickly, in order to understand where assumptions may be flawed and unknown elements may stand in the way of project progress: our TC 2. A traditional waterfall approach works well for well-understood design problems, but the typical capstone model of new clients and projects each year means projects are not always well-understood.

While many capstone programs require the construction of a working prototype, capstone courses generally also teach design process, making our connection to proposed TC 3. The capstone survey [16] reveals how programs balance concerns for product and process in their capstone projects. “Product” generally represents the actual design outcome, whether that is a detailed design concept or a built prototype. “Process” generally represents how effectively or appropriately students apply a structured design process. An instructor can place importance on the product outcome without concern for how that outcome was achieved, encouraging students to develop an ad-hoc approach to design that is difficult to generalize to future engineering design work. Conversely, an instructor focusing on process with less explicit concern for the actual product outcome is encouraging students to internalize a generalized approach to design even if it means extra time is spent practicing the process. In theory, a good product results from following a sound process, but sometimes an acceptable product can be achieved without following a structured design process, particularly if the problem has a fairly obvious solution that will give satisfactory results. Of 208 individuals responding to this question, approximately ¾ responded that they weight product and process equally or near-equally. From this we can conclude that the design process is an important component of most capstone courses, but building some type of working prototype is also important in some conditions. Since concept generation/selection and decision making are part of a structured design process, we consider those to be part of the same category. Thus, we conclude that our proposed TC 3 is likely to apply to other capstone programs.

Using reflection to invite students into thresholds

One approach to helping students internalize these TCs may be reflective writing assignments, a practice that was proposed by Venters, et al. [12], [20] and implied in Townsend & Urbanic's Plan-Do-Check-Act approach to teaching project management [11]. In a collaboration between the University Writing Program and the College of Engineering capstone design program at RIT, we are exploring the use of periodic "write to learn" reflection assignments targeted at these TCs. Two recurring reflection activities related to TCs were implemented beginning in Fall 2022:

- *Individual* reflection on individual project scheduling, linked to team performance: What did you plan to do during the past 4-week phase, what did you actually do, and what can you learn from the difference? (4 per semester)
- *Team* reflection on what they learned from their early prototyping activities: What were you hoping to learn from your prototype, what were the limitations of the prototype, what did you learn, and what decisions did you make as a result? (3 per semester)

Methodology

In a class of about 365 students on 70 teams, there are nominally 1460 individual one-paragraph reflections on phase plans, and 210 team-level one-paragraph prototyping reflections. For this work in progress, a selection of submissions was preliminarily inspected to look for evidence that the students were engaging with and progressing through the TCs we identified.

Preliminary Observations, by Concept

<u>Complex engineering problems are best solved by teams working together</u>: In light of the large amount of raw data available, written reflection samples were pulled from 25 students on five teams and reviewed in detail. Of the 25 students sampled, 5 students either failed to submit the reflection or copied and pasted the same block of text into each submission. Most took the

assignment seriously, though, and some showed clear evidence of growth. Extrapolating to the full class of 364 students, this means that about 290 students *did* submit the assignment. Figure 1 shows a student progressing from fairly superficial observations and no apparent concept engagement to critical and honest observations about their own efforts in the class and a prime observation about how their individual work could have been improved if the team had worked together more effectively (highlighted).

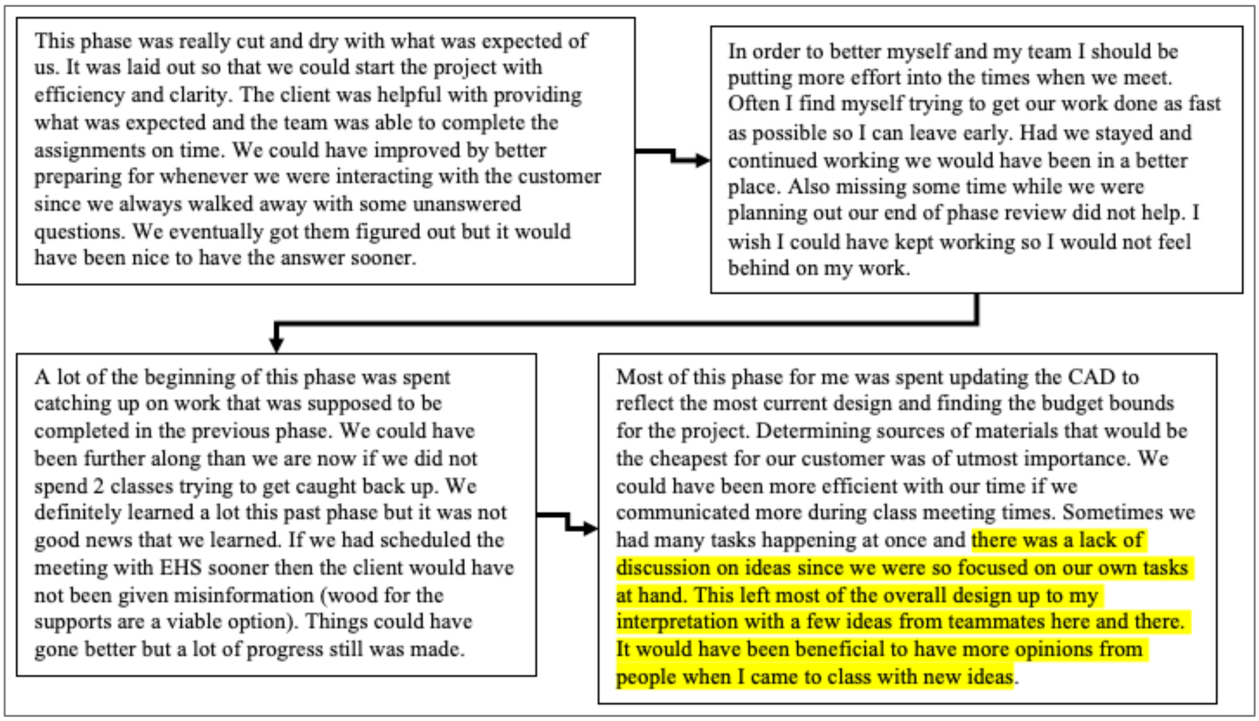

Figure 1: Reflections on individual teamwork, in the order submitted during the semester. Highlighted text hints at students beginning to grasp concept 1.

Submissions from a student on a different team (Figure 2) began with reflections related to the student's own schedule, then observations related to a team-level schedule. The third assignment (highlighted) acknowledged the way the student's own work impacted their teammates, and in the end, the student recognized the benefits of asking for help and planning meetings collaboratively with a teammate.

While these two examples show students who appear to be grasping the concept that teams are better at solving problems than individuals, other students' observations, not shown here, remained fairly superficial for each of the four submissions. Some submissions pointed toward valuable lessons learned related to other TCs than the one intended:

> *"The team encountered unexpected setbacks when the prototype didn't function initially, but this alone is a lesson in the value of taking steps toward a product instead of jumping head-first into making the final product. Because we created a proof-of-concept*

prototype, it was less consequential to fail in this phase than in a later phase." (engaging with TCs 2 and 3)

"I learned that in terms of prototyping, it is better to first focus on implementing the things that are most important first. For example, in our case we kept rethinking how to bring steam into the closet because it might interfere with secondary functions of ionization or adding fragrance." (engaging with TC 2)

"The biggest thing I learned over this past phase is how important it is not to skip steps. We were able to catch several mistakes by taking a moment to reflect on our work before moving forward." (engaging with TC 3)

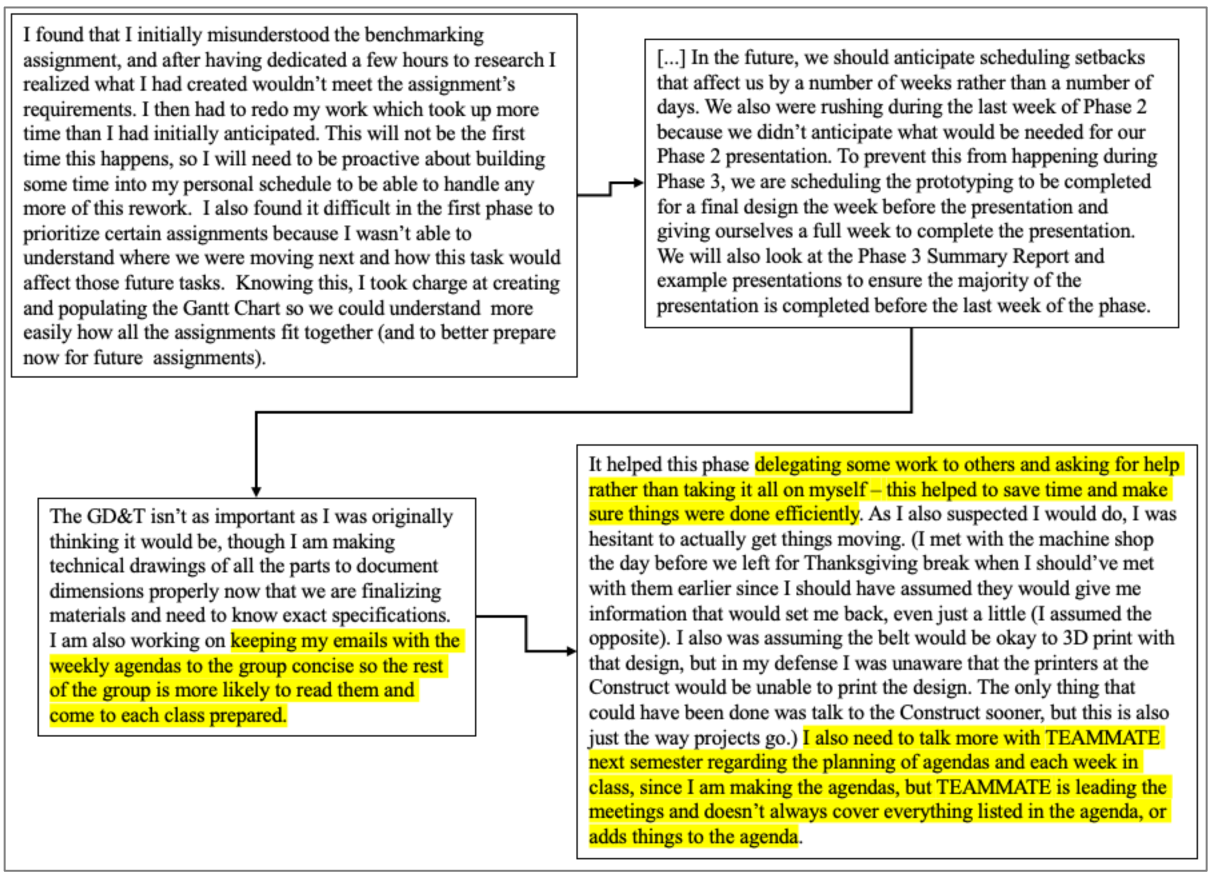

Figure 2: Reflections on individual teamwork, in the order submitted during the semester. Highlighted text hints at students beginning to grasp concept 1.

A prompt that more specifically directs students to consider a particular TC is likely to be more effective, but we also need to ensure that we are not shutting down incidental opportunities for reflective learning.

A team can learn a lot from a prototype, even (especially?) when it doesn't work: Reflection submissions related to prototyping from 10 teams were reviewed. Teams frequently focused their reflections on computer modeling rather than a physical build. Even the submissions that went into detail on physical prototyping work were sometimes just answering the questions posed in the assignment, without the students articulating any insights they may have gained. Additionally, some teams' advisors observed that students were so eager to start their prototypes that they didn't consider the purpose: they were building to build, not to learn. This is counterproductive and should be addressed in future iterations of the reflection assignment, although some teams were able to identify this behavior themselves, as in this example:

> *"[…] Additionally, the feasibility analysis portion of the design process was more helpful than just blindly building a prototype as we had originally planned. It raised several practical design concerns that we needed to work with CLIENT to obtain answers for." (also shows engagement with TC 3)*

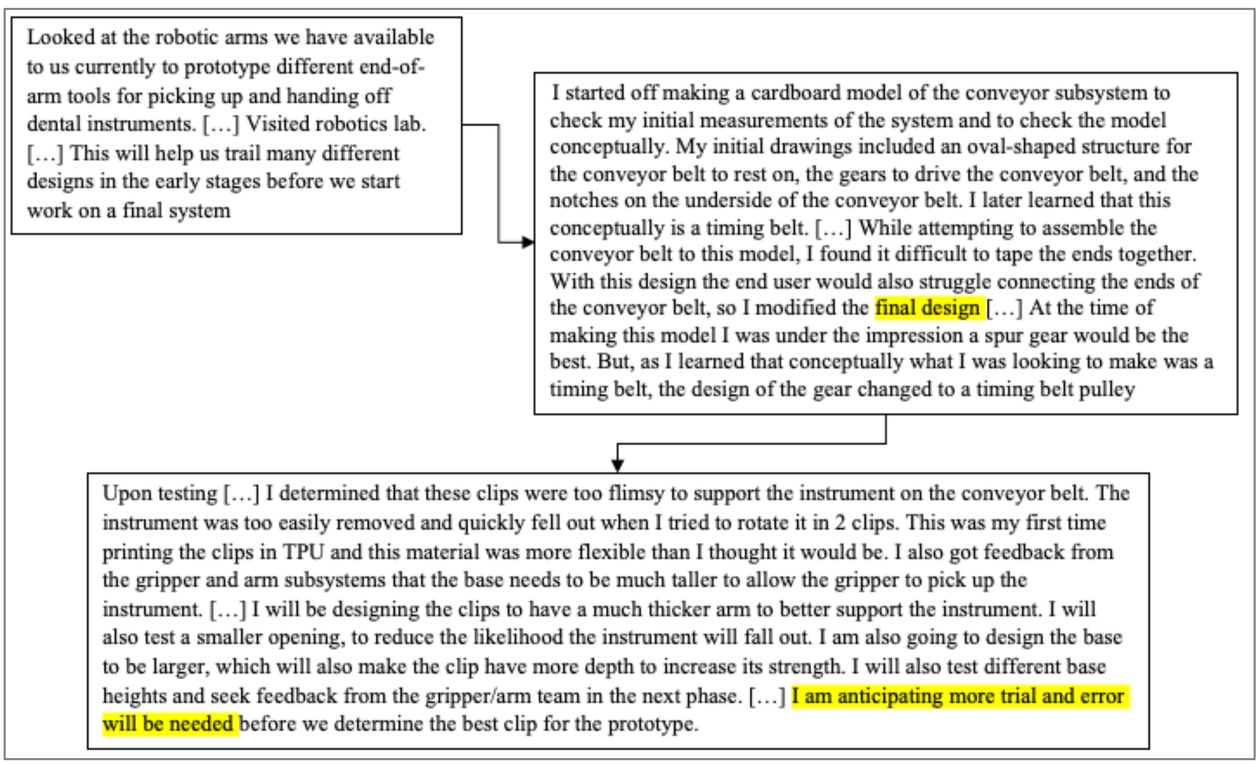

Figure 3: Reflections on the value of prototyping, in the order submitted during the semester. Highlighted text shows a change from thinking of a design as final vs expecting the design to continue evolving. Some extraneous project-specific detail was removed and is indicated by [...].

Figure 3 shows evidence of a team learning progressively from their prototype. Of particular note, in the second submission, the student refers to their "final design", while in the third submission the student acknowledges that more trial and error will be needed to learn what works best. Interestingly, the third submission also refers to the fact that the student sought input from teammates working on a different subsystem. In this case, the team's prototyping activities may have helped them understand the importance of collaboration within the team, demonstrating that concepts 1 and 2 are integrative, even as they value different ostensible concepts. The second example of prototyping reflection (Figure 4) is from a team whose members seem to grasp the concept that you can learn a lot from a prototype. The team articulated the fact that they intentionally limited their prototypes by only building what they needed in order to learn.

> We wanted to explore both the current iteration of the project as well as the improvements that have been made by the community since our proposal. To this end, we have constructed prototypes of both the current iteration of [two product benchmarks], the version considered to be the greatest improvement by the community currently. Ideally, we wanted to conclusively determine which design, if either, was suitable to build our improvements on top of. To this end, the mechanical components of each prototype were printed and assembled by TEAMMATE, then passed off to TEAMMATE for wiring, programming, and testing. To conserve our budget, each prototype was primarily constructed of reclaimed or spare parts […]. To save time and effort, only one out of five fingers of each prototype were constructed, simply to get a feel for the haptic mechanism, and determine which "felt" better and was easier to work with. The electronics were hastily assembled, without much thought given to space or cleanness, but more, "just to get the thing to work." […] Despite the limited nature of the test, we feel that the experience of building the prototype offered a lot of great insights into how to go forward with designing a PCB, setting up the wiring, and improvements to be made to the mechanics. We don't feel that we've quite learned enough to decisively say which mechanical system is best, but PRODUCT is certainly a contender.

↓

> The primary goal of our prototyping so far has been to reach a final decision on what kind of mechanism we want to go with, and secondarily, to feel out how much space/weight we have to work with for components […]. We constructed two prototypes based on existing designs […] Both prototypes were not super reliable, it takes lots of troubleshooting to get them to work, but once they did, they gave us lots of valuable perspective. After testing the prototypes […] we learned a lot about each one. [Design 1] had worse force feedback, and was much harder to assemble. It made better use of space on the hand however, and successfully implemented splay tracking. [Design 2] was generally simple to assemble, but used up a lot of hand space. It provided good force feedback, but the vibrations from the servos made the experience less immersive. After testing the prototypes, we had a group meeting to decide the direction of our design. We decided to move forward with [Design 2]. We felt like it had a stronger foundation with lots of room for improvement.

Figure 4: Reflections on the value of prototyping, in the order submitted during the semester. Highlighted text reflects indications that the students are not viewing their prototypes as final. Some extraneous project-specific detail was removed and is indicated by [...].

Conclusions and Next Steps

This is a first step toward identifying capstone design TCs and using written reflection to help students through the liminal space associated with these concepts. The reflection assignments described in this paper address two of the three concepts, and an assignment for the third must be developed in the future as well. Student responses to the teamwork reflection were encouraging, if not the grounds for statistically significant evidence that reflection supported progress through TCs.

There are a number of opportunities to improve this work as we continue. First, increasing the prominence of the TC in the syllabus/course and the grading weight of the assignment might reduce the number of non-respondents on the reflections. Currently, the reflection is a small portion of a much larger holistic grade, so there's little apparent penalty for not putting effort into completing it. Second, based on student misconceptions about what prototyping means, and the lack of insight in the reflections, the prompt in support of the "a team can learn a lot from a prototype" TC needs to be revised in order to promote actual reflection rather than a series of short-answer questions.

Next, the volume of text-based submissions to analyze is significant. The initial reviews and samples presented here are a small fraction of what was submitted. In order to make full use of this rich pool of information, next steps will include identifying approaches to methodically extract information from open ended student responses. There are examples in the literature specifically related to capstone design functions and student learning that can form the basis for this work ([21], [22]).

We are currently revisiting how these concepts are framed throughout the course–in the syllabus, across assignment instructional content, in assignment descriptions, and in the rubrics used to provide structured feedback to students–so that the reflective writing can draw on students' schemas. Now that this preliminary work is done, it may be worthwhile to conduct an exercise similar to that described by Reeping et al. [10], engaging capstone design instructors at other universities to refine these, and potentially identify additional TCs (e.g., related to communication).

References

[1] J. Meyer and R. Land, "Threshold concepts and troublesome knowledge: Linkages to ways of thinking and practising within the disciplines," Edinburgh, 2003. doi: 10.1007/sl0734-004-6779-5.

[2] G. Cousin, "An introduction to threshold concepts," *Planet*, vol. 17, no. 1, pp. 4–5, Dec. 2006, doi: 10.11120/plan.2006.00170004.

[3] "Criteria for Accrediting Engineering Programs, 2022-23," *ABET*. https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2023-2024/#GC5 (accessed Mar. 21, 2023).

[4] A. J. Dutson, R. H. Todd, S. P. Magleby, and C. D. Sorensen, "A Review of Literature on Teaching Engineering Design Through Project-Oriented Capstone Courses," *Journal of Engineering Education*, vol. 86, pp. 17–28, 1997, doi: 10.1002/j.2168-9830.1997.tb00260.x.

[5] M. C. Paretti, J. D. Ford, S. Howe, D. A. Kotys-Schwartz, and R. Ott, "It's a Context Gap, Not a Competency Gap: Understanding the Transition from Capstone Design to Industry," in *2021 ASEE Virtual Annual Conference*, ASEE, 2021. Accessed: Feb. 14, 2023. [Online]. Available: https://peer.asee.org/37411

[6] J. Ford *et al.*, “Transitioning from Capstone Design Courses to Workplaces: A Study of New Engineers’ First Three Months,” *International Journal of Engineering Education*, vol. 35, no. 6B, pp. 1993–2013, 2019.
[7] D. Reeping *et al.*, “How are Threshold Concepts Applied? A Review of the Literature,” in *2017 ASEE Annual Conference & Exposition*, Columbus, OH: ASEE, 2017. doi: 10.18260/1-2--27965.
[8] K. O’Keefe, E. Rangelova, S. C. Packer, Q. K. Hassan, and I. Detchev, “WIP: Decoding a discipline-towards identifying threshold concepts in geomatics engineering,” in *2018 ASEE Annual Conference & Exposition*, Salt Lake City, UT: ASEE, 2018. doi: 10.18260/1-2--31248.
[9] H. W. Fennell, G. S. Coutino, A. J. Magana, D. Restrepo, and P. D. Zavattieri, “Enhancing Student Meaning-Making of Threshold Concepts via Computation: The Case of Mohr’s Circle,” in *2017 ASEE Annual Conference & Exposition*, Columbus, OH: ASEE, 2017. doi: 10.18260/1-2--28279.
[10] D. Reeping *et al.*, “Using Threshold Concepts to Restructure an Electrical and Computer Engineering Curriculum: Troublesome Knowledge in Expected Outcomes,” in *2017 IEEE Frontiers in Education Conference (FIE)*, Indianapolis, IN: IEEE, 2017. doi: 10.1109/FIE.2017.8190444.
[11] V. Townsend and R. H. Urbanic, “Project Management Learning Takes Flight,” in *2014 ASEE Annual Conference & Exposition*, Indianapolis, IN: ASEE, 2014.
[12] C. Venters, L. D. McNair, and M. C. Paretti, “Using Writing Assignments to Improve Conceptual Understanding in Statics: Results from a Pilot Study,” in *2012 ASEE Annual Conference & Exposition*, San Antonio, TX: ASEE, 2012. doi: 10.18260/1-2--22207.
[13] S. C. Hargrove-Leak, “Developing Threshold Conception in Statics,” in *2013 ASEE Annual Conference & Exposition*, Atlanta, GA: ASEE, 2013. doi: 10.18260/1-2--19421.
[14] L. Domingo, D. Moore, D. Sirkin, G. Toye, L. Leifer, and M. Cutkosky, “STRATEGIC PROTOTYPING TO LEARN IN STANFORD UNIVERSITY’S ME310 DESIGN INNOVATION COURSE,” *Proceedings of the Design Society: DESIGN Conference*, vol. 1, pp. 1687–1696, May 2020, doi: 10.1017/dsd.2020.176.
[15] M. Lande and L. Leifer, “Prototyping to Learn: Characterizing Engineering Students’ Prototyping Activities and Prototypes,” in *Proceedings of ICED 09, the 17th International Conference on Engineering Design, Vol. 1, Design Processes*, M. Norell Bergendahl, M. Grimheden, L. Leifer, P. Skogstad, and U. Lindemann, Eds., Palo Alto, CA: Design Society, 2009, pp. 507–516. Accessed: Mar. 21, 2023. [Online]. Available: https://www.designsociety.org/download-publication/28558/Prototyping+to+Learn%3A+Characterizing+Engineering+Students%E2%80%99+Prototyping+Activities+and+Prototypes
[16] S. Howe, L. Rosenbauer, and S. Poulos, “The 2015 Capstone Design Survey Results: Current Practices and Changes Over Time,” *International Journal of Engineering Education*, vol. 33, no. 5, pp. 1393–1421, 2017.

[17] A. Sarang-Sieminski and R. Christianson, “Agile/Scrum for Capstone Project Management,” in *2014 Capstone Design Conference*, Columbus, OH, 2014.

[18] R. Stansbury, M. Towhidnejad, J. F. Clifford, and M. P. Dop, “Agile Methodologies for Hardware/Software Teams for a Capstone Design Course: Lessons Learned,” in *2011 ASEE Annual Conference & Exposition*, Vancouver, BC: ASE, 2011. doi: 10.18260/1-2--17432.

[19] G. Kremer, J. Juratovac, and J. Smith, “Sprint+PDCA Approach to Improving Project Management Skills and Mindset in Capstone Design,” in *2018 Capstone Design Conference*, Rochester, NY, 2018.

[20] C. Venters, C. Groen, L. D. Mcnair, and M. C. Paretti, “Using Writing Assignments to Improve Learning in Statics: A Mixed Methods Study,” *International Journal of Engineering Education*, vol. 34, no. 1, 2012, doi: 0949-149X/91.

[21] B. Lutz and M. Paretti, “Exploring Student Perceptions of Capstone Design Outcomes,” *International Journal of Engineering Education*, vol. 33, no. 5, pp. 1521–1533, Jan. 2017.

[22] J. J. Pembridge and M. C. Paretti, “Characterizing capstone design teaching: A functional taxonomy,” *Journal of Engineering Education*, vol. 108, pp. 197–219, 2019, doi: doi.org/10.1002/jee.20259.