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BOARD # 438: Research Initiation: Facilitating Knowledge Transfer within Engineering Curricula

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Introduction

The transfer of knowledge (or transfer of learning) is often defined as the ability to apply knowledge gained in one situation to a new, different situation [1]. While teaching the ability to transfer learning is a major goal of education, it is well-established that students have difficulty transferring theory and skills between courses in their undergraduate curriculum[2-4]. Typical reasons given for these difficulties include items such as:

- A lack of sufficient original learning of the knowledge or skills to be transferred [5,6].
- Not revisiting important knowledge and concepts throughout the curriculum such that students are only exposed to them for single or brief instances [7].
- Not teaching material via problems, examples, or by using applications [8].
- Not making explicit the connections between knowledge and concepts used in various areas of the curriculum [9].

Various authors in both the cognitive and disciplinary sciences have discussed these difficulties with the transfer of knowledge, and noted the need to develop tools and techniques for promoting knowledge transfer, as well as to help students develop cross-course connections. This work aims to address these barriers to knowledge transfer, and crucially develop the needed activities and practices for promoting transfer by answering the following research questions:

1. What are the primary challenges experienced by students when tasked with transferring theory and skills from prior courses, specifically mathematics and physics?
2. What methods of prior knowledge activation are most effective in enabling students to apply this prior knowledge in new areas of study?

In this paper we present a summary of the most recent work completed under NSF Award No 2301341. Findings from a series of n=23 think aloud interviews, in which participants were asked to solve a typical engineering statics problem were presented previously and serve as background to the work presented here [10-12]. Analysis of these interviews suggests there were multiple barriers to knowledge transfer (RQ1; lack of prior knowledge, accuracy of prior knowledge, conceptual understanding, lack of teaching of applications, language of problem, curricular mapping) that hindered participant success in terms of using their mathematical skills to solve the problem. Findings also indicated the importance of reflective thinking on behalf of the participants and its relation to their problem solving success (a potential answer to RQ2).

Based on this initial work using think alouds, a further set of interviews (n=8) were conducted to more deeply examine student conceptions of important mathematical topics that are transferred into engineering such as integration and centroids. These interviews sought to provide further context to the challenges identified as part of RQ1. Following up on this study based around centroids, the importance of reflection on behalf of the problem solver was also examined in more detail and in order to consider the value of reflective thinking as a potential remedy to aid problem solving success and prior knowledge activation (RQ2).

Methodology

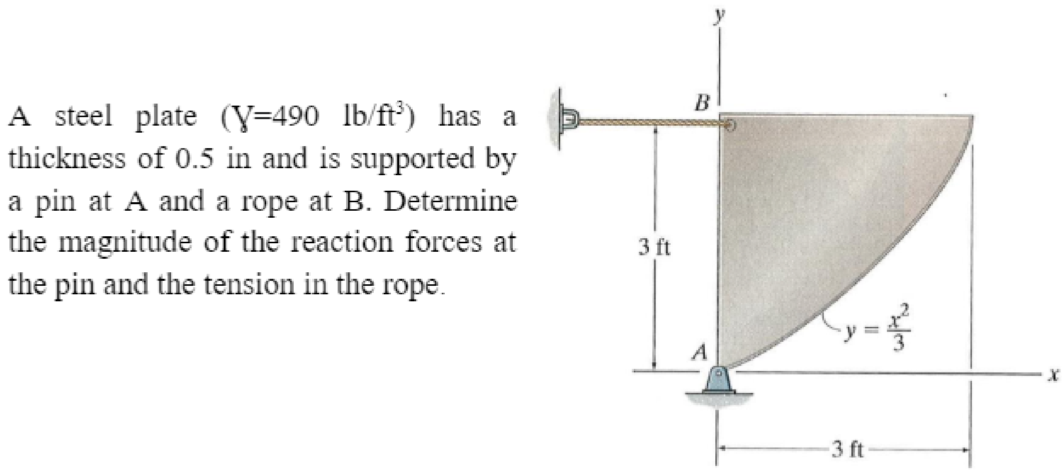


Figure 1: Engineering statics problem used in think-aloud interviews [13].

In prior work [10-12], a think aloud interview protocol [14-17] was developed around solving a rigid body equilibrium problem typical of engineering statics (Fig.1). This kind of problem is used in various foundational engineering courses and requires the transfer of various concepts (mathematical and physical) in order to solve. As such it represents a useful case for assessing knowledge transfer. The problem and think aloud protocol were initially used to assess the challenges students faced when tasked with transferring prior knowledge (RQ1), before being extended to include and assess the effectiveness of various prompts designed to activate prior knowledge (RQ2). The implementations of the protocol and problem are detailed in [10-12] and summarized here:

1. n=11 participants (9 UG students, 2 faculty) attempted to solve the statics problem in order to generate pilot data concerning approaches to solving the problem and to identify challenges faced in solving the problem.
2. n=5 participants (all UG, 4 male, 1 female) completed the problem with a mathematical prompt provided if the subjects required help to solve it.
3. n=7 participants (1 faculty, 6 UG students, all male) completed the problem with an applied prompt based on course notes to be provided if necessary.

Data resulting from the think aloud interviews consisted of both written artifacts (solutions to the problem), as well as interview transcripts. These data were then analyzed using thematic analysis alongside a provisionally determined rubric [18,19] based on the knowledge transfer framework of Belenky and Nokes [20,21]. Multiple investigators conducted the interviews and analyzed the resulting data before peer debriefing within the project team was used to develop and integrate the resulting themes and discuss patterns in the data.

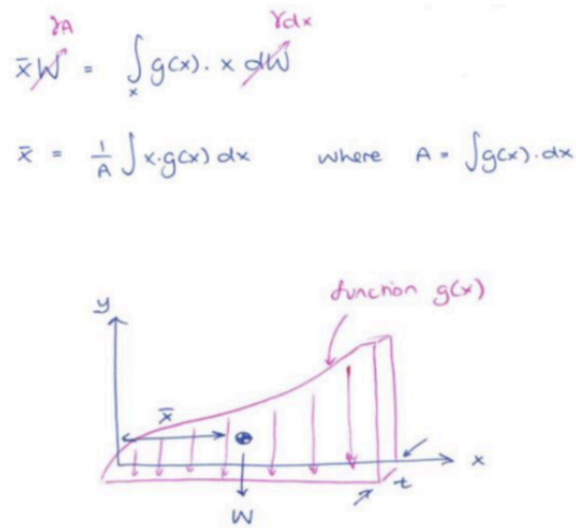
These first three implementations of the think aloud protocol and problem solving activity are further detailed in [10-12]. A summary of the major findings of these activities is as follows:

- Across all implementations, only one UG student was able to correctly solve the problem without any additional help or prompting.
- The accuracy and completeness of the prior knowledge required to solve the problem appeared to differ significantly across the sample population.
- The major knowledge gap concerned centroids and how to find them for a non-standard shape. Note that all participants *should* have had this prior knowledge based on prior course enrollments as this was a requirement of participation in the study.
- Use of a mathematical prompt was ineffective in promoting problem solving success.
- An applied prompt was more successful in helping student participants to solve the problem but it was unclear how the prompt aided participants or if they "copied the pattern" they saw in the prompt.
- Persistent issues with units and problem-solving methodology were observed amongst a majority of student participants.
- Reflective practice emerged as a potential behavior promoting success in solving the problem.

Given that many of the sampled participants did not appear to have the prerequisite knowledge of centroids to solve the statics problem (a challenge and potential answer to RQ1), an investigation into student understanding of centroids was conducted and is reported on here. In this study, eight UG students (all male) were enrolled in a think aloud protocol probing their understanding of centroids. The protocol asked students to first identify and/or calculate the location of the centroid for several standard shapes (square, triangle, quarter circle) before moving on to the mathematical formulation for the centroid and examining student understanding of that formulation - after finding the centroids of the shapes, students were presented with an equation and asked what it calculated (the equation was for the location of the centroid of a generic shape) before being asked to identify terms in the equation and to describe why the equation was formulated in the way it was. If students could not sufficiently discuss the mathematical representation of the centroid equation, a more applied version of the equation taken from course notes was provided along with a graph to add context. Both representations of the centroid equation used in the protocol are provided in Figure 2. Similar to prior stages of this study reported on in [12], data resulting from these think aloud interviews was coded for themes by the research team who debriefed as a group before integrating and interpreting the resulting data.

$$\bar{x} = \frac{1}{A}\int x \cdot g(x) \cdot dx$$

...where $A = \int g(x) \cdot dx$



(a) Mathematical formulation for the centroid. **(b) Applied formulation from course notes.**

Figure 2: Formulations for calculating the centroid presented to study participants.

In addition to the observed student difficulties with centroids, observations from prior implementations of this work [10-12] also noted the potential importance of reflective thinking in transferring knowledge and solving the statics problem (Fig.1). Anecdotally, expert problem solvers (faculty participants) were observed to be significantly more metacognitive and reflective than novice problem solvers (students) and the only student who correctly solved the problem unaided was very reflective in their approach. Adding further interest to this topic, one other student who came very close to determining the answer on their own also showed metacognitive tendencies that were rare amongst the novice participants.

In order to follow up on, and better understand these observations, a comparison of the approaches to solving the statics problem employed by both expert and novice problem solvers was conducted in order to better understand the role of reflective thinking in this activity. This aspect of the current work aimed to assess how reflective thinking might promote problem solving success and knowledge transfer (RQ2). The comparison was completed via further analysis of existing data already generated and detailed in [12]. In particular, one expert (faculty) and the lone student participant who managed to correctly solve the problem were compared. As with prior work, the data from these participants was a priori coded based on the stages of the knowledge transfer framework of Belenky and Nokes (Fig.3 [20]) as well as being analyzed thematically for instances or indications of reflective thinking. See [10-12] for further discussion of this framework in the light of this study. In this analysis, portions of the transcript were coded based on the stage of the framework that the participant appeared to be operating in at a given instant. The time spent in each stage and when changes in stage were noticed was also recorded.

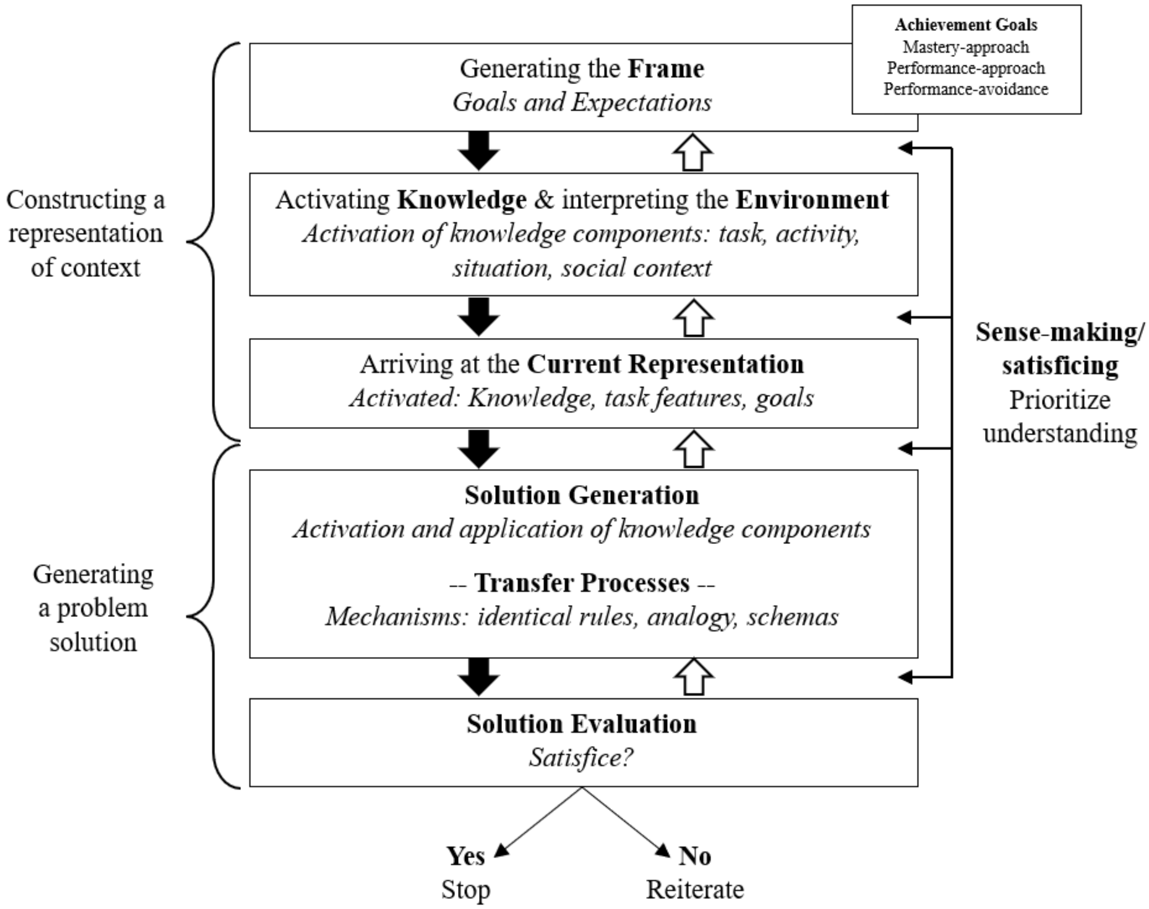


Figure 3: Sense-making framework of knowledge transfer. Adapted from [20].

All participants in this study were from the mechanical engineering department of a large, Mid-Atlantic university. Both theoretical and convenience sampling was used following a multi-level (nested) design in which mechanical engineering students from various years of study were asked to participate. Sampling continued until themes and patterns emerged and the research team agreed that some degree of saturation was attained. Key limitations of this study revolve around the use of a (mostly) a-priori determined coding scheme that could have limited the emergence of new or novel themes and a clear bias in the participant sample - most student volunteers had cumulative GPAs >3.5 and were predominantly white and male. Finally, the think aloud methodology used in this study has been shown in the past to positively influence student performance such that this activity may overestimate actual student performance "in the field" [22,23].

Findings and Discussion - Conceptual understanding of centroids

The student participants were generally able to determine the centroid of squares (all participants) and triangles (6/8 participants). Only 4/8 participants described where the centroid of the quarter circle would be located and none of these did so mathematically. Students' determination of the centroid of these shapes appeared to be based on more geometric and "intuitive" considerations rather than mathematical formulations. For example, several participants described the centroid as the center of the "*geometrical parameters of the shape*" or the point at which you can balance an object; "*So the centroid the way I was taught it is if you pick up a shape, … , you pick up a shape by a certain point, that's where you balance it. That's the center of mass in a way.*"

Students noted having learned about centroids in their engineering statics class, while some participants made mention of other courses such as solid mechanics. Only one student linked the concept of finding the centroid to the center of pressure, a concept used in fluid mechanics and which is calculated in much the same manner as a centroid. Interestingly, when asked how they had used centroids in the past, several students then talked about using similar equations to resolve distributed loads on an object. The majority of students did not initially discuss distributed loads as being related to centroids before being prompted with this additional question, however.

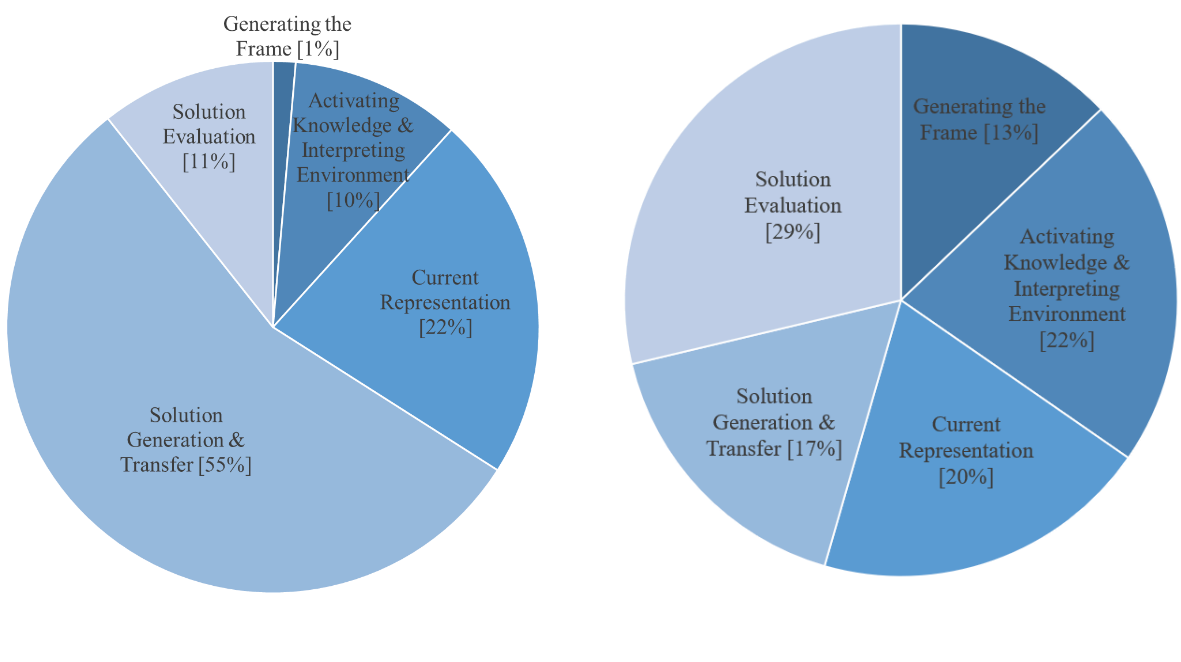
Another significant observation was that student conceptions of centroids clearly did not account for objects that had a non-uniform density - likely due to the fact that these kinds of objects are not covered in introductory engineering courses. While this lack of conceptual understanding does not hold students back in undergraduate courses where objects of uniform density are the norm, if students are faced with (more authentic) non-uniform density objects in later courses or their careers there could be cause for concern.

Only half (4/8) of the participants recognized the mathematical formulation for determining the centroid. The other half of the sampled students did not recognize the equation and could not immediately talk about what it might represent either mathematically or physically. When asked to talk about the equation and the terms within it in more detail, all participants referred to the integral function as being "the area under a curve" while only one participant mentioned the term "summation". The fact that students did not recognize the equation for the centroid was not surprising given that the participants stated that it was not commonly used in our curriculum (and likely not in the majority around the country). It was surprising, however, that students could not talk about the equation more generally using meaningful mathematical or physical terms. Many student participants displayed a relatively rudimentary or generic understanding of integration and were not able to discuss ideas like summation, or weighted sums in relation to the topic of centroids and the given prompts (Fig.2).

Issues surrounding centroids and student lack of deeper understanding of them seemed to result from a lack of application and usage of centroids within the curriculum. Almost all participants made reference to the fact that while centroids are taught in engineering statics, where mathematical formulations are used to find them, later courses often limit cases to simple shapes (squares, rectangles, etc.) or shapes for which data such as the centroid is tabulated and can be found online or in a textbook. Common to all participants was a lack of finding or using centroids, especially via equations after centroids as a topic had initially been introduced in the curriculum via the engineering statics class. It was also apparent that the connections to this concept in other courses (such as center of pressure in fluid mechanics) were not being made explicit to the students.

Overall from this phase of the study, it appears that students do not possess the deep understanding of centroids, or the mathematical underpinnings of their determination, that would allow them to transfer this knowledge in order to solve new problems (RQ1). If this information does not exist to a sufficient degree, as appears to be the case here, it is not surprising that novice (student) problem solvers were unable to solve an engineering problem requiring the successful transfer of this knowledge [1].

Findings and Discussion - Expert v Novice Problem Solving Comparisons



(a) Novice distribution **(b) Expert distribution**

Figure 5: Percent of total time spent solving the problem in each stage of the framework

Data presented here comes from one expert (faculty, white, male) participant in the study who has taught a range of UG courses but who has not directly taught centroids as a topic and one novice (UG student, white, male) participant in their sophomore year who had first learned about centroids in their engineering statics class in the prior semester.

A deep dive into the expert (faculty) problem solving method revealed the extent to which they reflected on their work during the activity. Figure 5 details the fact that the expert spent almost one third (29%) of their time working through the problem reflecting on their work to that point. The expert also spent significant amounts of time examining the problem and setting it up such that the actual solution generation and active, mathematical problem solving components only represented 17% of their time spent on the problem. These observations are in direct contrast to the novice (student) problem solver who, while correctly solving the problem, only spent one tenth (11%) of their time reflecting on their work but more than half of their time (55%) actively solving the problem.

Both the expert and novice participants verbalized various reflective statements as they solved the problem. Sample statements from the expert included:

"*So I'm getting a number that makes sense to me. I don't know if this is correct, but it seems like it should be closer to A than to over here, because…*"

"*I'm gonna give you a different perspective…*"

… which indicated that the expert knew intuitively or based on experience that the centroid should be in a given location, that their solution agreed with this instinctive solution, and that they had multiple perspectives they could draw on for how to solve the problem or think about their solution.

Sample statements from the novice included:
"At intermediate stages, you should ask yourself if it makes sense."

"This does make sense. An important part of engineering problems is asking yourself if it does make sense. This does make sense because we know that as we go more left by the equation, we're taking off more and more mass. So then it would be on the left side of the exact like midpoint of three feet. So it'd be less than 1.5 feet, and I'm, I'm thinking this is like 1.125."

… which indicated an approach to reflection that was perhaps based on their training rather than their experience. The novice states that they "should check" their work as part of solving a problem which indicates an external motivation for doing so rather than an internal one. The second novice statement, however, about location moving in a certain direction does speak to a more instinctive or geometrical understanding of the problem and where the centroid should be located that agrees with their mathematical solution. The majority of other novice participants did not make this geometric comparison.

Interestingly, the only other novice (UG student, white, male) participant who displayed significant reflective practice did not solve the problem correctly but did come very close to deducing the location of the centroid based on their knowledge of centroids of other shapes (specifically a square and triangle) and guessing a value in between these two. This particular student talked through this process during their think aloud interview which was somewhat unique. Most other students who could not solve the problem simply gave up when they realized they did not remember the equation and did not try to use other approaches or persist in other ways.

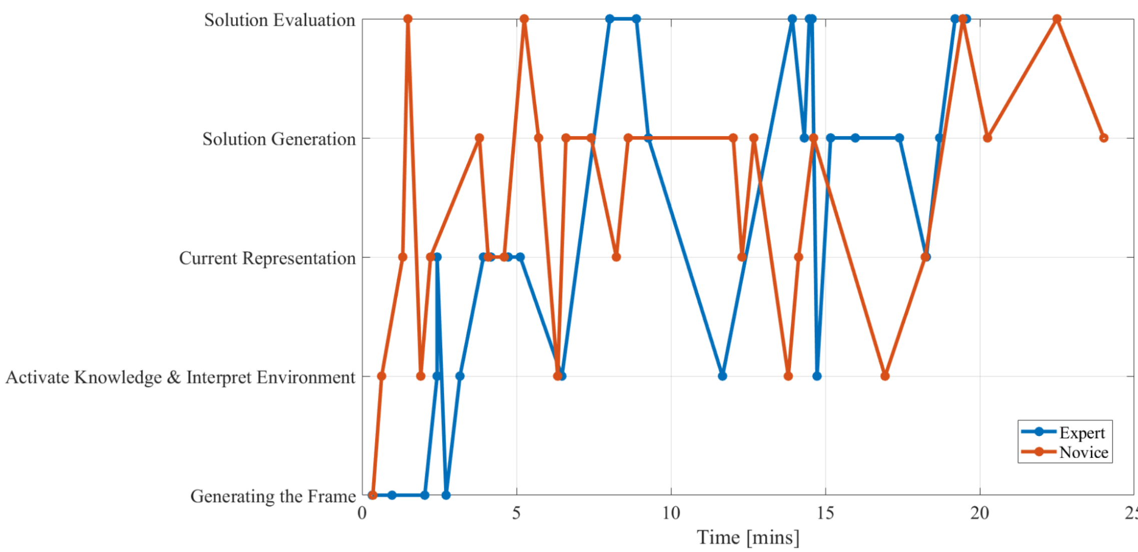


Figure 4: Sequence of framework stages participant was working in (coded from transcript) v. time spent solving the problem.

An examination of the stages of the knowledge transfer framework that participants were working in during the problem solving process is detailed in Figure. 4. As can be seen in the figure, both the expert and novice participants shift frequently between evaluating their work (reflective thinking) and actively working on the problem via the other stages. The novice participant spends a lot of time in the middle of the exercise (from approx. 6 - 18 mins) actively working out the problem while the expert seems to break the problem down into smaller chunks of problem solving before considering the next stage of the activity. The ability to break problems down into smaller chunks is indicative of expert level thinking and is typically developed over time [24]. It is, therefore, not surprising that the novice participant did not break down their problem solving approach to the same degree. It is interesting to note that the student participant followed a very standard engineering problem solving approach as is commonly advised for students to follow of drawing a diagram, writing governing equations, etc. and that this approach, while helpful, may not allow for the overall problem to the broken down into smaller segments in the same way that a more freeform approach might. In this case in particular, the student participant clearly felt beholden to this trained approach: *"I'm drawing it, because it's what I've been told to do, if I'm being completely honest, but it does help a bit, in terms of like, conceptualizing what you need to do"*.

In terms of the other participants in this study, a full analysis of the stages of the framework that they were working in was not completed as a direct comparison between their work and that of the experts (faculty) could not be made (they did not fully solve the problem). It was observed, however, that the majority of student participants did not display any reflective practice whatsoever or only did so in a very limited sense. Student participants were directly asked as part of the protocol how they knew their answer was correct (a leading, metacognitive question) and most discussed ideas relating to rechecking their math, or asking someone else for help or guidance rather than using another approach to validate their result.

Further details of this aspect of the research and comparisons of expert and novice approaches to solving the problem are provided in [25,26].

Summary & Implications

The investigations detailed in this work revolve around transferring knowledge to solve a fundamental engineering statics problem. The challenges students face in transferring their knowledge of centroids to solve a statics problem (RQ1) was examined conceptually using a think aloud protocol focused on the topic of centroids. Secondly, the potential for reflective thinking to aid knowledge transfer (RQ2) was assessed by conducting a deeper analysis of existing think aloud interview data concerning problem solving.

Findings indicated that participant knowledge and understanding of centroids in particular was generally based around more intuitive or geometrical conceptions rather than concrete physical or mathematical models. This more basic understanding would potentially limit student ability to solve more complex problems using centroids if their understanding is not deep or meaningful enough to enable this kind of transfer or problem solving (which appears to be the case here).

Comparison of expert (faculty) and novice (student) approaches to problem solving demonstrates how often experts reflect on their progress during the solving process and the manner in which they are able to connect problems in one context to similar problems they have encountered in the past in other areas of engineering. The ability of experts to "chunk" problems into smaller stages and reflect on individual elements of the problem at hand rather than the problem as a whole was also seen to be a differentiating factor in their approach as compared to novices.

In terms of the initial RQs, the lack of understanding of centroids would appear to limit student ability to transfer this knowledge successfully (RQ1). The importance of reflective practice in problem solving observed here is indicative of a potential answer to RQ2 but further work is needed to both demonstrate the lack of understanding of centroids across the wider student body, and to trial mechanisms for promoting metacognition during problem solving.

Acknowledgements

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