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A Comparison of Novice and Expert Approaches to Problem Solving

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Introduction

Teaching the ability to transfer knowledge between courses and contexts is a major goal of educators. 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] and is commonly associated with solving new or ill-defined problems. Educators still struggle to teach or train students how to transfer their knowledge and the many and varied challenges that students face when tasked with doing so have been widely reported in the literature [2-8].

Comparisons of expert and novice problem solvers have been made in the past in an attempt to better understand the problem solving process, what best practices for problem solving and knowledge transfer might exist, and how these practices might be taught to others [9-12]. Important differences between expert and novice problem solving approaches have been observed. Examples include how experts are better able to identify the most salient features of a given problem, and how they can leverage their more advanced and rich knowledge structures to reduce cognitive load in the problem solving process [13-17]. In cases where experts were presented with less structured or familiar problems, studies have observed that experts displayed more reflective and metacognitive strategies, and were better able to leverage their breadth of knowledge to solve the problem relative to novice practitioners [8,18-20].

The concept of adaptive expertise [21,22] has also been introduced to describe how experts are able to "apply, adapt, and otherwise stretch knowledge" to solve novel problems [18]. The adaptiveness of the expert is thought to comprise multiple dimensions; (1) the ability to take on multiple perspectives, (2) metacognition, (3) goals and beliefs, and (4) epistemology [22]. Importantly for this particular definition of adaptive expertise, one does not necessarily need to be a content expert in order to be adaptive - the four dimensions that comprise adaptive expertise are skills or dispositions rather than relying on domain knowledge. Thus, it should be possible to train novices in these dispositions in order to better enable them to solve novel problems before they have achieved the depth of knowledge possessed by an expert in the field.

In this study we more closely examine the problem solving processes of an expert and novice tasked with solving the same problem that requires the transfer of knowledge to complete. This investigation grew from prior studies [23-25] that aimed to develop activities to promote the activation of prior knowledge and improve problem solving success. The impact and usefulness of these activities was found to be highly context dependent, as well as highly dependent on the exact prior knowledge of the participant, such that the activities would most likely be difficult to generalize. Observations from this work did, however, point towards the importance of metacognition and reflective thinking in both enabling prior knowledge activation, or in allowing participants to move past or around obstacles related to a lack of complete or correct prior knowledge.

Based on these initial, and at the time, anecdotal observations [23-25], we report here on a deeper investigation of the problem solving, and in particular, reflective practices employed by both a novice and expert participant in order to examine their overall approach. If the successful aspects of their problem solving approach could then be taught, trained, or generalized, they could potentially be used to promote problem solving success as was the initial goal of the parent project of this work.

Methodology

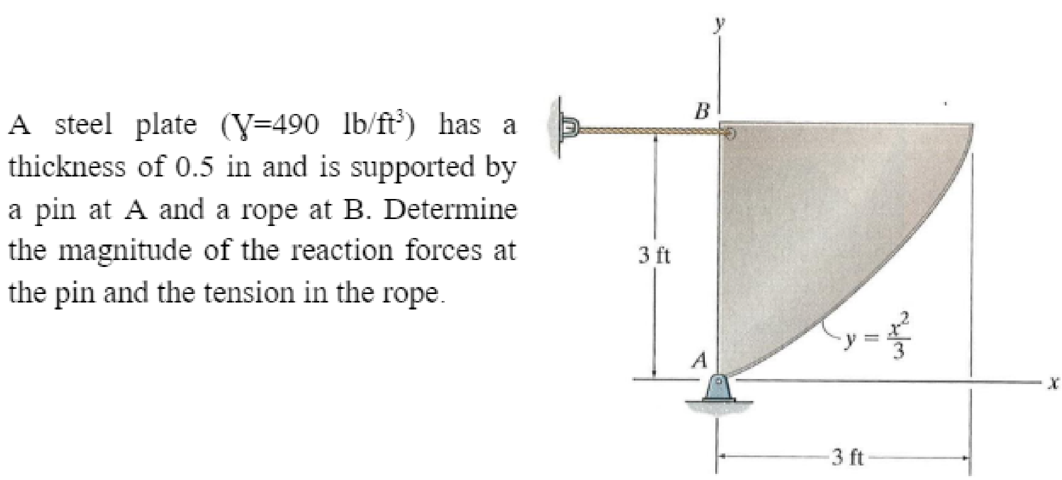


Figure 1: Engineering statics problem used in think-aloud interviews [26].

A think aloud interview protocol [27-30] was developed for use in this, and prior, studies in which participants were tasked with solving a rigid body equilibrium problem typical of an engineering statics course (Fig.1). As is typical of think aloud interviews, participants were asked to verbalize their thoughts as they solved the problem, while the investigator probed their thinking or added followup questions. Research participants were selected from a mechanical engineering department using both theoretical and convenience sampling in a multi-level (nested) design. Overall, n=31 participants (3 faculty, 28 students) were recruited into the larger study and interviewed[1]. The investigation presented here, however, focuses on one particular expert (faculty, white male) participant and one novice (2nd yr UG student who had taken statics the prior semester, white male, 3.99 GPA) participant, who were both interviewed as part of the prior study. These participants were chosen for further investigation as a comparative case due to the fact that this student in particular was the only novice participant (1/28) who correctly solved the statics problem (Fig.1) without any aids. The faculty member was chosen from the three expert (faculty) participants as they had not taught engineering statics before and so their

[1] See [23-25] for details concerning other studies analyzing this dataset and the participant demographics.

knowledge of the topic and problem was less fresh than the other two faculty members who had taught statics more recently. Hence it was expected that the problem solving strategies employed by the selected faculty expert would potentially be more interesting to analyze than those from an expert with a more immediate, working knowledge of engineering statics.

Data resulting from the think aloud interviews consisted of an audio transcript, as well as written artifacts produced by the problem solver (typically their solution to the problem). These data were then coded and subjected to thematic analysis based on the sense-making framework of knowledge transfer suggested by Belenky & Nokes (Fig.2) [31] which had been used and justified in prior aspects of this study [23-25].

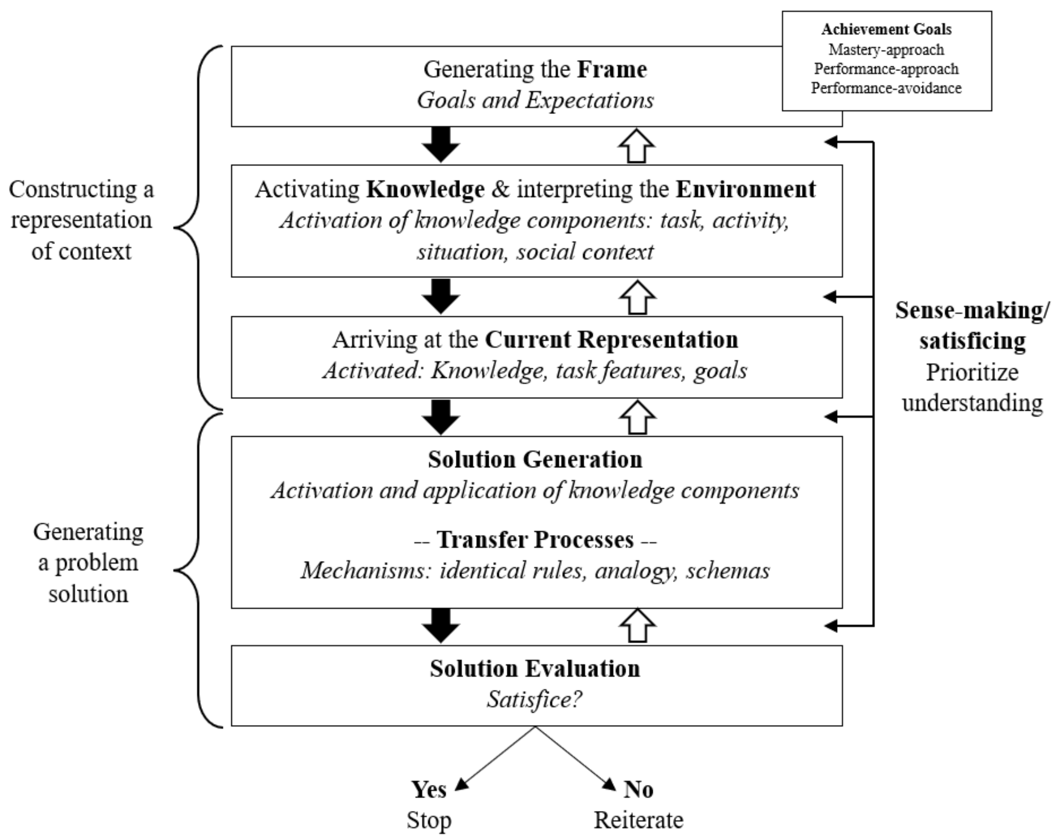


Figure 2: Sense-making framework of knowledge transfer. Adapted from [31].

A provisional coding scheme was developed based on the five stages of knowledge transfer identified in the framework (Fig.2):

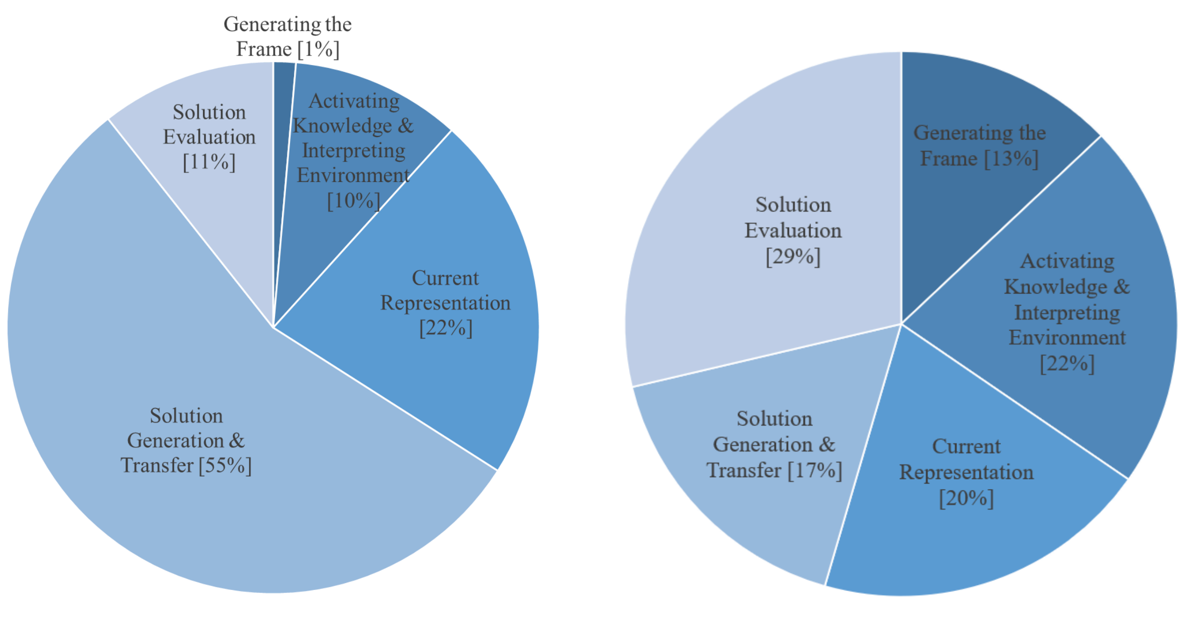
1. Generating the **Frame** (an attempt to decide "what is happening here"?)
2. Activating **Knowledge** & interpreting the **Environment** (what prior knowledge might be applicable and what tools and resources are available to solve the problem at hand?)
3. Arriving at the **Current Representation** (problem solver summarizes what is going on in the problem and what is expected of them)
4. **Solution Generation** & **Transfer Processes** (the problem is solved)
5. **Solution Evaluation** (problem solver asks "does this make sense?")

This scheme was then used to code the transcripts for areas in which the participants were judged to be working in the different levels of the framework. Given the limits of this coding scheme in allowing for new codes to emerge, process coding was also applied to the transcripts as it relates directly to the actions being performed by the participants at an instant. Axial coding [32] was then used to integrate the provisional and process coding schemes before the data was analyzed for themes and patterns [33]. Throughout the coding process, thorough records were kept (electronic data, recordings, memos) and peer review and debriefing was used among the research team (one engineering faculty member, one social scientist, one engineering education faculty member).

Positionality

Several aspects of positionality have been woven into this work already. Other potentially important factors relate to my (the PI's) belief that students should be able to solve the problem presented in Figure 1 and the use of a theoretical framework for analysis that I personally agree with. As for my background, I am a white male faculty member with little formal training in engineering education and who has likely pursued this study from something of a positivist perspective.

Findings and Discussion



(a) Novice distribution (total ~24 mins) **(b) Expert distribution (total ~20mins)**

Figure 3: Percent of total time spent solving the problem in each stage of the framework

Initial findings revealed the amount of time spent in each stage of the knowledge transfer framework by each participant (Figure 3). Particularly striking is the fact that the expert (Fig.3b, faculty member) spent almost one third (29%) of their total time on the problem reflecting and evaluating the work they had done to that point. Only 17% of their time was coded as them actually solving the problem. In contrast, the novice (student) participant spent over half of their time (55%) actively working out the problem and only 11% of their time evaluating their work. Note that the 11% of time spent evaluating their work was an outlier amongst student participants (n=28) as the majority of novices did not reflect on or evaluate their work at all - so this 11% is actually "good" in comparison to other students. Also interesting is the fact that the expert spent significantly more time setting up the problem than the student did and discussing the type of problem, how it related to aspects of engineering, and how it might be solved. These observations are consistent with prior work in the field that has demonstrated the problem solving processes displayed by experts who are typically better at identifying important features within problems and tend to work through problems in successive stages [14,15]. The time spent by the novice participant in actually solving the problem is perhaps indicative of the cognitive load they were burdened with at this stage of the process, again a factor that has been commented on in the past [13-16].

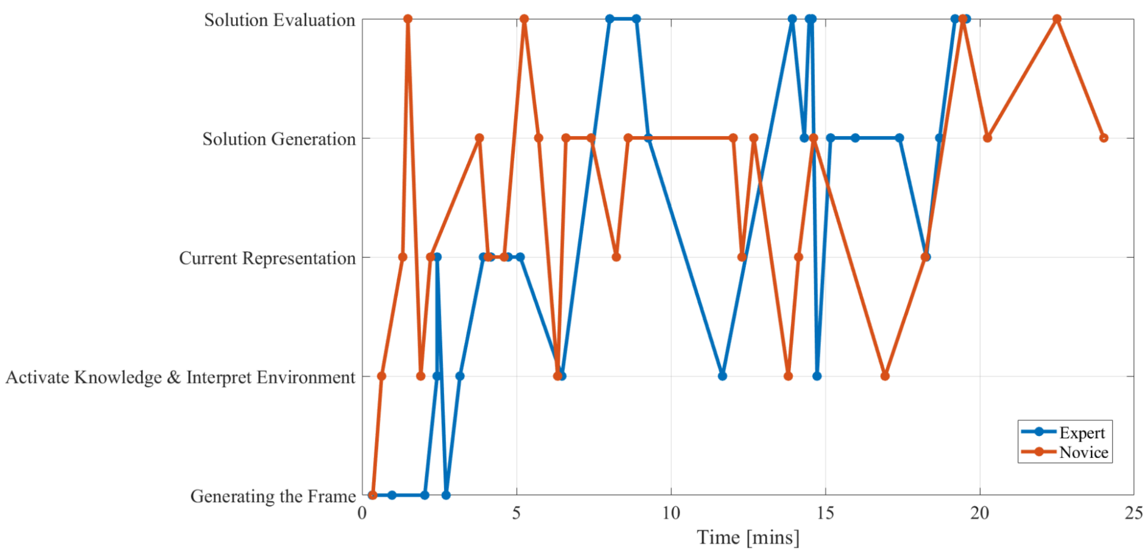


Figure 4: Sequence of framework stages participant was working in (coded from transcript) v. time spent solving the problem.

Figure 4 breaks down the stages of the knowledge transfer framework that the expert and novice subjects were working in as a function of time spent solving the statics problem. As was indicated in Figure 3, the expert spends more time upfront in determining the salient aspects of the problem and framing it before they move on to the next stage. It was interesting to see that the expert also spent significant time evaluating their work at this stage in order to assess its correctness before moving forward. In contrast, the novice participant very quickly moved into attempting to solve the problem - a behavior that was a trend amongst all student (n=28) participants in that they preferred to find values and solve equations before knowing exactly how, or if, those values would be needed to solve the problem.

Quotes from the expert during the early stages of the think aloud demonstrate their thinking and the time they are spending to first understand the problem and its requirements:

“If I had to guess, I'm going to need to compute what the weight is and where it's occurring to kind of figure out what some of these reactions are because [it] looks like a statics problem.”

“I haven't solved anything like this in a little while. Okay, so I guess usually what I do is… [several minutes of discussion]…and then I'm really just looking at what's interacting with this, which, in this problem, it really is the thing that I'm looking for.”

In these examples it is clear that the expert has some initial idea of what the problem requires. They then spend significant time (close to 5 minutes) thinking through various aspects of the problem before identifying and settling on the exact nature of the problem and what is needed to solve it. Again this observation is consistent with prior observations that have indicated the ability of the expert to recognize features of the problem at a deeper level than a novice [8,15,18].

Similar to the expert, the novice participant also initially verbalized their framing of the problem as a static equilibrium-type problem:

“This is a problem involving the center of mass slash gravity in an object. And based on that, determining reactions at different points.”

“So the way I approach problems is I start first, the givens, then what is required, and then I have a solution space.”

In contrast to the expert however, the novice spent much less time thinking through the problem up front and preferred to rely on the engineering problem solving approach that they had been trained to use. When asking novice (student) problem solvers about their approach in this study, many commented that they followed the rote, engineering problem solving approach that is typically taught in engineering courses (i.e. problem statement, diagram, governing equations, etc.). It is possible that in teaching this rote approach to problem solving, and commonly using textbook style problems, students are not being given the opportunity to think more critically about the problem they are facing - this method for example only encourages reflection or evaluation of the problem at the end of the process and not during the approach. This observation also raises the idea of using distractors or extraneous information to help teach problem solving. If additional and non-useful information was included in the problem, the problem solvers would need to filter this information out and would be perhaps working under more realistic conditions that have the potential to create better problem solvers. As has been stated in other work [34,35], there is clear evidence across the literature that asking students to solve authentic, open-ended problems would benefit their problem solving abilities and learning.

In terms of reflective thinking, the expert spends more time and more frequently evaluates their work than the novice (Fig.4). There were three distinct periods where the expert was judged to have stopped to evaluate their progress; at the beginning, middle, and end of the problem. In this manner the expert appears to be chunking the problem or breaking it down into sub-problems. The exact stages of the problem that the expert works on, and then evaluates were related to; (1) the governing equations, units and set up of the problem; (2) calculations based on the geometry of the situation; (3) the final moment and force balances. Within each of these sub-problems the expert appears to progress through almost all stages of the knowledge transfer framework. The following quotes reveal the thinking of the expert within these discrete problem solving stages. They also reveal processes that the expert is using to determine the correctness of their work:

"Or maybe it's divided by the area because those units are gonna work out. Yeah, I think instead of one over L_x, I actually want to divide by the area so then I end up with units of feet."

"Pretty sure that is sound. So that'd be nine. I'll put the units in at the end. Zero to 3x squared over three."

"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 there's more mass over here. And so the halfway point would be 1.5. And I'm below, I'm almost at a third. Which, to me at least, makes sense. I don't know if this form is perfect, but this number doesn't ring or wave any red flags to me."

"I think so because, you know, assuming that the calculations are correct, these numbers should be equal to each other. This number here, so we're at a distance of three feet. And here rarely a distance of a little over one. So it makes sense that it comes out to be like around a third a little more than a third of 122. So yeah, I think they are consistent with each other."

Initially the expert is seen to use units and dimensional analysis to come to the conclusion that they do not have the right equation and to modify it to be dimensionally correct. None of the student participants (n=28) across this entire study displayed this behavior. In fact, to the contrary, many novice participants exhibited difficulties in employing the English units used in this problem. A fact that likely added additional cognitive load to them and which betrayed their lack of a deeper understanding of dimensions and units. The second and third quotes from the expert reveal a more geometric or intuitive understanding of the problem and their answer based on the mass distribution of the object. In this case the expert is able to use this more instinctive understanding to check their numerical answer and finds that both are in agreement. In contrast to the expert, the novice (student) was only observed to evaluate their work at two instances; initially as they set up the problem, and secondly once they had a final answer and wanted to check it. The following quotes are taken from the interview transcript for the novice at these instances:

"We have two supports, and we have three equations that we can use. So we should be able to figure out the reaction at both points."

"Right now it's looking like, if I find weight I can find F_A, because F_A has a component in the Y and tension doesn't. And from that, I can look at the magnitude and break that down."

"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."

The first two quotes from the novice relate to the set up of the problem and represent them thinking through the equations they would need to use to solve it. The second quote comes from the end of the process when the student is checking their answer. The comments made by the student are indicative that this checking is a result of their training, and along with the fact that they don't continuously evaluate their work, reveals that reflective thinking is likely not yet ingrained into the entire problem solving process for them. Having said this, almost none of the other participants evaluated their work or reflected on it in any way so this level of reflection, while less than that displayed by the expert, is high relative to the other student participants.

Another interesting observation was that the expert in this case clearly did not remember the equation for the centroid which was required to solve this problem. They were however able to derive it from their breadth of understanding. The quote: *"... Or maybe it's divided by the area because those units are gonna work out…"* is indicative of the thought process that the expert utilized to derive the equation for the centroid and to determine its correctness. The expert also clearly related the centroid to other concepts such as "weighted averages" that they discussed as they sought the equation they needed. This ability to derive the equation they needed, or to otherwise determine its form from their breadth of knowledge, was unique to this expert, faculty participant. The novice participant here clearly remembered the equation for the centroid so did not need to find it in another manner. Of the other novice (student) participants, the determination of the centroid of the shape was the key factor that they could not remember and the reason why the majority of students could not solve this problem. The majority of students did not try to find the equation for the centroid when they realized they did not remember it and only two student participants made significant attempts to derive the centroid's location using any other means.

In the overall study that this work is part of, only one other student displayed higher levels of reflective thinking as they worked through the problem. This student (white, male, 4.0 GPA) did not correctly solve the problem but did deduce an answer very close to the correct value based on the geometry of the situation and comparing the shape of the object in Figure 1 to a triangle and a square - objects they could determine the centroid of more easily. The behavior of this participant was clearly more evaluative and reflective than the typical student and they also displayed a persistence and breadth of understanding that was somewhat unique amongst the novice subjects.

Other observations from the interviews concerned the expert's deeper understanding of mathematical concepts and their ability to see the problem from multiple perspectives, as has been described in the adaptive expertise literature [36]:

"Yeah, because in my mind, this term in brackets is sort of like the weighting. Like if you divided this into vertical slices, it's kind of like the weighting of each slice. I guess since this is massive, literally the weighting of each slice so it's a weighted average and then the X is the position, so I am weighting the position from A based on the height of that slice, and then dividing it by the total area."

"I'm gonna give you a different perspective… [further discussion of mathematical concepts] …then calculus can be thought of as like the present, the past and the future."

"I was thinking about as well, like, another backup plan would be, if I had access to a PC instead of trying to remember what this formula was, then I would like write a computer code to like break this into little pieces. Right? And I would say, Well, if this piece is above the curve, add it. If it's below the curve, don't. And then average all of that."

In the first comment above, the expert demonstrates their deeper understanding of the mathematical underpinnings of the centroid concept and how it relates to the broader idea of weighted averages. This discussion was unique to this particular expert participant and is revealing of the importance of deeper conceptual understanding in problem solving as well as the need to make these kinds of connections and ideas clear to students - none of the student participants talked about the centroid in this manner. The latter two quotes from the expert demonstrate their ability to see the problem from multiple viewpoints and develop multiple approaches to solving the problem. Again this ability to view a problem in many ways is indicative of expert thinking [22] and represents another way in which students could be trained to better solve problems - by seeing the same problem solved using multiple, different approaches.

Limitations of Study

There are clear limitations of this study associated with the extremely narrow focus in terms of participants who are both high achievers academically. The use of a think aloud methodology in itself is also a potential limiting factor as literature has shown how these interviews can positively influence performance [37,38]. The mostly provisional coding scheme used to examine the data is also a limitation in that it could have reduced the opportunities for new themes to emerge. Finally, there are obvious questions related to the short duration of exposure and lack of persistent observation of the participants given that the problem solving process they employ may differ depending on the context of the problem they are trying to solve.

Summary, Implications & Outcomes

This work examined the problem solving processes employed by an expert (faculty) and novice (UG student) participant as they solved a rigid body equilibrium problem typical of engineering statics. The goal of this study was to better understand the problem solving processes used by expert practitioners such that differences between them and novices could be elucidated and then, potentially, reduced with training. A think aloud interview protocol was developed for this purpose in which participants solved an engineering statics problem. The resulting data was then coded for themes derived from an existing framework of knowledge transfer.

Observations indicated that the expert spent significantly more time setting up their problem and then splitting it into smaller chunks than a novice who spent more time on the actual mechanics of solving the problem. The expert more frequently evaluated and reflected on their work, and did so to a greater degree than the novice participant. In addition, the expert displayed the ability to see the problem from a variety of perspectives and a willingness to take a variety of paths to generate a solution. Interestingly, it was clear that the novice recalled the equations they needed to use to solve the problem but that the expert did not remember these equations. Instead, the expert derived the necessary knowledge from their deeper understanding of the problem and their broader knowledge of the subject.

From these observations, it appears that the ability of the expert to employ extensive metacognition practices, as well as their ability to take on a variety of perspectives was key to their problem solving success. The degree to which the expert displayed these behaviors was in stark contrast to the novice participant, and the other participants examined in the larger study. These findings suggest that teaching students to reflect on their work, and engendering the ability to take on multiple perspectives could be significant in enabling them to transfer their knowledge and solve more complex engineering problems.

At the same time as observations suggest that these behaviors need to be imparted, it was also observed that the rote, problem solving approach displayed by the novice (and participants in the larger study) may actually pose a barrier to problem solving in that it dissuades students from taking a more freeform approach. It was observed that the novice followed this approach as they had been told to do so, not necessarily because they made the decision to do so themselves, and that this approach was a major factor in their evaluation of the problem at the end of the process rather than throughout.

In summary, the observations made in this work indicate the degree to which metacognitive and reflective thinking can promote problem solving success, as well as the importance of taking on multiple viewpoints when solving problems. Further work should explore how these dispositions (metacognition and multiple perspectives) can be developed in engineering students in order to promote their success in transferring knowledge to solve problems.

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