Paper ID #45026

A Phenomenological Study of Expert Problem Solving

Dr. Alexander John De Rosa, University of Delaware

Alexander De Rosa is an Associate Professor in Mechanical Engineering at The University of Delaware. He gained his Ph.D. in Mechanical Engineering from The Pennsylvania State University in 2015, where he worked on experimental combustion research applied to gas turbine engines, and his M.Eng. in Mechanical Engineering from Imperial College London in 2010. Alex's research focuses on the transfer of learning between various courses and contexts and the professional formation of engineers.

Dr. Teri Kristine Reed, OU Polytechnic Institute

Teri K. Reed is the inaugural Director of the OU Polytechnic Institute and Professor and George Kaiser Family Foundation Chair at OU-Tulsa.

©American Society for Engineering Education, 2024

Investigating an Expert Approach to Problem Solving

1. Introduction & Goals of Study

I initially became interested in knowledge transfer after observing my students' general inability to use mathematical knowledge and skills in an applied (engineering) context. My personal belief was that the students *should* have an understanding of basic basic mathematical concepts, like integration, and be able to use them correctly to solve problems. Clearly, something was missing in my students' understanding or perhaps memory that was causing them problems in this regard. In my initial work, I found that many students did not even recognize the need to integrate to solve a problem framed in an engineering context unless they were prompted to do so (De Rosa et al. 2019, De Rosa 2020). Concerned by this troubling observation, coupled with my belief that engineers should be able to both understand and apply mathematical concepts in their coursework and careers, I determined to investigate the cause of the problem and, if possible, evidence a potential solution to help students transfer mathematical knowledge into an applied (engineering) context.

Grounded in these observations and beliefs, this study that I have set upon seeks to further explore the connections undergraduate students make between their courses, and how they learn to apply knowledge from one course into another area of study. In particular, the links students make between their foundational mathematics and physics courses and their major engineering courses will be explored by building on my prior work in thermodynamics (De Rosa et al. 2019, De Rosa 2020). The key research questions (RQs) to be investigated are as follows:

RQ1: What are the primary challenges experienced by students when tasked with transferring knowledge from prior courses, specifically mathematics and physics?

RQ2: What methods of prior knowledge activation are most effective in enabling students to apply this prior knowledge in new areas of study?

2. Review of Relevant Literature

A review of the literature surrounding knowledge transfer revealed similar trends to those that I had previously observed in my own classroom. Bransford & Schwartz (1999) have written extensively about the phenomenon of transfer of knowledge (learning) and recognized many potential difficulties students face in doing so. Similarly, entire textbooks have been written by other authors on this topic (Detterman & Sternberg, 1993), as well as numerous other articles (Barnett & Ceci, 2002; Bransford et al., 1999). I personally have also observed how many college-courses are typically taught in silos, without discussing how the information being taught might be applied elsewhere. Indeed, in conversations with our mathematics instructors, I was told that "*our courses are taught entirely from a mathematical perspective, without any applications being demonstrated*". Is it then surprising that students are unable to transfer and integrate knowledge from multiple areas into new problems as part of capstone design courses, for example, or in their careers?

This ability to transfer knowledge between courses in the undergraduate curriculum, and then into one's career, is an important skill that we should be imparting in our students - both ABET, the National Academy of Engineers, and ASEE have written about this need and the desire for graduating engineers to be "T-shaped" professionals (Moghaddam et al. 2018) who have a deep subject knowledge - the vertical of the "*T*", with the ability to apply that knowledge across a broad range of contexts - the horizontal of the "*T*", (ABET 2021; NA 2004; ASEE 2013).

A survey of literature in the mathematical field suggests several approaches to remedying this problem and aiding students in transferring knowledge. For example, the idea of revisiting and weaving fundamental mathematical concepts through the curriculum was discussed by Orton (1983). Similarly to my discussion with our mathematics faculty, thought has also been given to the fact that while students may understand the math, they might not see how it is applied in a given context, or the approximations and assumptions they are required to make to solve a certain problem (Rebello et al. 2007; Schoenfeld 1985). Interestingly, the idea of using a prompt or activity to activate and promote the transfer of prior knowledge into a new context was discussed as a potential tool for remedying these problems but has not yet been explored (Loverude et al. 2002; Meltzer 2004) - lending credence to the usefulness of investigating RQ2 as defined here.

2.1 Theoretical Framework

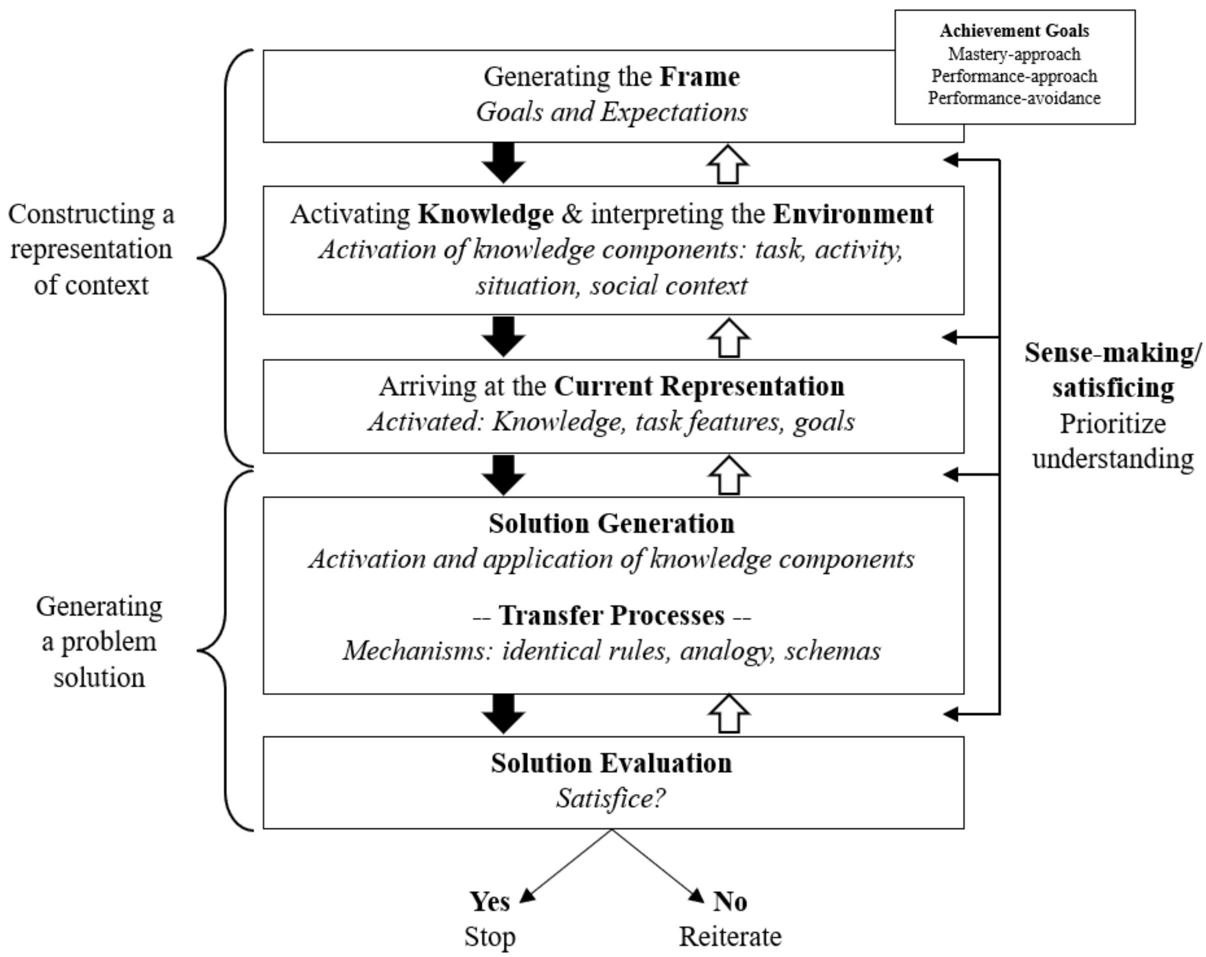

Figure 1: Sense-Making Framework of Knowledge Transfer (Nokes and Belenky 2011)

In order to better understand, visualize and analyze the knowledge transfer process, I chose to ground this study in a theoretical framework of knowledge transfer as defined by Nokes & Belenky (2011) and displayed in Figure 1. This framework mirrors my own understanding of the knowledge transfer process and, importantly to me, incorporates student motivation as a factor in the process - I have seen how student goals can affect their attitude towards learning and given the observed difficulties with transferring knowledge, I expected motivation to affect student performance and persistence within this process. The framework also follows a logical progression through the problem solving process that meshes with the “engineering problem solving process” that we typically espouse in the classroom in many engineering classes:

The framework builds linearly through the following stages that the “thinker” moves between i.e. from one to two, then three, or back to stage one if the individual cannot make sense of the current stage and needs to rework the prior stage. In more lay terms these stages can be described as follows:

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?”)

3. Methodology

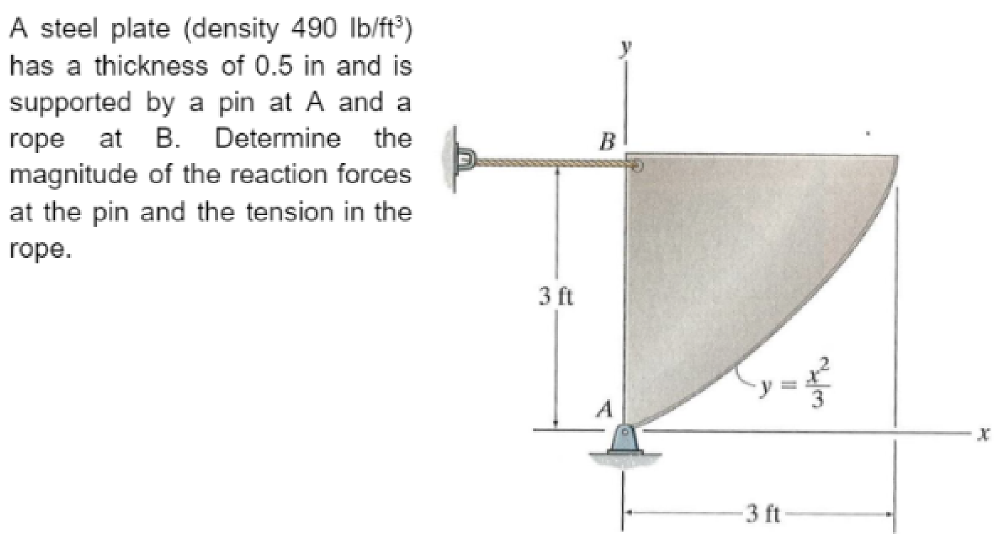

Figure 2: Knowledge Transfer Problem to be Solved (Hibbeler, 2004)

In order to examine the phenomenon of student ability to transfer knowledge, a think aloud interview protocol (Vgotsky, 1962; Ericsson & Simon, 1980; Charters, 2003; Cowan, 2019) based around a problem solving activity (Gagne et al., 1962; Davis et al., 1968; Litzinger et al., 2010; Passmore et al., 2010; Koro-Ljungberg et al., 2013; Lee et al., 2013) was developed. I decided to structure the interview protocol around a problem solving activity as the knowledge transfer process is both creative and task oriented and, an activity based interview, seemed a logical mechanism for revealing this process in the participants. In this problem-based interview, participants were asked to solve a typical engineering problem from an undergraduate statics course. The exact problem chosen is detailed in Figure 2 and comes from the Engineering Statics textbook written by Hibbeler (2004), and which we use in our (mechanical) engineering courses. This problem is an example of a rigid body equilibrium in which the weight of the plate must be determined by using an integral to find its volume (area) and then further integrals to find the centroid of the plate (the singular point at which its weight can be assumed to act).

In order to examine the knowledge transfer process during the course of solving this problem, a semi-structured interview protocol was developed in which the participant would think aloud (verbalize their thoughts) while they solved the problem. Several interviewer prompts and lines of questioning were also listed in the protocol based around the conceptual framework described in Figure 1. For example, early in the problem solving process as participants are generating the frame and their representation of the problem, they would be asked what type of problem they think they are dealing with, their plan for solving it, and so on - assuming they were not verbalizing these ideas already. Following the problem solving portion of the protocol, space was given to allow for open discussion and responses, for example asking how often the participant had used these skills in the past, following up on observed behaviors, etc. Interviews were anticipated to be around 45 minutes in length, would be conducted in an office or conference room in a private setting, and will be transcribed using Otter.ai ©.

The intent of the overall study is to conduct the interview protocol with a variety of stakeholders in a mechanical engineering department in order to examine the ability of various groups to solve this problem and to make comparisons between expert (faculty) and novice (student) transfer processes - I expect that the approaches taken by novices and experts will differ and that trying to determine the factors that lead to successful transfer of knowledge will be useful in developing ways to promote knowledge transfer. In pursuing this approach, I will be able to observe how an expert overcomes some of the challenges in solving this problem that students might face and not know how to handle (RQ1). I will also be able to investigate how the expert draws on their prior knowledge and engineering skill to solve this problem (RQ2). For example, the expert draws on their deeper understanding of the concepts at play rather than specific equations to solve the problem. They use this understanding to generate their equations rather than memorizing them. This is a different use/form of prior knowledge that can be compared to students who typically memorize and do not understand the deeper concepts at play.

As various populations will be studied (faculty and students), participants for this study will be sampled following a multi-level (nested) design in which mechanical engineering students from various years of study will be asked to participate, as well as engineering course instructors. I chose this multi-level approach in order to (hopefully) allow me to make analytic generalizations and apply the results to wider theories of knowledge transfer based on the responses of the various participants. As such, any mechanical engineering students from second year onwards, as well as faculty in the department, will be eligible to participate in the study as they should have the requisite prior knowledge required to solve the problem (having studied engineering statics, typically a second year course, in the past). Both theoretical and convenience sampling methods will be pursued within this nested approach to find participants that might aid the study based on findings as the study progresses, and based on my access to students in my own courses and within the department who I might advertise it to. This convenience sampling strategy will be employed using both verbal and email recruitment taking place via departmental mailing lists and in the PIs face to face interactions with students (i.e. recruitment efforts in the PIs classes). Sampling will continue until the themes and patterns in responses obtained during the course of this study are saturated. This inductive thematic saturation will be decided upon once new themes stop emerging in the analyzed data and will be decided upon by the project team in post analysis debriefing sessions.

3.1 Data Analysis and Coding methods

As a phenomenological study of the knowledge transfer process grounded in an existing theoretical framework, a thematic analysis was performed on the think aloud interview data to identify themes and patterns in responses that aligned with the chosen framework and would provide rich detail of the processes displayed by the participant.

Given that I was using an existing framework as a guide for this study, it seemed logical to initially apply a provisional coding approach (Saldana, 2021) based on the five stages of the knowledge transfer framework (Nokes & Belenky, 2011; Figure 1) in order to examine the approach used by the study participants. In this manner, participant behavior and use of the given framework would be directly deduced based on their discussion during the interview process. A limitation of the provisional coding scheme is, however, its reliance on existing codes that are decided apriori. This reliance limits its ability to recognize emergent or unexpected codes and themes that were not previously identified or looked for. I recognized this limitation and, as an attempt to employ a similar coding approach but allow for more emergent codes to be recorded, also applied process coding to the data. The choice of process coding was made as I was interested specifically in the problem solving approach used by the participants and felt that this coding scheme, based around actions and verbs might help to elucidate this process while allowing for emergent codes to be recorded. Axial coding (Saldana, 2021) was then used to integrate the provisional and process coding schemes and examine more specific actions that the participants were taking at each stage of the problem solving process. After these first and second cycle coding processes, the data was analyzed for themes and patterns in responses (Braun and Clarke, 2006) while remaining grounded in the chosen theoretical framework.

3.2 Positionality

I hope that much of my positionality and reflexivity has come through and been woven into the fabric of this article - such as in the clear bias I have introduced by examining a problem framed in an engineering context, that requires math knowledge to solve, and which is being examined using a very specific framework that I agree with personally. Other aspects of my identity that might be relevant to this study include the fact that I am a white male faculty member working at a predominantly white university who has little formal education in qualitative methods. Within this context I recognize the fact that I am pursuing this problem from something of a positivist background and also one that is grounded in white privilege - while I am interested in examining the knowledge transfer processes of different student groups, my aim is to find, or evidence, mechanisms that promote knowledge transfer (RQ2) and that benefit a majority of students.

3.3 Trustworthiness and Evidence of Rigor

In order to evidence the trustworthiness of the findings of this study, I kept thorough records (recordings, episode profiles, memos, etc.) to constitute an audit trail and am working with multiple other investigators on this project. These collaborators allow for peer review and debriefing (Creswell & Miller, 2000) as we analyze the data together and each provide our own perspective on the results (I am a "traditional" engineer by background, one of my collaborators is a social scientist and the other is an engineering faculty member who has worked in the field of educational research for several decades). The sampling of multiple participants also allowed for each to provide contributions to the same themes as the interview protocol was so heavily grounded in the chosen conceptual framework that examining each a-priori theme in the light of every participant was embedded into the research process.

3.4 Limitations of Study

In addition to the issues with the coding schemes described already, which skew towards being less interpretive based on their deductive origins, this study is also limited based on several factors, not least of which is my own choice to ground it in a very specific model of knowledge transfer (Nokes & Belenky, 2011) that matches my own thoughts about the process. Further limitations in particular relate to the study lacking prolonged engagement with participants or persistent observation in which the knowledge transfer process might be examined in different contexts within engineering. There is also a lack of triangulation of data as multiple types of data are not currently used - in the future I would like to correlate findings with quantitative indicators of student ability such as GPAs, scores in prior courses from which the knowledge is to be transferred, etc. To date however, this has not been done. 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" (Gagne et al., 1962; Davis et al., 1968).

4. Presentation of Data

This paper presents data taken from the analysis of a single interview from this study. In this case a faculty member in a mechanical engineering department was the participant. Two main themes emerged in the analysis of the data; (1) the extensive use of reflection by the participant in evaluating their problem solving approach and solution(s); (2) the deep understanding of the topic they displayed. I deemed the use of evaluative processes important as this is, in my experience, not a problem solving behavior students (novices) typically display and in this case, was instrumental in allowing the participant to successfully solve the problem. Similarly, the deeper understanding of the concepts evident in the work of the expert participant were a point of contrast to the general student body that I have observed. In developing comparative data, these two themes in particular seemed striking to me in their difference to what I imagine to be the student problem solving process.

4.1 Extensive use of Reflective Practices

The first theme I observed in the data was the consistent, extensive use of reflective and evaluative practices on behalf of the participant at all stages of the problem solving process. This finding was unexpected to me based on my prior (informal) observations of the knowledge transfer process (predominantly in students) and based on the framework I had chosen for this study which is much more linear in nature and where evaluation is the final element of the process.

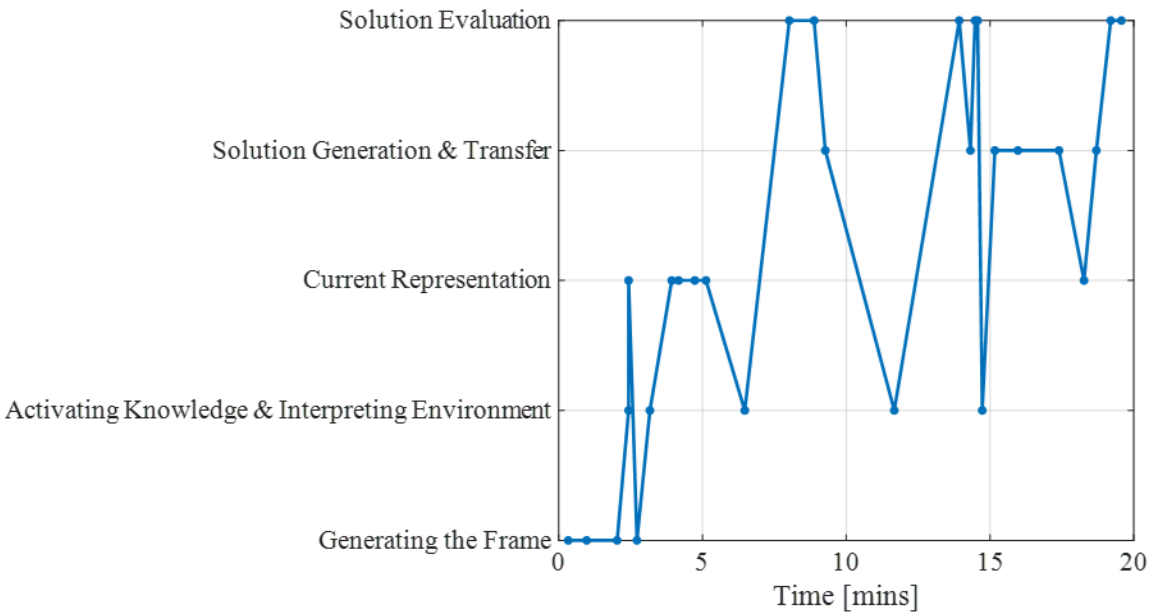

Figure 3: Sequence of framework stages participant was working in (coded from transcript) v. time spent solving the problem.

After initial application of the provisional coding scheme, I made an attempt to visualize the problem solving process of the participant and match their process to the framework. This visualization is shown in Figure 3 where the coded stage of the framework that the participant was operating in is shown as a function of time - or how far through the problem solving process they are. Several interesting features are revealed in this representation; clearly there is a progression with time through the stages of the framework from stage 1-5 but there is also a lot of iteration and both backwards and forwards "jumps" between stages. These jumps are in contrast to the more linear nature of the process suggested by the authors of the framework in which there is only back and forth between stages theorized, not discreet jumps between higher and lower levels as is observed here. While Figure 3 represents a single case only, this divergence from the literature is extremely interesting to me, especially in the use of solution evaluation at multiple stages of the process before coming back to an earlier stage. The fact that the participant evaluates their work so many times was a factor in their problem solving success as it allowed them to "catch" and correct mistakes they made, and could represent a different paradigm in terms of knowledge transfer that is missing from the framework suggested in the literature.

This theme of reflective practice (evaluation) is demonstrated in the following quote, which also demonstrates higher level thinking about the problem; "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." In this quote, the participant is talking through their cognitive process in terms of evaluating their work at an early stage of solving the problem solving process. In particular they are checking the units of an equation they intend to use and realize that there is an inconsistency in what they have done. Their process of rectifying this error is then demonstrated in which the participant thinks through the units of the equation and how using an area instead of a length would provide dimensional homogeneity. Considering the units of the solution is something that demonstrates a higher level of understanding as, working with Bloom's taxonomy, it signifies that the participant is able to work at a higher level of cognition beyond just application. Similarly, the evaluation process employed by the participant at the end of the problem is indicative of this higher level thinking:

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.

Here the participant is considering the validity of their final answer. They have found that the location of the centroid is roughly one third of the horizontal length of the plate and relate this to the location of the centroid for a square which would be at 1.5 ft in this case. They know that the centroid location has to be less than 1.5 given the shape of the plate and can use this value to judge the accuracy of their response. Again this example is indicative of reflection and evaluation on the part of the participant and displays a level of understanding of the physical underpinnings of the problem that (I believe) is typical of more experienced engineers.

Breaking down the total time spent by the participant in each stage of the framework is also suggestive of the degree to which reflection and developing a thorough understanding of the problem is utilized by the participant. As shown in Figure 4, roughly 29% of the participants' effort is spent on evaluating their work in this case. Without a point of reference this is difficult to explain or discuss in more detail but my suspicion is that this large percentage of time spent on reflective practice will be in contrast to more novice (student) approaches to problem solving. Reflection and evaluation are typically indicative of higher level (expert) thinking (see Bloom's Taxonomy for example) and is not often something students are asked to do. My own teaching experience corroborates this idea in that I have not observed students to be reflective to this extent in my own classrooms. I am, therefore, interested to see if a similar pattern results from student problem solving processes.

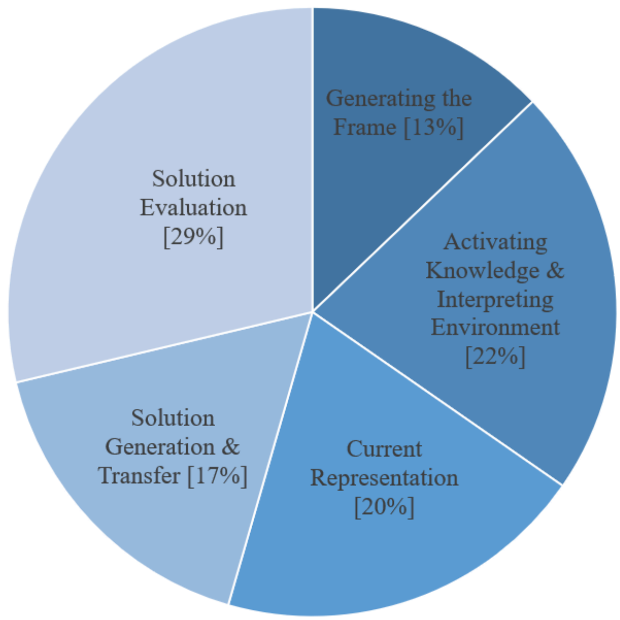

Figure 4: Percent of Total Time (1218s) Spent Solving the Problem in each Stage of the Framework

In terms of the research questions driving this study, the use of reflective practice observed here relates to ways in which problem solving success and knowledge transfer might be promoted (RQ2). The quotes and articles discussed clearly indicate the need for this expert participant to reflect on both their problem solving process, as well as their solution, in order to successfully solve the problem (which they did). A key example of this is the check they performed after noticing that they did not have dimensional homogeneity in one of their equations. Without this reflective element, they would have used an incorrect equation and developed an incorrect answer to the problem. While this is an early observation, it seems that encouraging reflective practice in students might be one mechanism for promoting success in transferring knowledge and solving applied problems.

4.2 Depth of Conceptual Understanding

In order to examine the barriers students might face in transferring knowledge, I asked the expert participant how they came up with their equations. They, the faculty participant, had solved the problem successfully and as such, a comparison of their thinking process compared to a novice could reveal potential challenges that might be faced by the students, as well as ways in which their success might be promoted by learning from the processes of an expert. This line of questioning revealed the deep understanding held by the expert of not only the subject at hand, but of other, similar concepts that could be stretched and twisted to fit this problem:

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.

This quote is the response to a somewhat leading question on my part: “So you're thinking about whether this equation is correct in a more holistic sense?” but demonstrates the participant’s understanding of the concept of integration at a deeper level as they are able to describe it using somewhat lay terminology. It also demonstrates the use of a metaphor on behalf of the participant to describe their thinking. Being able to relate the concept at hand to other ideas (as in a metaphor) seems to me to be demonstrative of deep understanding as one must fully understand the concept at hand in order to relate it to other ideas and describe it in a different way.

To follow up on these ideas discussed during the process of solving the problem, at the end of the interview I asked the participant how they came to their equations and knew that their formulations were correct: “Well, I knew that there had to be an x inside here. Because, in a sense, you're averaging something over the direction x.” This idea of integration to find the centroid being similar to an average also came up a little later in this discussion: “Yeah, I mean, like in statistics, this is like the average right of a continuous variable is x times that variable, and then you're integrating it over the possible range of values of that variable.”

In these quotes, the participant is able to explain the use of integration and their equations as similar to an average. They are able to simplify their thinking and relate the concept to another, analogous idea. The use of an analogy is indicative of deeper understanding in that the participant is able to explain their ideas in novel ways that are more relatable - one must understand the core concept at play in order to do this.

The participant’s deeper understanding of the mathematical concept of integration is further evidenced by their ability to explain integration in simpler terms using another analogy to time:

I'm gonna give you a different perspective. Proportional is now, integral is the past, and derivative is the future. So the integral and you're adding up all the things that you did in the past and you're creating a response based on all that derivative is like, here's where I am and here's my velocity, where am I going to be in half a second. So it's looking slightly into the future. And I think that kind of clicks with them because they did. They'd never heard that at all that like calculus can be thought of, like if you're if your horizontal axis is time, then calculus can be thought of as like the present, the past and the future.

This ability to provide an alternate perspective on a given topic is again typical of deeper conceptual understanding and expertise where adaptive experts are able to approach a problem from multiple perspectives (Hatano & Inagaki, 1986; Fisher & Peterson, 2001). Another example of this depth of understanding is how the participant was able to relate this problem to other contexts within engineering that would use a similar formulation to solve them or involve similar math and physics concepts. The following quote is a clear example of this: “Oh, that looks like you know, in fluid statics where you have like a curved surface underwater, and you're figuring out where the center of pressure is.”

In this quote, the participant is able to relate the concept of finding the centroid of the plate, necessary to solve the interview problem used in this study, to the center of pressure of a surface underwater. This example is another case of static equilibrium and finding the center of pressure is analogous to finding the centroid of the plate - the math is the same. This ability to link the concepts required in this problem to another context is indicative of an expert knowledge structure which is more interwoven than novice structures (Ambrose et al., 2010) and relates concepts from separate courses rather than viewing the material from a given course as separate from other pieces of the curriculum.

Again demonstrating their deep level of conceptual understanding, the participant was able to explain several other methods for solving the statics problem beyond just the analytical solution they employed (and were forced to employ) here:

I mean, like if I if I had my druthers, I would, you know, after I sketched this out, I would look at this and I would go online and say, Okay, what's the center of a quarter circle or, or I guess this isn't a quarter circle, but like, what's the center of like a figure that looks like that? Like like looking at centroid, because I know like on Wikipedia, they have like a whole bunch of like different centroids and I try to find something similar to that and see if there's like a pattern, you know, so like, if this wasn't perfect circle, I would just pull it from there and I wouldn't think twice about it.

*[Quote does not follow on from previous text, separate excerpt:] Yeah. Well, I mean, and I was thinking about as well, like, another backup plan would be, if I had access to 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. So you do have to remember that as an average is some kind of average. If you another way you could think of that is each of these pieces has like a tiny little m*g term. And so if I just add all those up, I would get the equivalent of mg*x bar. So I think if a student understood that, that would be good enough because you could write, you know, a script to do that.*

These comments came in the more free-form discussion towards the end of the interview process where I asked the participant to describe other ways of thinking about or solving this particular problem. In the first quote, they are able to discuss the use of tabulated or already extant data to solve the problem or enable them to make an educated guess of sorts. In the second quote, they describe a more elaborate approach to solving the problem numerically utilizing a computer code. This ability to take on multiple approaches to problem solving is indicative of a level of expertise beyond even routine expertise as might be developed by one entrenched in a given discipline (Hatano & Inagaki, 1986; Fisher & Peterson, 2001).

The deep understanding of the concepts at play in this problem relates to barriers to problem solving success that students might face (RQ1). Deeper knowledge structures are typically developed through experience and time spent working with similar problems and would not necessarily be expected of students, yet they are arguably required (in my mind) to be a successful engineer. Given that so many of our courses have prerequisite knowledge and require the successful transfer of this prior knowledge, it would seem however that other educators value this ability more broadly as well. As I have seen, and as discussed in the literature, many novice students do not possess this deeper understanding, which could represent a barrier to knowledge transfer if the knowledge to be transferred is not well understood or deeply ingrained to enable easy retrieval.

5. Summary, Implications & Outcomes

This study examined the process of knowledge transfer in the context of the approach to problem solving taken by an expert (faculty member) when tasked with solving a typical rigid body equilibrium problem typical of an undergraduate statics class. Importantly, this problem requires knowledge of mathematics and physics in order to solve correctly and the participant must successfully transfer this knowledge in order to correctly answer the problem. A semi-structured think aloud interview protocol based around solving the statics problem, coupled with an existing framework for knowledge transfer, was used to investigate the expert process.

After analysis of the resultant data, two major themes were identified in the participant's response to the interview protocol and questions. The expert participant displayed significant use of reflective and evaluative actions at all stages of the problem solving process, as well as a deep, conceptual understanding of the core concepts at play in the problem. This deep understanding, coupled with their evaluative thinking allowed them to formulate the governing equations for the problem based on first principles and analogy to other, similar problems without the need for memorization. These actions also allowed them to recognize and fix problems with units in their equation before they propagated through their solution. With regards to the research questions, and in particular RQ2 (mechanisms to promote successful knowledge transfer), if the importance of reflection is borne out in future work, there would seem to be some evidence for promoting evaluative and reflective practices amongst students to promote the successful transfer of knowledge. This statement is only true if this expert perspective is borne out in future investigation, however, and turns out to be a major point of comparison to the general student population (which my prior experiences lead me to believe it will be).

A secondary, but no less interesting outcome related to the significant use of reflection on the part of the participant, is that they did not strictly follow the framework of knowledge transfer chosen for this study. The use of evaluation and reflection at all stages of the problem solving process was unexpected to me, although it makes sense in hindsight. I am unsure if this is evidence of a limitation or inaccuracy in the chosen framework for this study, or if we could perhaps employ the framework in much smaller stages - it could be applied many times to sub-elements of the problem studied in this project.

Concerning the future of this study, the participant also discussed their thoughts as to whether this problem was an authentic one to solve in the open-ended discussion at the end of the interview. Personally, I am torn on this subject as my belief is that students should be able to transfer math skills to solve engineering problems but I also recognize that in the "real world" they would not solve a problem like this by hand. Is it then an authentic problem or case to analyze? The participant expressed the following thoughts:

I'm not sure. I... My perspective is like if you can either write a code or like design a simple experiment, to like answer the question but I can I guess I'm torn because I think being able to, at least derive the equations or if you're presented with the equations, be able to describe why the equation has that format. Maybe. Maybe that's what I really want to get out. So a student's solving this like being able to recall this equation to me is less important than if I wrote this equation down obviously with the A in here, but if I wrote this equation down, could the student describe why the equation has that form and why that particular form is needed to solve this problem?

This excerpt makes me think that my problem solving approach to examining knowledge transfer might not be the best course of action - especially given my doubts about the authenticity of this particular problem. The participant is correct in that we want the students to understand and be able to explain (conceptually and mathematically) what is happening here but I don't care if they can necessarily recall the equation from memory. They need to understand the concepts in order to apply it correctly and perhaps if they understand the concepts they could recall the equation better or formulate it themselves as this participant did? This line of thinking relates back to the deep understanding displayed by the participant, which again I assume would not be displayed by students. Does this lack of understanding on behalf of the students constitute a barrier to knowledge transfer (RQ1) and does the ability to transfer knowledge come with this deeper understanding? In which case we should be teaching this understanding more explicitly and not promoting knowledge transfer so explicitly? Clearly there are thoughts and ideas that this study has provoked and that I need to resolve with my project team as we carry this work forward.

Acknowledgements

Support for this work was provided by the National Science Foundation under Award No. 2301341. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. I would also like to thank Dr. Sam Van Horne for his input into this study, as well as my qualitative research course professor, Dr. Sarah Curtiss. Research work was conducted under institutional IRB protocols, IRB#1965654.

References

ABET, "Criteria for Accrediting Engineering Programs, 2020 – 2021 | ABET," ABET, 2021. https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2020-2021/ (accessed Nov. 02, 2021).

Ambrose, S. A., Bridges, M. W., DiPietro, M., Lovett, M. C., & Norman, M. K. (2010). How learning works: Seven research-based principles for smart teaching. John Wiley & Sons.

ASEE, "Transforming Undergraduate Education in Engineering: Phase 1 Synthesizing and Integrating Industry Perspectives," ASEE, 1, May 2013. Accessed: Oct. 27, 2021. [Online]. Available: https://tuee.asee.org/phase-i/report/

Barnett, S. M., & Ceci, S. J. (2002). When and where do we apply what we learn?: A taxonomy for far transfer. Psychological bulletin, 128(4), 612.

Bransford, J. D., & Schwartz, D. L. (1999). Chapter 3: Rethinking transfer: A simple proposal with multiple implications. Review of research in education, 24(1), 61-100.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). How people learn (Vol. 11). Washington, DC: National academy press.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. Qualitative Research in Psychology, 3(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Charters, E. (2003). The use of think-aloud methods in qualitative research an introduction to think-aloud methods. Brock Education Journal, 12(2). https://doi.org/10.26522/brocked.v12i2.38

Cowan, J. (2019). The potential of cognitive think-aloud protocols for educational action-research. Active Learning in Higher Education, 20(3), 219-232. https://doi.org/10.1177/1469787417735614

Creswell, J. W., and D. L. Miller. 2000. Determining validity in qualitative inquiry. Theory into Practice 39 (3): 124–30.

Davis, J. H., Carey, M. H., & Foxman, P. N. (1968). Verbalization, experimenter presence, and problem solving. Journal of Personality and Social Psychology, 8(3, Pt.1), 299–302. https://doi.org/10.1037/h0025519

De Rosa, A. J., Serbin, D., & Lee, S. (2019, November). Facilitating Cross-Course Connections & Knowledge Transfer between Engineering Thermodynamics and Mathematics (WIP). In 2019 Fall Mid Atlantic States Conference.

De Rosa, A. J. (2020, June). Examining Knowledge Transfer Between Thermodynamics and Mathematics. In 2020 ASEE Virtual Annual Conference Content Access.

Detterman, D. K., & Sternberg, R. J. (1993). Transfer on trial: Intelligence, cognition, and instruction. Ablex Publishing.

Ericsson, K. A., & Simon, H. A. (1980). Verbal reports as data. Psychological Review, 87(3), 215–251. https://doi.org/10.1037/0033-295X.87.3.215

Fisher, F., & Peterson, P. (2001, June). A tool to measure adaptive expertise in biomedical engineering students. In 2001 Annual Conference (pp. 6-120).

Gagné, R. M., & Smith, E. C., Jr. (1962). A study of the effects of verbalization on problem solving. Journal of Experimental Psychology, 63(1), 12–18. https://doi.org/10.1037/h0048703

Hatano, G. and K. Inagaki (1986). "Two courses of expertise." Child development and education in Japan: 262–272.

Hibbeler, R. C. (2004). Engineering mechanics: dynamics. Pearson Education.

Koro-Ljungberg, M., Douglas, E. P., Therriault, D., Malcolm, Z., & McNeill, N. (2013). Reconceptualizing and decentering think-aloud methodology in qualitative research. Qualitative Research, 13(6), 735-753. https://doi.org/10.1177/1468794112455040

Lee, C. S., McNeill, N. J., Douglas, E. P., Koro‐Ljungberg, M. E., & Therriault, D. J. (2013). Indispensable resource? A phenomenological study of textbook use in engineering problem solving. Journal of Engineering Education, 102(2), 269-288. https://doi.org/10.1002/jee.20011

Litzinger, T. A., Meter, P. V., Firetto, C. M., Passmore, L. J., Masters, C. B., Turns, S. R., ... & Zappe, S. E. (2010). A cognitive study of problem solving in statics. Journal of Engineering Education, 99(4), 337-353. https://doi.org/10.1002/j.2168-9830.2010.tb01067.x

Loverude, M. E., Kautz, C. H., & Heron, P. R. (2002). Student understanding of the first law of thermodynamics: Relating work to the adiabatic compression of an ideal gas. American Journal of Physics, 70(2), 137-148.

Meltzer, D. E. (2004). Investigation of students' reasoning regarding heat, work, and the first law of thermodynamics in an introductory calculus-based general physics course. American Journal of Physics, 72(11), 1432-1446.

Moghaddam, Y., Demirkan, H., & Spohrer, J. (2018). T-shaped professionals: Adaptive Innovators. Business Expert Press.

N. A. of Engineering and N. A. of Engineering, The Engineer of 2020: Visions of Engineering in the New Century. Washington, DC: The National Academies Press, 2004.

Nokes, T. J., & Belenky, D. M. (2011). Incorporating motivation into a theoretical framework for knowledge transfer. In Psychology of learning and motivation (Vol. 55, pp. 109-135). Academic Press.

Orton, A. (1983). Students' understanding of integration. Educational studies in mathematics, 14(1), 1-18.

Passmore, L., & Litzinger, T., & Masters, C. B., & Turns, S., & Van Meter, P., & Firetto, C., & Zappe, S. (2010, June), Sources Of Students' Difficulties With Couples And Moments In Statics Paper presented at 2010 Annual Conference & Exposition, Louisville, Kentucky. 10.18260/1-2--16198

Rebello, N. S., Cui, L., Bennett, A. G., Zollman, D. A., & Ozimek, D. J. (2017). Transfer of learning in problem solving in the context of mathematics and physics. In Learning to solve complex scientific problems (pp. 223-246). Routledge.

Saldaña, J. (2021). The coding manual for qualitative researchers. Sage.

Schoenfeld, A. H. (2014). Mathematical problem solving. Elsevier.

Vygotsky, L. S. (1962). Thought and language. (E. Hanfmann & G. Vaker Eds., Trans.). Cambridge, MA: MIT Press.