2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering Education for 130 Years
Paper ID #37336

Work in Progress: Using Think-Aloud Sessions to Understand Student Problem-Solving Approaches

Natalie Dow
Ryan Lee
Ms. Zihui Zhu, Embry-Riddle Aeronautical University - Prescott

Zihui Zhu is a senior at Embry-Riddle Aeronautical University (ERAU) in Prescott, Arizona, majoring in Aviation Business Administration with minors in mathematics, economics, and global business. She anticipates earning her Bachelor of Science degree in Aviation Business Administration from ERAU by May 2023, after which she will continue her studies at Johns Hopkins University graduate school, where she is going to major in applied economics.

Dr. Kaela M Martin, Embry-Riddle Aeronautical University - Prescott

Kaela Martin is an Associate Professor and Associate Department Chair of Aerospace Engineering at Embry-Riddle Aeronautical University, Prescott Campus. She graduated from Purdue University with a PhD in Aeronautical and Astronautical Engineering. Her research interests in engineering education include developing classroom interventions that improve student learning, designing experiences to further the development of students from novices to experts, and creating engaging classroom experiences.

Dr. Elif Miskioglu, Bucknell University

Dr. Elif Miskioglu is an early-career engineering education scholar and educator. She holds a B.S. in Chemical Engineering (with Genetics minor) from Iowa State University, and an M.S. and Ph.D. in Chemical Engineering from Ohio State University. Her early Ph.D. work focused on the development of bacterial biosensors capable of screening pesticides for specifically targeting the malaria vector mosquito, Anopheles gambiae. As a result, her diverse background also includes experience in infectious disease and epidemiology, providing crucial exposure to the broader context of engineering problems and their subsequent solutions. These diverse experiences and a growing passion for improving engineering education prompted Dr. Miskioglu to change her career path and become a scholar of engineering education. As an educator, she is committed to challenging her students to uncover new perspectives and dig deeper into the context of the societal problems engineering is intended to solve. As a scholar, she seeks to not only contribute original theoretical research to the field, but work to bridge the theory-to-practice gap in engineering education by serving as an ambassador for empirically driven educational practices.

Dr. Adam R Carberry, Arizona State University

Dr. Adam Carberry is an associate professor at Arizona State University in the Fulton Schools of Engineering, The Polytechnic School. He earned a B.S. in Materials Science Engineering from Alfred University, and received his M.S. and Ph.D., both from Tufts University, in Chemistry and Engineering Education respectively. His research investigates the development of new classroom innovations, assessment techniques, and identifying new ways to empirically understand how engineering students and educators learn. He currently serves as the Graduate Program Chair for the Engineering Education Systems and Design Ph.D. program. He is also the immediate past chair of the Research in Engineering Education Network (REEN) and a deputy editor for the Journal of Engineering Education (JEE). Prior to joining ASU he was a graduate research assistant at the Tufts' Center for Engineering Education and Outreach.

WIP: Using Think-Aloud Sessions to Understand Student Problem-Solving Approaches

Motivation and Background

Problem-solving is an essential skill needed in the field of engineering [1]. The ability to effectively solve complex engineering problems can be the difference between project success and failure, but problem solving differs based on expertise. Experts are known to employ different problem-solving strategies compared to novices [2, 3]. Experts' greater information processing capacity [4] allows them to approach a problem in a non-systematic manner [5]. Specific skills that allow experts to effectively solve a problem are the ability to mentally represent a situation and the ability to employ different problem-solving approaches for different types of engineering problems [6]. Expertise is largely developed through experience [7, 8], and problem solvers can use their prior experience for insight into the approaches and strategies needed to effectively navigate and resolve a complex engineering problem [7-9]. This insight is captured in the expert-specific problem-solving skill of intuition, a skill that remains understudied in engineering.

Experience, and the development of intuition that comes with it, can promote a transition from novice to expert [7, 10, 11] through the accumulation of knowledge over time [8, 12]. An accumulation of problem-solving experiences subsequently allows engineers to become domain experts [13] and exercise intuition in problem solving [9]. The accumulation of these experiences arguably begins during undergraduate, or even K-12, education. We aim to better understand students' approaches to engineering problem solving, particularly whether intuition is used as a means for advancing knowledge on expertise development and problem solving in engineering.

Our work explores the role intuition plays as part of problem solving. We have designed an instrument intended to capture when and how students use intuition during the problem-solving process [14]. This work-in-progress paper describes emergent findings from think-aloud sessions used to inform the development of the instrument, Predicting and Evaluating Engineering Problem Solving (PEEPS).

Methods

Qualitative data was collected during think-aloud sessions completed in spring 2021 with a sample of seven undergraduate students who had previously taken and passed a statics course. The PEEPS instrument presented statics problems for this iteration but is designed in a way that problems can be easily interchanged for other engineering concepts. The sessions were recorded using the Zoom video conferencing tool. Two interviewers were present to facilitate and observe each session. The primary interviewer asked questions from the interview protocol (Appendix) as the participant worked through the PEEPS instrument, which includes the statics problems and follow-up questions. The interviewer stressed that the purpose of the session was not to get the correct answer but for the participant to talk through their thought process in selecting an answer. The secondary interviewer took notes and asked additional questions if appropriate.

The instrument was initially given in Microsoft Forms and then transitioned to Qualtrics Evaluation Tool. The instrument that participants completed included two statics problems (one required evaluating an answer and the other predicting an outcome) and follow-up questions including their confidence in their answer choice and whether they would take additional steps to justify their answer. Participants were instructed to answer the problems while verbally annotating their thoughts and actions to allow the research team to follow their process and answer choice. The statics problems used were based on the Concept Assessment Tool for Statics (CATS) [15]; in one problem participants were asked to predict an outcome from a scenario and in the other to evaluate an existing outcome.

All seven participants attended a private southwestern university and majored in aerospace engineering. The majority of participants were White and male (Table 1). A small fraction of the participants reported a military status and most were in their final year. Pseudonyms were given to the participants to maintain confidentiality and safeguard their identities. All participants reported having received either an A or B in their statics class (taken at least a year prior); Adam noted receiving a B after the second time taking the course. Participants noted a variety of prior professional engineering experience, including work experience associated with the military or internships.

Table 1 Survey Participants Detailed Demographics (*n* = 7)

Name	**Gender**	**Military Status**	**Race or Ethnicity**	**College Year**	**Time Since Statics (yr)**	**Statics Grade**	**Professional Engineering Experience (yr)**
Noah	Male	ROTC	White or Caucasian	Senior	1-2	B	0.5
Olivia	Female	N/A	White or Caucasian	Senior	> 2	B	0.3
Liam	Male	Veteran	White or Caucasian	Senior	> 2	B	10.8
Lucas	Male	N/A	Native Hawaiian or Pacific Islander	Senior	> 2	A	0.5
James	Male	N/A	Middle Eastern or North African	Senior	1-2	A	0.7
Ethan	Male	N/A	White or Caucasian	Senior	> 2	A	0
Adam	Male	N/A	White or Caucasian	Junior	1-2	B	0

Preliminary analysis of the interviews considered common themes during the engineering problem-solving portion of the interview. Three team members watched the interview videos separately and noted the emergent factors that contributed to an individual's problem-solving approaches. The team members then met as a group to identify common themes and discuss notes of interest. The emergent ideas were then organized to identify overarching themes across participants that represented factors that affect problem-solving approaches.

Limitations
The major limitations of this work are the small sample size and lack of diversity in the sample. The lack of diversity exists as a limitation but is typical within the field of engineering in the United States [16]. We also acknowledge that the data presented here was collected at a fixed point of time and responses could change over time.

Results and Discussion

Responses to the statics problems included hesitation when viewing the concept inventory questions. In solving the problems, participants applied different approaches that were affected by their prior engineering experience. Participants with prior internship experience were more likely to conceptualize the problem as a problem-solving strategy and more likely to select the correct answer.

Participant Hesitation
Participants were told ahead of time that the instrument would require them to solve statics problems, but many appeared startled or unprepared when the first statics question was presented to them. Liam stated, "If I was in statics that would have gone a lot better." The participants' surprise could have been caused by a lack of recent experience or exposure to statics concepts and could also explain why participants expressed hesitation when asked to explain their answers. This hesitation manifested as either modifying their answer to the concept inventory question or verbally stating hesitation. More than half of the participants modified their choices after completing the instrument question that asked them to justify why they selected a particular answer. This signals that the participants were not entirely confident in their initial choices. It is highly possible that in recalling information to explain their answer, participants recalled additional information that led them to change their answer. There were no significant differences in the length of time it took participants to answer the concept questions based on how long it had been since they took statics suggesting that participants were able to recall information with equal difficulty or ease, regardless of how recently they completed statics. The three participants that spent the longest time on the prediction problem (three to four minutes) ultimately selected the correct answer and two of the students who answered the questions without seeming to give much thought or time (less than one minute) ended up selecting the incorrect answer, suggesting that length of time spent thinking about the problem does allow the participants to recall more relevant information and supports problem-solving success.

Influence of Prior Engineering Experience
Participants used a variety of different strategies to select their answers. Some interviewees used a process of elimination explaining why each answer choice was correct or incorrect. Other students read the question, verbally described what the solution should be, and then found a

corresponding answer choice. The contrast in processes used to select an answer demonstrates the variety of problem-solving strategies students develop throughout their education as they develop expertise in solving problems [7, 8].

Prior professional engineering experience held by five of seven participants may have influenced their problem-solving approaches. For example, Olivia used prior knowledge from an internship focused on similar concepts (material and tensile testing). She very clearly worked through the problem aloud starting with looking at the forces and identifying them using prior knowledge to characterize the system. Olivia then stated, "so this looks like a three fourths member which means they should all be coincident at a point." After recognizing the problem type, she started to problem solve by conceptualizing the motion of the system. Looking at the forces, she mentioned, "these probably cancel each other out and this is going down" before selecting a corresponding answer choice. Observing Olivia's use of her previous knowledge to understand the type of system and conceptualize how the forces interact with one another demonstrates the direct influence of prior knowledge on her problem-solving approaches. In justifying her answer on the instrument, Olivia responded, "Probably not perform calculations, that's usually not my first jump to. I kind of like to physically demonstrate the system. I'm very tactile so I like to see how something would work." Olivia's response reflects a level of self-awareness (recognition that she is tactile) as a factor that influences her problem-solving approaches.

The other four participants with prior engineering experience similarly appeared influenced by their recent engineering experiences in their approach to the problems. Other research has shown that students often use their lived experiences to approach problem solving [17]. All four used previous knowledge of statics in discussing the sum of forces and moments. Lucas stated, "Oh my it's been a while" while trying to remember how the system works. A few minutes later, Lucas mentioned he remembered the qualities of a free rotating system and immediately stated, "Oh I understand this more now" and came to a conclusion. James, a student who previously held two different internship experiences, used the exact same approach as Olivia. James also began with identifying the forces, then used prior knowledge for sum of forces, sum of moments, reactions of a pin support, and qualities of a frictionless reaction before finding a matching answer.

Of the two participants who did not have prior engineering experience one, Ethan, answered quickly (a few seconds) and the other, Adam, took about a minute on both concept inventory questions. Adam struggled to discuss his thoughts out loud during the session, which left his actions unclear. Ethan conceptualized the sum of forces and moments briefly and then quickly jumped between different answers. When asked about his confidence in his answer selection of "maybe/not sure," Ethan proceeded to say, "I mean there is nothing certain in this world but the speed of light." When asked about justifying their response, Ethan responded that he would prefer to use equations or Matlab to verify the answer. The desire to use numbers to determine the solution shows a contrast to the participants who used prior knowledge and were able to think through the reactions of the system conceptually instead. The ability to determine the outcome of a system without using numbers suggests more advanced problem-solving skills and progression towards expertise and the role experience plays in the development of problem-solving skills [18]. Students with a novice skill level may be more likely to rely on numbers since they have not developed the skills required for more conceptual problem solving.

Participants recognized the importance of conceptual understanding, as evidenced by Ethan's statement that, "It's always good to go to the fundamentals and basics and sometimes you realize maybe we should spend some time reviewing past concepts." He went on to state that, in school, engineering students are always using calculators or software, causing complacency in conceptual-style questions. Ethan's ability to recognize his dependency on numbers in problem solving highlights the importance of emphasizing conceptual understanding throughout engineering education.

Conclusion and Future Work

Our primary findings revealed hesitation on the part of students when asked to solve statics problems and suggests that prior professional engineering experience may influence problem-solving approaches. These findings map to existing literature [9]. Participants with prior engineering experience were more likely to successfully solve the problems and were able to use their prior experience to arrive at their answers. This result strengthens the argument for ensuring that engineering students gain exposure to the engineering field during their studies.

This study is part of a larger ongoing effort to understand the use of intuition in engineering problem solving. Future work will deploy a revised instrument to a broader participant pool with the purpose of gaining data from a larger, more diverse sample of engineering students. The instrument will continue to include two problems and follow-up questions on confidence, next steps, and justification of answers. Open-ended questions provide an opportunity to gather richer data from participants, though the richness of the data will be more limited than interview methods would provide. This larger dataset will allow for more definitive results to determine direct linkages between experience and problem-solving approaches, while investigating potential demographic variable impacts. Students with prior professional engineering experience appeared to be confident in their responses, but we did not have a large enough sample to determine if there is a true correlation between confidence and experience. Further research will allow us to determine factors that influence engineering students' approaches to problem solving and identify areas that may need greater attention in engineering education.

Acknowledgements

This work was supported by the National Science Foundation under Grant No. 1927149 and Grant No. 1927250.

References

[1] D. Jonassen, J. Strobel, and C. B. Lee, "Everyday Problem Solving in engineering: Lessons for Engineering Educators," *Journal of Engineering Education*, vol. 95, no. 2, pp. 139–151, 2006.

[2] D. Tirosh and J. Clement, "Use of physical intuition and imagistic simulation in expert problem solving," in *Implicit and Explicit Knowledge: An Educational Approach (Human Development)* , vol. 6, Hillsdale, NJ: Ablex Pub. Corp., 1994, pp. 204–244.

[3] T. J. Nokes, C. D. Schunn, and M. T. H. Chi, "Problem solving and human expertise," in *The International Encyclopedia of Education*, 3rd ed., Amsterdam: Elsevier Academic Press, 2010, pp. 265–272.

[4] B. Adelson, “Problem solving and the development of abstract categories in programming languages,” *Memory & Cognition*, vol. 9, no. 4, pp. 422–433, 1981.
[5] J. Metcalfe and D. Wiebe, “Intuition in insight and noninsight problem solving,” *Memory & Cognition*, vol. 15, no. 3, pp. 238–246, May 1987.
[6] D. H. Jonassen, “Toward a design theory of problem solving,” *Educational Technology Research and Development*, vol. 48, no. 4, pp. 63–85, 2000.
[7] S. E. Dreyfus, “Five-stage model of adult skill acquisition,” *Bulletin of Science, Technology & Society*, vol. 24, no. 3, pp. 177–181, 2004.
[8] M. T. H. Chi, R. Glaser, and M. J. Farr, *The nature of expertise*, 1st ed. 1988.
[9] E. E. Miskioglu *et al.*, "Situating Intuition in Engineering Practice," *Journal of Engineering Education,* vol. 112, no. 2, pp. 418-444, 2023, doi: 10.1002/jee.20521.
[10] K. A. Ericsson, N. Charness, P. J. Feltovich, and R. R. Hoffman, M. T. H. Chi, “Two approaches to the study of experts' characteristics,” in *The Cambridge Handbook of Expertise and expert performance*, Cambridge: Cambridge University Press, 2006, pp. 21–30.
[11] A. Ericsson, J. Smith, V. L. Patel, and G. J. Groen, “The general and specific nature of medical expertise: A critical look,” in *Toward a general theory of expertise: Prospects and limits*, Cambridge: Cambridge University Press, 1991, pp. 93–125.
[12] National Research Council, *How people Learn: Brain, Mind, Experience, and School: Expanded Edition*. 2000. The National Academies Press. [Online]. Available: https://doi.org/10.17226/9853
[13] P. J. Feltovich, K. M. Ford, R. R. Hoffman, C. M. Seifert, A. L. Patalano, K. J. Hammond, and T. M. Converse, “Experience and expertise: The role of memory in planning for opportunities,” in *Expertise in context: Human and machine*, Menlo Park, CA: AAAI Press, 1997.
[14] K. M. Martin, E. Miskioglu, C. Noble, A. McIntyre, C. S. Bolton, and A. Carberry, "Predicting and Evaluationg Engineering Problem Solving (PEEPS): Instrument Development," presented at the Research in Engineering Education Symposium & Australasian Association for Engineering Education Conference, Perth, Australia, 2021.
[15] P. S. Steif and J. A. Dantzler, “A statics concept inventory: Development and Psychometric Analysis,” *Journal of Engineering Education*, vol. 94, no. 4, pp. 363–371, 2005.
[16] *Profiles of Engineering and Engineering Technology, 2021*. 2022, American Society of Engineering Education: Washington, DC.
[17] J. Stransky, C. Ritz, E. Dringenberg, E. Miskioglu, and C. Bodnar, “Students use their lived experiences to justify their beliefs about how they will approach process safety judgments,” presented at ASEE Annual Conference, Baltimore, MD, June 2023.
[18] S. E. Dreyfus and H. L. Dreyfus, *A five-stage model of the mental activities involved in directed skill acquisition*. Berkeley: Operations Research Center, University of California, Berkeley, 1980.

Appendix - Interview Protocol for Think-Aloud Sessions

1. Introduce yourselves and the think-aloud process (asking participants to narrate their experience as they work through the Rep – with emphasis on how they are interpreting what each question is asking – you'll be mostly observing but asking them to expand). Let the participant now who will be speaking with them, and who is mostly observing/there as backup in case of a technical glitch (e.g., main-interviewer loses internet connection). Mention we don't care about the right or wrong answer. Just want your reaction.

2. Ask for permission to record (emphasizing that the recording will only be viewed by the study team, to verify that we don't miss anything important!)

3. Send link in chat

4. Ask participant to share screen, and to go to the survey

5. Observe, take notes, prompt as needed. Potential prompts:
    a. How do you interpret this prompt/question? (consider for each page or each question)
    b. Did you have any hesitation about what was being asked?

6. At end of survey, move into questions
    a. What was your impression of the survey?
        i. Was it easy to navigate?
        ii. Was it straightforward?
        iii. Did you understand each question/prompt? Were any confusing? (which ones, why if they can identify it)
    b. Should the statics question order be changed in the survey?
    c. How was the survey length?
    d. Were any answers missing from the multiple-choice questions?
    e. Was there any information that you felt was unnecessary in the survey? If so, what?
    f. Ask if other interviewer partner has anything to add.

7. Ask the participant: Is there anything else you'd like to add? Can we follow-up if we have any follow-up questions?