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Predicting and Evaluating Engineering Problem Solving (PEEPS): Instrument Development

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ABSTRACT

CONTEXT

Judging the feasibility of solutions has become an increasingly important engineering skill as engineering problem solving has become more complex and technology-dependent. Engineering education must take care to foster engineering judgement in our students to produce robust problem solvers primed to critically evaluate and interpret output. Our work uses expertise development and dual-cognition processing theories (Dreyfus & Dreyfus, 1980; Smith, 2009; Simon, 1987) to frame such engineering judgement as engineering intuition or the ability to assess the outcome of an engineering solution and predict outcomes within an engineering scenario (Miskioğlu and Martin, 2019).

PURPOSE OR GOAL

Our overarching goal is to create classroom interventions that explicitly recognize and enhance the development of engineering intuition. Accomplishing this goal requires a means of measuring engineering intuition before and after such interventions. This paper discusses our process to develop the Predicting and Evaluating Engineering Problem Solving (PEEPS) tool for measuring engineering intuition.

APPROACH OR METHODOLOGY/METHODS

PEEPS is built directly on our prior qualitative work with practicing engineers, which revealed the construct of engineering intuition (Aaron et al., 2020). The emergent findings were combined with questions adapted from the Concept Assessment Tool for Statics (Steif & Dantzler, 2005) to create a preliminary survey assessing intuition. Additional items asked participants to assess their level of confidence in their answers. The survey was designed such that the statics problems could be switched out for other forms of engineering problems. Think-aloud sessions were used to check face validity and usability prior to full deployment in Spring 2021.

ACTUAL OR ANTICIPATED OUTCOMES

This study details the process used to create PEEPS. Modifications were made following 19 think aloud sessions. The initial deployment in Spring 2021 resulted in 88 completed responses with responses primarily coming from white, male, aerospace engineering students who had previously performed well in their statics courses.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

This work showcases a new survey designed to assess the engineering intuition of engineering students. Next steps include expanding the work to a more diverse sample of engineering students, further validity checks of the instrument, and pairing the instrument with newly created educational interventions designed to better foster engineering intuition development in students.

KEYWORDS

engineering judgement, problem solving, survey development

Introduction

It is important for engineering students to develop requisite technical and professional skills in preparation for an engineering career. This skill includes an ability to navigate problems, or intuition, which is critical to engineering practice (Miskioğlu et al., 2021b). A better understanding of intuition is central to being able to design curricula that promotes intuition development.

Intuition is a key trait of the expert in most expertise development models (e.g., Benner, 1984; Dreyfus & Dreyfus 1980; Chi, 2006). The concept of intuition also emerges as one-side of many dual-cognitive models. For example in Kahneman's model of System 1 versus System 2, intuition lies within System 1 and relies on fast responses and "gut feelings" that arise through recognition of patterns and previous experience (Kahneman, 2013). Intuitive responses are fast and effortless and accompany the development of expertise (Dringenberg & Abell, 2018). Experience is a primary contributor to development and implementation of intuition (Kahneman, 2013; Dreyfus & Dreyfus, 1980). Intuition is often domain-specific like expertise. Research has suggested that engineering intuition results from experience with the specific methods and situations of engineering problems (Penner & Klahr, 1996; Miskioğlu et al., 2020).

Engineering intuition has not been widely studied in engineering but has emerged in the fields of nursing and management because of its perceived role in expertise development. Intuition has been shown to be prevalent in nursing with more frequent use among more experienced nurses (Leners, 1992). Business managers use their intuition to make faster decisions when information is missing (Simon, 1987; Burke & Miller, 1999). Studies performed in both nursing (Smith, 2009) and management (Simon, 1987) have claimed that expertise is developed primarily through experience and recognition. A clear definition of and way to measure intuition are missing in the existing literature despite the wide acknowledgement of intuition in expertise models and the literature on nursing and management.

We have studied the definition of engineering intuition in previous work. We define it as the ability to: (1) assess the feasibility of a solution or response, and (2) predict outcomes and/or options of a scenario (Aaron et al., 2020). Our emergent definition comes from interviews with practicing engineering professionals to better understand how they make decisions on the job as well as their own perception of intuition and its use in engineering (Miskioğlu et al., 2021a). Our current aim is to develop an instrument capable of measuring engineering intuition quantitatively. Here we discuss the steps undertaken to create the Predicting and Evaluating Engineering Problem Solving (PEEPS), a tool designed to measure engineering intuition. The final objective of PEEPS is to measure the effectiveness of classroom interventions to support the development of intuition.

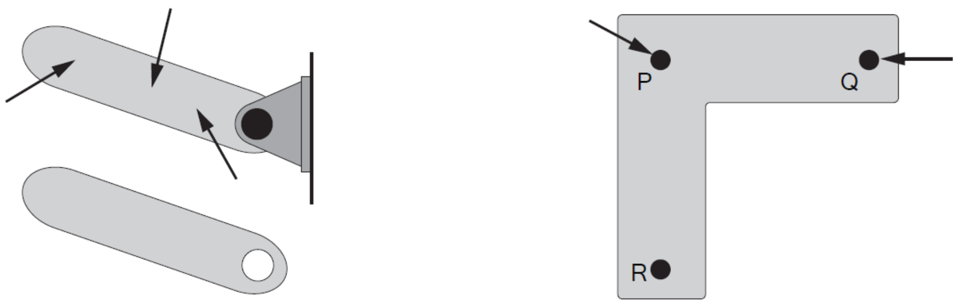
Methodology

PEEPS was developed during Spring 2021 as part of a mixed methods study. The design of PEEPS was informed by emergent themes that arose through qualitative interviews of practicing engineers. Themes were used to design survey questions that were tested using a think-aloud approach prior to deploying PEEPS more widely.

Question Development

Our qualitative work revealed that intuition consists primarily of two abilities: (1) the ability to predict an outcome, and (2) the ability to judge the feasibility of a solution or outcome (Aaron et al., 2020). The instrument consists of two main questions that ask respondents to provide a prediction and a "sensibility check" (i.e., judging the outcome).

Our previous work has also shown that intuition and expertise are domain specific (Miskioğlu and Martin, 2019; Aaron et al., 2020; Patel & Groen, 1991; Seifert, Patalano, Hammond, Converse, 1997; Chi, 2006). For example, you might have intuition about how much stress a steel beam can sustain at room temperature but not at extremely low temperatures. Our survey structure recognizes this domain-specificity and serves as a template in which the technical question can be replaced to test intuition with respect to any engineering domain. Our initial work uses the domain of statics. Questions were obtained from the Concept Assessment Tool for Statics (CATS), which has been tested with adequate validity evidence (Steif & Dantzler, 2005; Steif & Hansen, 2006; Roman, Streveler, Steif, & DiBello, 2010). The two CATS problems we chose are shown in Figure 1.



Which one of the following additional loads, if given the right magnitude, could lead to equilibrium?	Given the two non-zero forces in the image, which additional load, if given the right magnitude, could lead to equilibrium?
a. Sensibility check problem	***b. Prediction problem***

Figure 1: Statics problems used for PEEPS

The CATS problems are context-free. A context was developed for each problem to better mimic a real-world engineering scenario. Stories, scenarios, or cases have been shown to support problem solving (Jonassen & Hernandez-Serrano, 2002; Mariappan, Shih, & Schrader, 2004; Segall, 2002). The prediction problem in Figure 1a became a partially opened hatch with the following setup.

> *You are building a bookshelf and are placing an L-bracket to keep a shelf in place. Given the two non-zero forces in the image, which additional load, if given the right magnitude, could lead to equilibrium?*

The sensibility check problem in Figure 1b became a support for a bookshelf initially with the following description.

> *Imagine that you are trying to open a hatch. You can only open the hatch partway, so the system is in static equilibrium. One side of the hatch has a pin which allows the part you are pushing to rotate freely without friction. Assume the weight of the system and your push through two hands results in the following 2D loads. Could the reaction of the pin be as shown?*

The modified CATS problems were reviewed by the research team and were also externally reviewed by a long-time statics instructor to ensure that the contexts we developed were appropriate.

The CATS problems described above represent the interchangeable domain-specific technical scenarios. The heart of the survey are the follow-up questions. For both problems we asked about the participant's confidence in their answer as our qualitative results demonstrated a link between confidence and use of intuition (Aaron et al., 2020). We also asked about their general process for arriving at the selected answer. The sensibility check question asked an additional three questions regarding the likelihood of taking additional steps to justify their answer if someone challenged them, the reasoning for their likelihood, and their first approach to justify their answer. The prediction question asked how likely they would be to go with just this prediction to their manager, the reasoning for the likelihood, and what would make them more likely to go to their manager. The survey ended with demographic questions to support testing differences between groups.

Face-validity Data Collection

Face-validity data was collected through a series of approximately 30 minute think-aloud sessions (Ericsson & Simon, 1993) with 19 undergraduate student participants between February and March of 2021. All participants were recruited from a single US institution after having completed statics. The intial pool consisted of 100 students. We ultimately pivoted to convenience sampling due to low yield from initial recruitment. PEEPS was initially created in Microsoft Forms for simplicity and was tested in Microsoft Forms by seven students. Microsoft Forms did not have the desired functionality, so the survey was moved to Qualtrics for the remaining think-aloud sessions.

Think-alouds were conducted iteratively in cycles that allowed us to update and retest the PEEPS. During the think-alouds, students verbalized their thoughts as they progressed through the survey. We conducted brief interviews following each think-aloud to gather additional data on the user experience with the survey navigation, survey length, question order, and question clarity. Think-alouds concluded when the survey no longer needed modifications.

Deployment

We deployed the survey in April 2021 recruiting participants via email. The survey was sent to engineering students who were currently enrolled or had taken a statics class. Emails were sent by the authors, faculty at other universities who taught statics, and others within the broader engineering education community. We targeted instructors in our professional networks as well as those at US-based institutions whose instructors for statics and dynamics classes were publicly listed. We also advertised the survey through the Educational Research and Methods division of the American Society of Engineering Education. Most of the instructors that replied directly were from US institutions. Student university affiliation was not collected, so the reach of the survey beyond the US is unknown. Responses were collected until mid-May. A total of 172 responses were collected, of which 88 were complete (two of these 88 answered some but not all of the demographics questions) and used for our dataset.

Preliminary Results

The results presented here demonstrate the survey evolution through think-aloud sessions as well as early results from the first deployment of the finalized survey.

Think-Aloud Results

The sample (see Table 1) roughly mirrors the demographics found in a recent survey on engineering universities (Roy, 2019; ASEE, 2021). The prevalence of seniors with internships and good grades suggests that this sample was relatively experienced with the types of questions being asked in the first deployment as the think aloud sessions were selected by convenience.
In response to the think-aloud sessions the survey was modified by: (1) adding an initial warm-up question, (2) changing the problem order, (3) re-wording the CATS scenario prompt, (4) modifying the illustrations, and (5) altering the follow-up question wording.

Table 1: Think Aloud Participant Demographics (n=19)

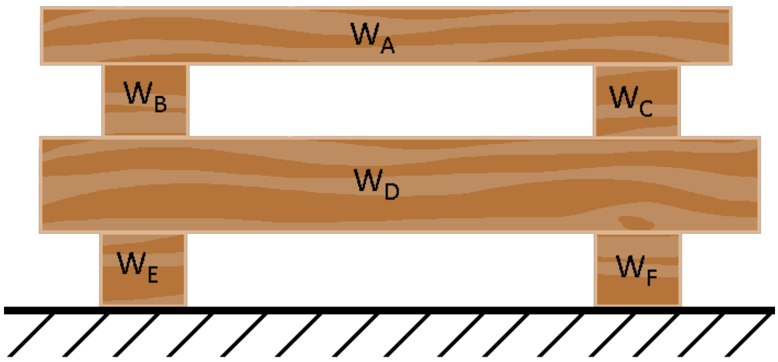
Gender	N	Year	N	Race/Ethnicity*	N	Internship	N	Statics Grade	N
Male	14	2nd Year	2	Asian	1	Yes	14	A	10
Female	4	3rd Year	2	Hispanic	3	No	5	B	9
Cisgender	1	4th Year	15	White	13			C	0
				Pacific Islander or Hawaiian Native	1			D	0
				Middle Eastern or North African	2			F	0
				American Indian Or Alaska Native	0				
				Black or African American	1				

* Multiple selections possible

(1) Adding an Initial "Warm-up" Question

Early think-aloud participants appeared to be startled by the question (responses were similar to "oh no") when they arrived at the first CATS problem. This response was alleviated by creating an easier problem (see Figure 2) at the beginning of the survey to reacclimate students with statics problems prior to assessing their responses. We once again added a context to the problem to help students situate the scenario.

Imagine that you are drying lumber by placing the drying pieces on top of smaller pieces of wood. The stack of wood is arranged symmetrically where $W_B = W_C$ and $W_E = W_F$.



Consider the free body diagram of W_B, W_C, and W_D. The contact force between two blocks is labeled so that N_{DE} is the force of block D on block E, and so forth. Which is the correct free body diagram?

Figure 2: Added initial statics problem

(2) Changing Problem Order

We switched the order of the two problems of interest (prediction and sensibility check) to align with increased perceived difficulty. Most students thought the prediction problem was more difficult, so this question was shifted to follow the sensibility check question.

(3) Re-Wording Sensibility Check Prompt

The prediction problem wording remained the same, but the sensibility check problem underwent a slight wording change with the final scenario sentence. Students were sometimes confused about the “push through two hands,” so we modified this language to “force through two hands” which was better received.

(4) Modifying Illustrations

We included figures within the survey to illustrate the context around the CATS questions. Figures (see Figure 3) were adjusted after feedback to better represent the forces in the CATS questions and clarify the images. For example, we rotated the “hatch” in the sensibility check problem (see Figures 3a and b) to better align the downward force seen in Figure 1a with gravity. The first version of the bookshelf prediction problem did not depict the L-bracket in Figure 3c as a flat object as shown in Figure 1b, so we modified how the L-bracket was attached to the bookshelf in the final version shown in Figure 3d. We also embedded the diagrams without forces from Figure 1 into the images in Figures 3b and 3d to better depict how the members related to the images in Figure 3.

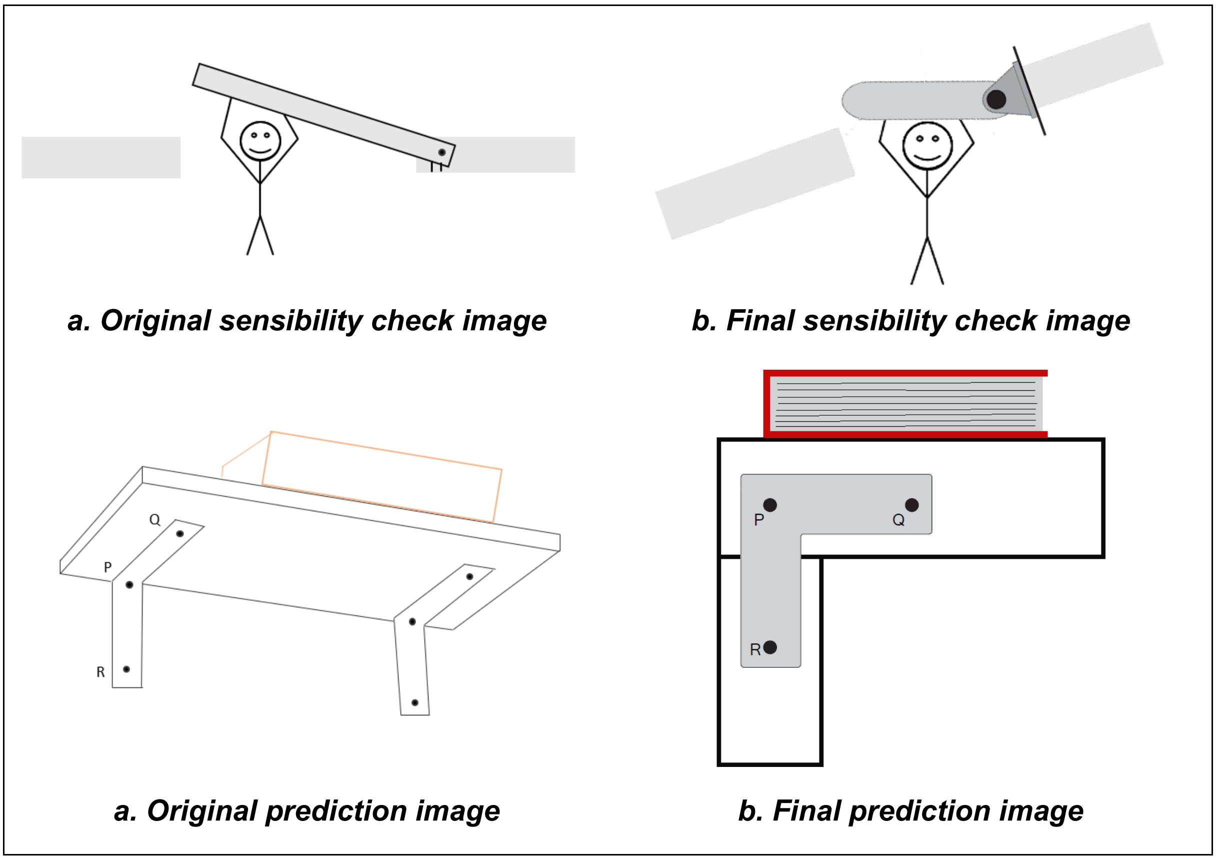


Figure 3: Figure changes between first and final version of PEEPS

(5) Altering Follow-up Question Wording

The first two questions after the prompts remained the same (“How confident are you in your answer?” and “How did you choose your answer?”). The remaining questions were altered.

The original and final sensibility check questions are listed in Table 2. We realized that the first question listed in Table 2 assumed that students would justify their answer, so we modified that question to the likelihood that they would take additional steps to justify their answer. We also added in logic to skip the justification approach (final question in Table 2) if the students answered “definitely would not.” During the think-aloud sessions, some students were confused with the last (original) question on what “previous question” referred to, so we clarified the previous question in the final version and changed the order. We initially left the justification approach question as an open-ended question. Answers quickly converged to allow this question to be converted to a fixed-item, multiple choice question with an option to specify if not listed.

Table 2: Original and final questions for sensibility check question

Original Questions	Final Questions
If someone challenged you on your answer, how would you justify your answer? *[open-ended]*	In the event that someone challenged you on your answer, what is the likelihood that you would take additional steps to justify your answer? a. definitely would not *[if selected, skip final question]* b. maybe/not sure c. probably would d. definitely would
How likely are you to go through with the justification approach you chose in the previous question? a. definitely would not b. maybe/not sure c. probably would d. definitely would	Explain your reasoning for the rating you gave in the previous question (the likelihood of taking additional steps to justify your answer). *[open-ended]*
Explain your reasoning for the rating you gave in the previous question. *[open-ended]*	What would be your first approach to justify your answer? a. Perform calculations b. Check reference materials (static notes, textbooks, etc.) c. Physically demonstrate the system d. Not listed (please specify)

The original and final prediction questions are listed in Table 3. Students were reminded to reflect on the statics question at the beginning of the questions. The format was modified to mimic the flow of questions in the sensibility check prompt. We modified the open-ended

Table 3: Original and final questions for prediction question

Original Questions	Final Questions
If you were in a situation where your manager asked a similar question, how likely would you be to go to your manager with just this prediction? a. definitely would not b. maybe/not sure c. probably would d. definitely would	You've made a prediction about the loads on the bookshelf (your answer on the previous page). If you were in a situation where your manager asked a similar question, how likely would you be to go to your manager with just this prediction? a. definitely would not b. maybe/not sure c. probably would d. definitely would *[if selected, skip last question]*
How would you check your answer?	Explain your reasoning for the rating you gave in the previous question (the likelihood that you would go to your manger with just this prediction). *[open-ended]*
	What would make you more likely to go to your manager? a. First performing calculations b. First checking reference materials (static notes, textbooks, etc.)

	c. First physically demonstrating the system d. Not listed (please specify)

question to align with our primary interest in understanding the reasoning behind the choice rather than how the students would check their answer. We still wanted to know what additional work students would complete to feel more confident in going to their manager. A question was added to capture what would make students more likely to go to their manager with similar options to the last question in Table 2.

First Deployment Results

The first deployment following changes made from the think-aloud sessions resulted in 88 completed responses. The respondent demographics are shown in Tables 4 and 5. Respondents primarily identified as white and male, were mostly aerospace engineers, and over two-thirds had a parent with at least a 4-year degree. Respondents were primarily in their second-year (42%) followed by third-year students (28%). The average internship experience (n = 33) was 7.3 months for those with such experience.

The demographics of our initial survey are roughly representative of the race and sex profile of undergraduate enrolment in US universities (Roy, 2019). Aerospace engineers are overrepresented as the author's university is primarily an aerospace-focused university. The number of students who self-reported receiving a B or better in statics indicates that our sample was relatively knowledgeable in the types of problems tested in this survey.

Table 4: First Deployment Participant Demographics (n=88)

Major*	**N**	**Race/Ethnicity***	**N**	**Parent's Degree**	**N**
Aero Engr.	45	American Indian	1	Doctorate	4
Mech Engr.	27	Asian	10	Masters	16
Civil Engr.	6	Black	3	4-year Degree	43
Other Engr.	3	Hispanic	7	2-year Degree	5
Physics	5	White	72	Some College	8
Math	2	Prefer Not to Answer	5	Professional Degree	1
Prefer Not to Answer	1			High School	7
				Less than High School	2
				Prefer Not to Answer	0

* Multiple selections possible

Table 5: First Deployment Participant Demographics Continued (n=88)

Year	**N**	**Internship**	**N**	**Gender**	**N**	**Statics Grade**	**N**
1st year	9	Yes	33	M	59	A	43
2nd year	37	No	52	F	24	B	25
3rd year	25	Prefer Not to Answer	3	Prefer Not to Answer	3	C	16
4th year	14					D	2
Prefer Not to Answer	3					F	1

						Prefer Not to Answer	1

Early Results: Relationship between Answer Correctness and Confidence

Our initial analyses considered differences in confidence levels among respondents who correctly answered the sensibility check and prediction problems. The answers to confidence levels were re-coded as numbers (1 = not at all confident, 2 = maybe/not sure, 3 = pretty confident, 4 = completely confident). Both the prediction and sensibility check were found to not be normal using the Shapiro-Wilk normality test ($p < 0.001$ for both the sensibility and prediction problems), so the unpaired, two-samples Wilcoxon test (also known as Mann-Whitney test) was used to determine if the confidence levels of the students who answered correctly differed from those who answered incorrectly. The correlations between average confidence levels and correct/incorrect answer were significant for both the sensibility check problem ($p < 0.003$) and the prediction problem ($p < 0.002$). Respondents who answered incorrectly had lower average confidence for both the sensibility check problem ($p < 0.002$) and the prediction problem ($p < 0.001$) as demonstrated by the means of each group in Table 6. This result suggests that respondents were more confident when they got the correct answer. This alignment of confidence and accuracy may be a result of the overall high statics-performance of the participant population. The majority of the respondents self-reported having received a letter grade of A or B in their most recent statics course making it possible that this sample was better able to predict their outcome. That is, their high competence in the subject area may have given respondents a more accurate ability to evaluate their performance (Kruger & Dunning, 1999). The alignment between confidence and accuracy also suggests high metacognitive sensitivity of the respondents (Flemming & Lau, 2014). Further analysis and additional data collection to diversify the sample is ongoing.

Table 6: Summary Statistics of Confidence Levels by Correct or Incorrect Response (n=88)

Answer Response	Confidence - Sensibility Check			Confidence - Prediction		
	N	Mean	SD	N	Mean	SD
Incorrect	31	2.52	0.677	55	2.55	0.789
Correct	57	3	0.756	33	3.15	0.795

Conclusions and Future Work

This work details the creation and design choices behind PEEPS, a new survey designed to assess engineering intuition. A series of think-aloud sessions were used to modify the survey before initial deployment in Spring 2021. The initial deployment resulted in 88 completed responses primarily by high-performing, white aerospace engineers. Preliminary analysis suggests that when answering the prediction and sensibility check problems correctly, respondents were more confident in their answer.

Next steps for this project include validity checks of the instrument, further analysis of the results, and expanding deployment during the 2021-2022 academic year to obtain a more diverse student sample. The eventual goal with this survey is to be able to measure educational interventions that are designed to better foster engineering intuition development in students.

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