



Practicing Civil Engineers' Understanding of Statics Concept Inventory Questions

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Abstract

Background: Engineering concept inventories have been broadly used to assess student conceptual knowledge and evaluate the effectiveness of educational innovations. Concept inventory questions were developed to isolate concepts and typically include common misconceptions as possible incorrect answers. Situated cognition theory suggests that knowledge is an interaction between the individual and the context and that isolated concepts may be of limited value in solving engineering design problems. We began to test this proposition by administering the statics concept inventory to practicing civil engineers.

Purpose: The purpose of this research is to gather data on practicing civil engineers' performance on the statics concept inventory.

Methods: The statics concept inventory, implemented as an online survey, collected responses from practicing engineers with a range of experience from 1 year to 45 years as an engineer.

Results: There were 25 participants, all of whom were practicing civil engineers. The average number of years of experience was 11.4 yrs. The participants, on average, answered 13 questions (out of 27 questions) correctly or a score of about 50%.

Conclusions: Our results provide insights into professional civil engineers understanding of statics concept inventory concepts. Although the data set is not necessarily indicative of the larger community of professional engineers, it provides early evidence that not all concepts from the statics concept inventory may be relevant for practicing civil engineers. More research is needed to understand how and why academic concepts are important to civil engineering practice.

Introduction

The goals of most engineering analysis courses is to empower students to apply established principles and methods to understand and quantify new unfamiliar situations^[1]. Oregon State University's civil engineering department's mission statement states that its goal is to "*prepare students for professional and responsible engineering and constructor positions.*"^[2] Many other universities including Washington State (WSU), University of Washington (UW), Virginia Tech (VT), and Purdue (PU) have similar goals for graduating engineers within their mission statements. WSU's mission statement notes its goal is to "*prepare our graduates to contribute effectively to the profession and society, for advanced study, and for life-long learning,*"^[3] while PU lists its goal to "*prepare graduates to successfully pursue their professional career objectives in a civil engineering-related field.*"^[4] Reflective of these mission statements, there

exists common desire for classes and material covered within the education plan of civil engineering students to prepare them for the profession after they graduate.

Universities generally undergo ABET certification because, as noted in the ABET website, *“accreditation is proof that a collegiate program has met certain standards necessary to produce graduates who are ready to enter their professions.”*^[5] For students, accreditation of a program means that the school *“knows their profession's dynamic and emerging workforce needs, they review academic programs to ensure these programs provide students with the technical and professional skills they need to succeed.”*^[5] For the general public, a school being accredited *“enables academic institutions to demonstrate to the public that they are serious about advancing the quality of their programs. It is recognition by the technical professions that these programs are preparing students well, and it encourages ‘best practices’ in education through formal, continuous quality improvement (CQI) processes.”*^[5] These suggest that accredited universities have an obligation to prepare graduates for the workplace and continuously understand and evaluate their process for doing so.

These expectations from regulating agencies, students, and the general public inherently link educational experiences and successful pursuit of professional work. As such, identifying fundamental areas of content knowledge that may be tracked between academia and practice must be addressed. Additionally, means to assess such knowledge must be identified and implemented. Currently, one of the foundational classes during the education of a civil engineer is statics. Steif's^[6] statics concept inventory is used to measure the ability of a person to use fundamental concepts of statics to answer questions. This has been used to evaluate students' abilities. This study probes its use in measuring professional engineers' knowledge of these concepts in order to understand how these fundamental ideas in statics are used and understood in the professional engineering field.

Concept inventories (CI) have been defined as, “Multiple choice instruments designed to evaluate whether a person has an accurate and working knowledge of a concept or concepts”^[7]. For the purposes of this project, this is the best suited definition because, unlike other definitions of CIs, it states “person” rather than “student.” Note that this project does not focus on students, but rather on licensed civil engineers.

Engineering CIs have been broadly used to assess student conceptual knowledge and evaluate the effectiveness of educational innovations^[8]. Conceptual knowledge goes beyond merely identifying a concept and spans into the understanding of interrelationships and application of fundamental ideas within some domain^[9, 10]. CI questions were developed to isolate concepts, and CIs typically include common misconceptions as possible incorrect answers^[6]. Traditional perspectives on application of CIs as assessment of conceptual knowledge, such as those investigating misconceptions, have come from the lens of individual cognitive theories^[8, 11].

Situated cognition theory generally lies in contrast with some cognitive approaches that suggest that if a person knows a concept well, they will be able to apply it in a multitude of contexts^[12]. Situated cognition theory suggests that knowledge is very contextual; to prepare students to do something, they should engage in that practice in as authentic a manner as possible^[13, 14]. Therefore, student's ability to answer questions about isolated concepts may not be a good measure of the ability of an engineer to be productive in the engineering workforce. We began to examine this proposition by implementing the statics CI to practicing civil engineers.

The *purpose* of this study is to gather data on practicing civil engineers' performance on the statics CI. To do this, the statics CI was used as an online instrument to collect responses from professional civil engineers. Previous studies were done using students; the engineers scored similarly to the students which is interesting since engineers have years of working experience to go along with their knowledge from their college statics course.

Literature Review

Misconceptions have mostly been investigated in engineering education through the development of CIs including statics, fluid mechanics, mechanics of materials, and many more^[13, 15-17] which were all spurred by the Force Concept Inventory^[18]. CIs have been widely used to assess student's deeper understanding of important concepts and to measure the effectiveness of curriculum^[19]. These CIs are partially based on an implicit assumption that the concepts that are tested and the way in which they are tested, are in fact relevant to the engineering profession. However, there is no research that explores how engineers perform on the CIs. Additionally, the assumption of concept inventories' relevancy to the engineering profession has not been examined. If that implicit assumption is true, then it would be interesting to compare how professional engineers and students differ on their answers or if they differ at all.

Situated cognition theory suggests that knowledge is not from a single person, but rather that knowledge resides within the group of people who share common goals and practices^[14]. Situated cognition may suggest that the degree of relevance of these concepts to the job of an engineer could question the validity of this assumption since situated cognition experts contend that knowledge only exists in context and has very limited meaning and usefulness when taught out of context^[14, 20, 21]. According to Hutchins^[22], apprentice navigators aboard ships needed practical training before they could become full navigators even if they had proper training at a school that taught them terminology needed for the tasks they would perform, but gave them no experience doing those same tasks. Although they were trained, they needed time actually performing the tasks of a navigator to be able to perform them by themselves without the supervision of another more experienced navigator. The context in which they learn the skills is important to the ship and its crew. The skills learned in school were the same as those learned on the ship, but disconnected from the situations encountered whilst practicing those skills made them much less useful than learning them in the context of how they are used on the ship. The

statics CI includes problems that should be relevant to practical engineering systems^[23]. However, as shown in the study done with navigators, the context of the concepts that were utilized is very meaningful in terms of the way they are understood. Also, engineering is a field that can require technical coordination to complete tasks where engineers influence each other to perform work^[24] making the individual nature of the CI another aspect to consider. Situated cognition theory is not tied to the methodology of this study, but it is a theory that may be useful in facilitating a discussion about the interpretation of why engineers perform as they do on concept inventories.

Although the statics CI is thought to be comprised of questions relevant to engineering practice, this CI has not been tested using practicing engineers. Noting the novelty of examining practicing engineers' understanding of concepts via CIs and the inherent characteristics of engineering practice, perhaps a new framework shaped by the lens of situated cognition will provide a better understanding of why engineers actually perform as they do.

Methods

Participants

Recruiting participants for this study was done in multiple ways. First, emails were sent to professional civil engineers that had helped in research projects before and were willing to help recruit other engineers from their companies and engineering societies that they belong to. American Society of Civil Engineering (ASCE) regional branch presidents were contacted in order to recruit via social events and newsletters put out by the separate areas. The total number of participants was 25, all of whom were practicing civil engineers from 20 different firms and government offices. The average number of years of experience as a practicing civil engineer for the participants was 11.4 yrs. 17 participants had bachelor's degrees, 7 had master's degrees, and 1 had a doctorate degree, all in civil engineering. When asked about what they would consider their area or areas of expertise 5 responded structural, 5 responded environmental, 19 responded civil, 7 responded water resources, 2 responded geotechnical, 3 responded management, and 1 responded waste water management. All of them worked for companies or offices employing fewer than 100 employees. 20 of the participants were males and 5 were female.

Data Collection and Analysis

The participants were given access to the CI through surveymokey.com. Participants were asked not to use reference material while they took the CI and were asked to limit their time for each question to less than 2 minutes each. Due to the nature of disseminating the CI online and not knowing if a participant was going to need to stop for work or another reason there was no time limit set in the survey for each question and there was no way to absolutely ensure that they were not using reference material while taking the CI. There are time stamps on surveymonkey.com that show how long it took each participant to complete the CI which helped to verify how long each participant took to complete it.

Results

Table 1 shows the sub discipline of the participants. The engineers that associated with the water resource discipline had a slightly lower average than the rest of the participants. The other three groups of engineers scored within 4% of the average of 48%.

Table 1. Participants score and experience by sub discipline.

	Number of participants	score	Experience (yrs)
Civil/WR	7	44%	9.5
Civil/Management	3	52%	17.3
Civil/Structural	5	51%	10.6
Civil/Other	10	48%	10

Figure 1 shows how the engineers that participated in this study scored on separate concept areas compared to an earlier study conducted with N=1378 students from 10 different statics classes at 7 different universities^[25]. The students were either finishing their statics class or had recently finished it when they took the concept inventory. Of the nine concepts that are being assessed, static equivalence over the three questions had the lowest average for engineers at 23%. The lowest scoring question across all engineers fell under that same category. 12% of the engineers that answered question 9 answered it correctly. In the highest scoring category, the questions focused on slots and over the three questions that covered this concept, an average of 68% answered correctly. The single highest scoring question was question 11 which is in the section about rollers and was answered correctly by 80% of the engineers.

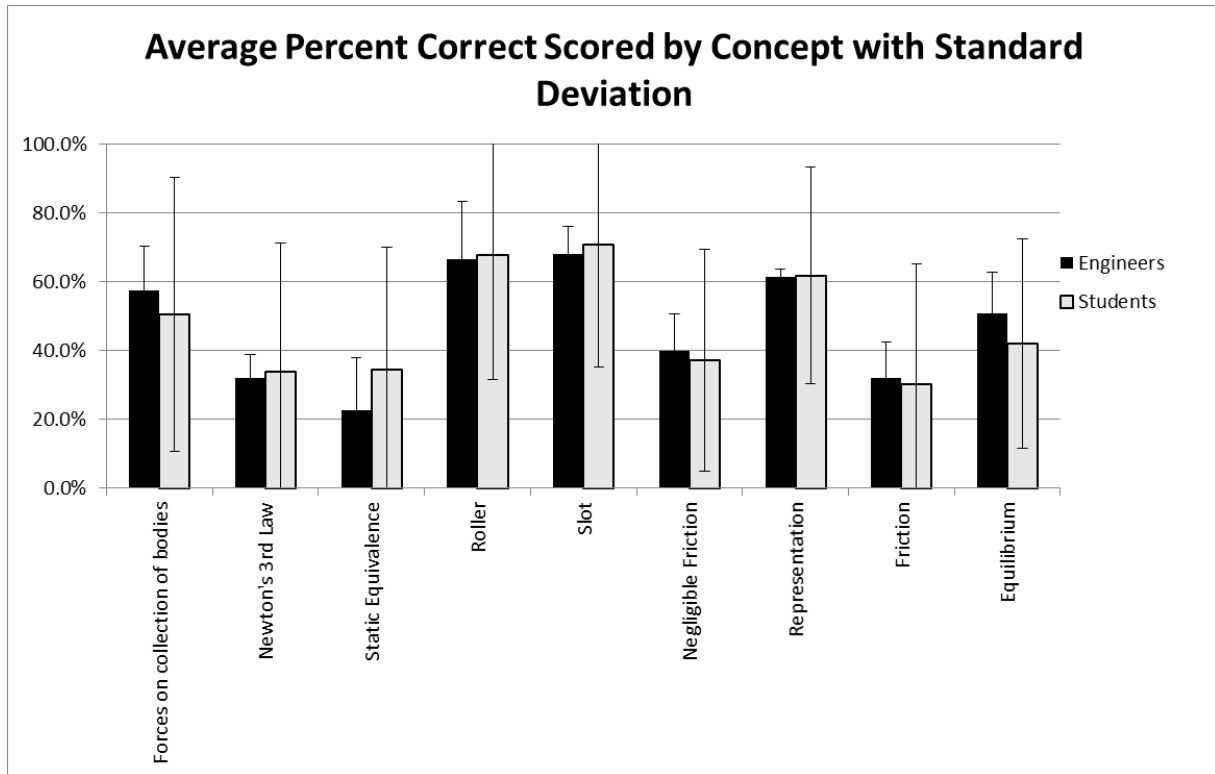


Figure 1. Concept Difficulty: Percent of engineers answering a set of questions about a single concept correctly.

Discussion

Practicing engineers have both scholastic and practical experience with engineering concepts. Since they have degrees and have worked as engineers, it might be assumed that their knowledge of engineering concepts is excellent and would allow them to answer most, if not all, of the questions on the statics CI correctly. The highest average score for any subgroup of engineers is 52% which is not what would be expected if knowledge from practical experience expanded on knowledge from classes taken at a university. Some possibilities that could explain the low scores from the participants in this study are:

1. The concepts in the statics CI are not commonly used in engineering practice and without reference material allowed while taking it the concepts, may have been too difficult and distant for the engineers to be able to recall them.
2. These concepts may be relevant as foundational to other concepts that are built upon these concepts, but are foreign compared to the more complex concepts which then caused the engineers to not score well on the CI.
3. Knowledge learned in classrooms is different than that learned through experience and the concepts, although they may be the same, may not be recognizable to practicing engineers in the format of these problems.

The first possibility is that the engineers are not familiar with the concepts because they learned them during their statics course and used them while in school, but after graduating the concepts were not used and, therefore, were harder to recall how to answer the questions correctly leading to low scores. This could imply that the engineers do not use the concepts often in their jobs. It might also mean that they do use the concepts, but in a way that they do not recognize when asked about them in the context of the CI. If this was the reason for low scores, one might expect that the engineers that had more work experience and, therefore, out of school for a longer period to have lower scores overall than engineers with less experience. This was not the case as the group with the most experience were those that identified management as one of their areas of expertise and had more experience than other engineers and they scored on average higher than any other group although only by 8%.

The next possibility is that these concepts may be relevant as foundational to other concepts that are built upon these concepts, but are foreign compared to the more complex concepts which then caused the engineers to not score well on the CI. Statics is generally taken in the second year of a civil engineer's college curriculum. It is considered a foundational class for many other courses in the third and fourth year of civil engineering programs and, as such, the concepts learned in statics are important to these classes. This could cause engineers to overlook the basic statics concepts during their regular work and possibly while they were taking the CI causing the low scores. If the concepts learned in statics are not used explicitly, then engineers may simply not remember them as those concepts, but rather as a piece to more complicated concepts. If the engineers were unable to separate the concepts they needed from the more advanced concepts learned in advanced classes, then it may have been difficult to make the connection about the concepts when asked about them during the CI.

Another possibility is that knowledge learned in classrooms is different than that learned through experience and the concepts, although they may be the same, may not be recognizable to practicing engineers in the format of these problems. Looking at the question that most engineers scored the lowest on, it was the third question on the concept of static equivalence shown in Figure 2: Question 3 of 3 on static equivalence. Only 12% of the participants answered this question correctly. It consists of a rectangle with arrows, dots, and labels. To an engineer this may look familiar as something they would have seen in school, but it is disconnected from projects that they now work with. There is no reference to how it is connected to a project they would be working on and situated cognition theory would suggest that this disconnect from the workplace disconnects the concept from their knowledge. This would not necessarily mean that the engineers do not know these concepts or that they are unimportant to their jobs, but rather that the questions in the CI are presented in such a way that the concepts become convoluted and the engineers are less likely to recognize them in this context.

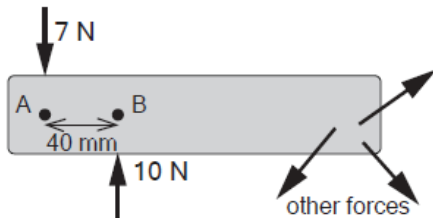
Situated cognition offers an explanation for each of these possibilities. The engineers were asked to take the CI without using reference material to help them remember how to use concepts if they felt they needed it or in order to verify that their answers were correct before submitting

them. The theory of the extended mind is an important piece to situated cognition and may explain why asking engineers to not use reference materials could cause them to not perform well on the inventories. The extended mind is a theory that claims that the boundaries of a cognitive system lie outside of the envelope of an individual person and extends to the physical environment^[26, 27], which would include books and reference material used by engineers. Clark and Chalmers^[26] proposed that an Alzheimer's patient that uses a notebook to remember important facts is only superficially different than a person that has a perfectly functioning memory that looks up information and stores it internally. Engineering reference books are used by many engineers as a part of their day to day routine that, considering the extended mind theory, if they are not allowed access to this information then they are almost being asked to not use part of their mind which may be extended into these reference materials. Engineers may also be *embedding* their minds in the reference material and the situations they commonly encounter at work in order to travel "informationally light"^[28]. If engineers use reference material to embed and extend their minds, then not allowing them to access it could cause them to not perform as well as expected.

Situational availability provides an explanation for the second point about statics concepts being foundational to other concepts more commonly used by civil engineers. Situational availability suggests that it is difficult to retrieve situations for abstract concepts^[29]. The concepts in the statics CI may be considered abstract by engineers if they are not rooted in situations related to their work. The concepts themselves may not be abstract, but how they are presented may make it difficult for engineers to retrieve the concepts because those situations are abstract.

It is theorized that concepts are stored situationally and engineers may have difficulty recalling the concepts as situated in the form the questions take in CIs. According to Yeh and Barsalou^[30], a concept produces different conceptualizations in different situations, with each form relevant to the current situation. According to this theory, concepts are not represented as generic, highly abstracted data structures, but rather their content is tailored to the current situation. The concepts in the statics CI might be presented to the engineers in a different situation than how the concepts might generally be presented. As a computer might be thought of as an instrument used for work when depicted in an office, it might be thought of as an entertainment device when depicted in the home. Statics concepts can be situated differently in the workplace compared to the classroom. Along with this idea that concepts are stored differently for each situation, it is important to consider that people may not store and retrieve surface stimuli, such as images and words, in the way that cameras and audio recorders do^[31]. It is possible that the images presented in the statics CI trigger the same stimuli in practicing engineers as it does in students, but for students this imagery may be recent retrieval rather than long term retrieval which may explain why they did not score better than the students. Although engineers have more experience and schooling, if they are expected to answer questions about abstract concepts then that experience would not be as useful to them as what was learned in school, giving them the same capacity as the students to answer the questions correctly.

The two forces with magnitudes 7 N and 10 N act in the directions shown through points A and B, which are denote with dots. These forces keep the member in equilibrium while it is subjected to other forces acting in the plane (shown at the right).



Assuming the other forces stay the same, what load(s) could replace the 7 N and 10 N forces and maintain equilibrium?

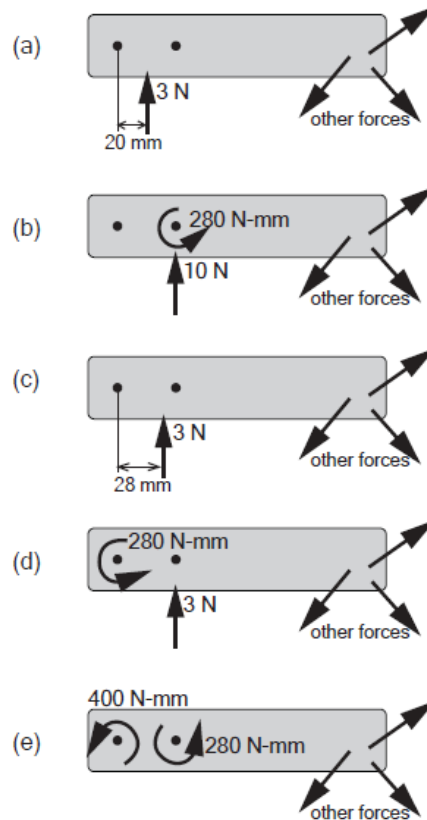


Figure 2: Question 3 of 3 on static equivalence.

Conclusions

Although this study only had 25 participants take the CI, it provided some initial insight into how professional engineers remember concepts, how they view concepts taught in statics classes, and how they may store those concepts. Since the data set was collected using 25 engineers, it may not be indicative of the larger community of professional engineers, but it does provide early evidence that not all concepts from the statics CI may be important to engineers or that they may not be presented in such a way that they are situated for engineers to be able to answer them correctly. It is also interesting that the practicing engineers did not score very differently than the previous student groups that took the CI. The more experience an engineer has, the better they might be expected to perform, but for this set of engineers, it shows that their experience may not have helped them any more than their college courses.

An interesting implication from this study is that concepts learned in school may be disconnected from those learned in the workplace, even if the concepts are the same. Engineers may not have recognized the concepts because of how the CI presents them, but that does not mean that they do not understand them. Another study that utilizes more engineers from different expertise areas could be helpful in determining if engineers from different areas have the same issues or different ones with different questions and concepts. This would require a minimum of 30 engineers from each area of expertise, but would be helpful in determining if there are shared conceptual misconceptions among civil engineers or if it's different depending on sub-discipline.

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