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Title: Exploring Civil Engineering Undergraduate and Practitioners' Performance on Strength of Materials Concept Inventory.

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Preparing successful engineering undergraduate students for the workforce is imperative and requires students to apply their conceptual understanding of engineering fundamentals to engineering design work. Conceptual understanding is assessed through the use of concept inventories. Learning theories may help explain differences in concept inventory performance. Expert novice theory suggests that experts understand the concepts as big ideas and would be able to solve problems where they have conceptual understanding. Situated cognition theory suggests that knowledge is contextual, and performance would hinge on the participant's familiarity with the question and the visual representations in the question. Although there is a growing body of literature analyzing students' conceptual understanding through concept inventories, few studies focus on how or if conceptual understanding transitions into engineering practice. The purpose of this study is to explore differences in conceptual understanding of strength of material concepts across engineering undergraduate students and professional civil engineers. Researchers implemented the Strengths of Material Concept Inventory, collecting data from 153 engineering undergraduate students and 119 practicing civil engineers. The statistical analysis revealed that overall structural engineers performed better than non-structural engineers and engineering undergraduate students. In addition, findings

from this exploration noted that performance from all participants is low in shear stress beam questions. Results suggest that differences in performance between the groups may be due to the way concepts are situated and interpreted across academic and workplace contexts. These findings point to the need to further develop the concept inventory through a qualitative interview approach investigating conceptual understanding in practice and validating the instrument. Focused, in-depth explorations can provide researchers with additional explanations and reasonings on practicing engineers conceptual understanding while solving problems. Obtaining this information can offer tools for aligning educational practices and prepare students for the engineering workforce.

Exploring Civil Engineering Undergraduate and Practitioners' Performance on Strength of Materials Concept Inventory

by
Dominga Sanchez

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Dominga Sanchez, Author

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The National Science Foundation (NSF) Women, Minorities, and Persons with Disabilities in Science and Engineering provides statistical information about the number of graduates each year. The latest report indicates that 7.9% in 2014, 6.7% in 2015, and 6.6% in 2016 of the Master graduates in the Civil Engineering field identified as Latinx Female graduates. I am now part of this small percentage and I didn't do this alone. It took a support system composed of individuals with different contributions to help me reach this achievement.

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CONTRIBUTION OF AUTHORS

Dr. Shane Brown designed the research and assisted with the interpretation of the data. Dr. Shane Brown and Dr. Matthew Barner co-authored the papers presented in Chapter 2 and Chapter 3.

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DEDICATION

This thesis is dedicated to my Grandfather Ernesto Garcia Garcia, you have always been my inspiration to pursue the engineering field. Your words of encouragement, wisdom, and humbleness will always be with me. To my children Yvonne and Geovanni Morales Sanchez, who have been my motivation and have supported my academic endeavors and to my mother Ciria Garcia Lopez, who has shown me resilience, strength, and determination. Thank you for your patience and support.

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Chapter 1- Introduction

Every year thousands of engineering students graduate from institutions all around the world and enter into an environment defined by complex open-ended problem solving with multiple solutions and constraints. To thrive in this environment, it is necessary to inculcate fundamental engineering knowledge to engineering undergraduates. There is increasing recognition throughout engineering education that establishing solid conceptual understanding in fundamental engineering concepts is essential and contributes to engineering undergraduates' success to prepare them for the workforce (Brown et al., 2018; Goold, 2015; National Academy of Engineering, 2005). In fact, studies have found that conceptual understanding is considered important for student success and linked to the situated learning context and the development of expertise (Litzinger et al., 2011; Lutz et al., 2019; Streveler et al., 2008). To help understand if and how students understand engineering concepts and misconceptions they have, concept inventories were developed to for many disciplines within the engineering sciences. Much of the recent emergence of concept inventories in engineering disciplines is due to the Foundation Coalition's work with support from the National Science Foundation (Evans et al., 2003). There is an abundance of literature focused on investigating student conceptual understanding using concept inventories and other methodologies (Evans et al., 2003; Krause et al., 2009; Midkiff et al., 2001; Prince et al., 2012; Steif & Hansen, 2007), few investigate how conceptual understanding compares between engineering practitioners and engineering undergraduate students.

Investigating conceptual understanding between engineering practitioners and engineering undergraduate students is important for several reasons. First, it can help understand how engineering practitioners demonstrate their conceptual understanding and what differences might exist relative to engineering undergraduate students. Thus, content knowledge transfer from an academia to industry and how experience in industry contributes to conceptual understanding in engineering content will be explored through the differences in conceptual understanding of engineering concepts by practitioners and engineering undergraduate students. Furthermore, the comparisons of the understanding of these engineering concepts will also provide insight into the different misconceptions that may exist in a specific content for engineering practitioners and engineering undergraduate students. Being able to identify conceptual understanding and misconceptions will provide academic instructors the opportunity to make changes in instruction and focus on concepts that are used by and important to engineers.

Concept inventories are an alternative form of academic assessment which resemble traditional multiple-choice exam but are different from them in structure, development, and purpose. One of the first and most successful concept inventory is the Force Concept Inventory (FCI) developed by David Hestenes (Hestenes et al., 1992). Concept inventories have been used broadly in engineering education as an assessment tool, an educational intervention, or a method to identify misconceptions and provide information about the strengths and weaknesses of individuals' conceptual understanding of the material. The Strength of Materials Concept Inventory (SOMCI) was partially developed within these efforts by Richardson and Morgan (Richardson et al., 2001), focusing on conceptual understanding around stress, strain, buckling, bending, torsion, and deflection of objects.

Conceptual understanding is considered to have the correct understanding of a concept or an idea and be free of misconceptions. Learning can be impeded by a lack of proper or correct conceptual understanding of fundamental concepts, also described as misconceptions. A unique aspect of concept inventories is that the incorrect answers are common student misconceptions (Evans et al., 2003; Hestenes et al., 1992; Krause et al., 2003; Krause et al., 2009; Richardson et al., 2003). A concept inventory contains questions addressing a range of conceptual understanding of the material such that any student who has taken a course covering the material should be able to take the concept inventory and be able to identify their strengths and weaknesses in conceptual understanding of the material. Identifying strengths, weaknesses, and misconceptions offers the opportunity to intervene and clarify misconceptions and areas where a course needs modification.

Relevant to conceptual understanding research is studies surrounding experts and novices. For purposes of this study, we consider practicing engineers to be experts and engineering undergraduate students to be novices. Studies show that conceptual understanding is linked and plays an important role in developing expertise (Bransford et al., 1999; Litzinger et al., 2011; Rittle-Johnson et al., 2001; Streveler et al., 2008). In addition, studies have stated that since practicing engineers have accumulated more time and practice than students, they are more likely to exhibit expert-like ways of understanding particular concepts (Brown et al., 2018). It can therefore be argued that practicing engineers may be expected to perform better than students on a concept inventory if the concepts are commonly used in the workplace.

However, studies have also shown that learning and development are also influenced by the environment in which learning occurs, which is different across a school and work environment (Brown et al., 2019; Lutz et al., 2019; Stevens et al., 2014). Situated cognition theory suggests that cognition is a social and situated experience in which activity, concept, and culture are interdependent (Bransford, Brown, & Cocking, 1999; Brown et al., 1989). In a study investigating how practicing engineers understand and use concepts in the context of their work, Bornasal et al. (2018) found that practicing engineers interpret the language and symbols differently than school-based representations. Situated cognition, therefore, suggests that the way concepts are represented would have a different meaning based on the way it was instructed. In this study, this would imply that practicing engineers may understand shear stress in relation to codes, design manuals, and failure, not in terms of equations and the diagrams that are typical representations in an academic mechanic's course. This is important because if learning and development of conceptual understanding are situational, then engineering practitioners may have a different understanding of the content than engineering undergraduates due to work experience. While numerous studies discuss the importance of how context plays a role in learning and development, few studies focus on the influence context has on conceptual understanding between engineering practitioners and engineering undergraduates.

While the research benefits of engineering concept inventories and conceptual understanding of engineering concepts from undergraduates has been fairly well explored, further investigation is needed to understand the difference in conceptual understanding of engineering concepts between engineering practitioners and engineering undergraduate students. By exploring concept inventory performance from engineering practitioners, we can learn how knowledge transfers to industry and how context contributes to conceptual understanding.

Thus, this research intends to explore the difference in performance on the Strength of Materials Concept Inventory (SOMCI) between practicing structural engineers, non-structural engineers, and engineering undergraduate students. Strength of materials is a fundamental course for civil and mechanical engineers typically taught during the sophomore year of an undergraduate engineering program. It is an essential foundational course analyzing stresses and strains that develop within a mechanical member. This conceptual knowledge is important to understand when designing structures, such as buildings and bridges. The research methodology includes conducting a one-way ANOVA to determine if an overall difference in performance exists between the three groups of participants, an independent samples t-test was performed to determine which group between pairs had a higher mean correct score on the overall SOMCI, and lastly, a chi-square test of independence was performed to each of the 23 questions for three pair comparisons; structural engineer vs non-structural engineer, structural engineer vs engineering undergraduate students, and non-structural engineer vs engineering undergraduate students, to determine if there are any differences or patterns of understanding among the three pair groups on individual questions.

The second chapter of this thesis is a journal paper submitted to the Journal of Civil Engineering Education, part of the American Society of Civil Engineers (ASCE). This paper aims to compare the performance of practicing civil engineers (both structural and non-structural) and civil engineering undergraduates in the Strength of Material Concept Inventory to determine if any differences in conceptual understanding of strength of materials exist and understand a potential explanation for these differences. The third chapter of this thesis is a conference paper submitted to be presented at the 2021 American Society for Engineering Education annual conference. This paper analyzes four questions focused on shear stress in beams to identify misconceptions and discuss differences in performance between practicing civil engineers (structural and non-structural) and engineering undergraduate students. This paper aims to identify engineering undergraduate student misconceptions related to the strengths of materials and interpret the results within the framework theory of conceptual understanding. Chapter four concludes this thesis by connecting the findings from the two papers as a whole and the implications they have for engineering education and future research.

Chapter 2- Comparing Engineering Student and Practitioner Performance on the Strength of Materials Concept Inventory: Results and Implications

2.1 Abstract

Preparing engineering undergraduate students for the workforce is a goal of engineering programs. Engineering educators arguably provide students with conceptual understanding of engineering fundamentals; however, few studies focus on how knowledge of these concepts transitions into the engineering field. Concept inventories have been used in engineering disciplines as a form of student assessment of conceptual understanding. As measured by concept inventories, conceptual knowledge is presumed to be important for conceptual growth towards successful engineering practice. This study explores the performance of strength of materials conceptual understanding between engineering undergraduate students and professional engineers. The Strength of Materials Concept Inventory was implemented, and data was collected from 153 engineering undergraduate students and 119 practicing civil engineers. The statistical analysis revealed varied consistency in performance across concepts and that structural engineers performed better than non-structural and engineering undergraduate students in 15 of the 23 questions, in which the performance difference is statistically significant. The difference in performance could be due to how concepts are situated and applied across academic and workplace contexts.

2.2 Introduction

A National Research Council publication prioritized students' development of conceptual understanding in science, mathematics, and engineering, with the goal to prepare students with skillful knowledge and contribute to innovative designs (National Research Council, 1999). The increasing importance of preparing engineering undergraduate students for the workforce has focused attention on how to better prepare students to develop conceptual understanding of engineering fundamentals (Brown et al., 2019; Jonassen, 2006; Litzinger et al., 2011). Developing conceptual understanding of engineering concepts provides engineers with the knowledge to solve challenging problems efficiently (Vosniadou, 1994). A common tool to assess understanding of conceptual understanding in a particular area is a concept inventory. Concept inventories have been used frequently to measure students conceptual understanding of engineering and science topics, including statics, physics, and heat transfer (Hestenes et al., 1992; Steif & Hansen, 2007; Streveler et al., 2008). Conceptual understanding, in this case, means being able to answer the correct question on a concept inventory. More broadly, answering a question correctly means they can assess the problem qualitatively, understanding the relationships between variables, without calculations, using the overarching ideas, or concepts for a particular problem.

There is substantial literature that suggests conceptual understanding is important for expertise (Litzinger et al., 2011; Streveler et al., 2008). Implementation of concept inventories to students is supported by the following logic; engineers require conceptual understanding, therefore, concept inventory performance is necessarily important for engineering practice. Engineering educators strive to provide students with essential understanding of fundamental engineering concepts, however there are few studies that focus on the presence and relevance of this knowledge transitioning to the engineering workforce.

The purpose of this paper is to compare performance of civil engineering undergraduate and practicing civil engineers (both structural and non-structural) in the Strength of Materials Concept Inventory (SOMCI). The SOMCI focuses on concepts of stress, strain, buckling, bending, torsion, and deflection of objects under load. Comparing the performance of engineering undergraduate students and professional engineers on SOMCI (Richardson et al., 2001; Richardson et al., 2003) can provide insights on these groups' conceptual understanding and the relevance of the SOMCI concepts to civil engineering practice.

2.3 Background Literature

2.3.1 Concept Inventories and Expertise

Concept inventories (CI) have been developed as a form of knowledge assessment, modeled after the Force concept inventory in Physics (Hestenes et al., 1992; Hestenes & Halloun, 1995). Concept inventories are instruments containing several multiple-choice questions, with one correct answer and multiple incorrect answers. The incorrect answers, which are identified as "distractors," are based on common student misconceptions of the content (Richardson et al., 2003), as they represent common incorrect ways of thinking about the concept at hand. One of the advantages of implementing a CI is to analyze individual questions or groups of questions to identify strengths and weaknesses of participant's knowledge of particular concepts (Evans et al., 2003; Krause et al., 2003). Identifying students' strengths, weaknesses, and conceptual understanding provide the opportunity to intervene and clarify those misconceptions in areas where a course or lecture needs to be modified. Concept inventories are typically used as a tool for assessing student understanding of particular concepts and can also help instructors identify and address misconceptions.

2.3.2 Expert and Novices

Studies of experts and novices conclude that expert knowledge is organized around large concepts and overarching ideas as opposed to novices whose knowledge is based on techniques or surface features and is not as broadly applicable as expert knowledge (Atman et al., 2007; Bransford, Brown, & Cocking, 1999; Ericsson & Ward, 2007; Jonassen, 2006). Researchers have claimed that conceptual understanding is linked to expertise development (Litzinger et al., 2011; Rittle-Johnson et al., 2001; Streveler et al., 2008). Bransford et al. (1999) emphasize how conceptual understanding plays an important role in the development of expertise through extensive reviews of several research studies that analyze students understanding of specific topics. One of the key findings discusses how the "key to expertise is the mastery of concepts that allows for a deep understanding of that information." They discuss how experts aim to develop an understanding of core concepts when problem-solving, as opposed to novices who are less likely to organize their knowledge around core concepts and instead focus on surface features of the problems. For example, in order to understand the difference between experts and novices, Chi et al. (1981) investigated the organization of physics knowledge by experts and novices and found that experts categorize problems defined by major physics principles, whereas novices categorized them by surface features such as the entities contained in the problem statement.

In efforts to improve readiness of engineering graduates, Litzinger et al. (2011) compiled key findings from studies focused on the development of expertise as it pertains to engineering education, emphasizing the importance of conceptual understanding of key concepts in order to facilitate students' abilities to access and transfer knowledge from the classroom to real-world applications. Furthermore, they highlight the importance of having a deeper understanding of a specific domain leading to expertise. Conceptual understanding of expert engineers has been developed by informed decision-making through their careers, which separates them from less experienced novices (Ahmed et al., 2003; Litzinger et al., 2011; Song & Becker, 2014).

While findings from various studies suggest that an increase in conceptual understanding is related to the development of expertise, less is known about engineering conceptual understanding between experts and novices as measured by a single instrument. Research on expertise and conceptual understanding suggests that engineers may have strong conceptual knowledge of strength of materials based on the development and use of this knowledge in education and work settings and, therefore, may perform better than students on concept inventory problems.

For purposes of this study, we consider practicing civil engineers to be experts and engineering undergraduate students to be novices. Strength of materials (SOM) is a 2nd year fundamental engineering course that introduces concepts such as stress, strain, buckling, bending, torsion, and deflection that is taken by civil and mechanical engineering undergraduate students. Structural engineering is a sub-discipline of civil engineering that focuses on the design of structural infrastructure, such as buildings and bridges, utilizing strength of materials concepts. We consider structural engineers to have more expertise related to the strengths of materials because they spend significant time analyzing beams, columns, and other structural members and concepts in their day-to-day work. Other civil engineering sub-disciplines may also utilize SOM concepts. For example, geotechnical engineers utilize concepts of stress and strain in foundation design. However, some civil engineering sub-disciplines, such as transportation and water resources engineering likely use SOM concepts less frequently in their work. Evidence of this could be found in syllabi from these disciplines that would not include concepts of stress, strain, and deflection. The SOMCI measures conceptual understanding of strength of material concepts such as stress, strain, buckling, bending, torsion, and deflection in different structural members. If structural engineers use SOM concepts in their practice, they would be expected to have a broad understanding of these concepts and be expected to perform better than engineering undergraduate students on the SOMCI. Depending on other civil engineering sub-disciplines' particular practices, engineers from those disciplines may perform better on particular SOM questions.

A study performed by Brown et al. (2019) compared engineering student's and engineer's performance on the statics concept inventory (SCI) and provided additional insights that may inform how civil engineers will perform compared to engineering students on the SOMCI. The statics concept inventory included 27 questions incorporating seven concepts related to Free Body Diagrams, Newton's Third Law, Rollers, Slots, Negligible Friction, Representations, Friction, and Equilibrium. Results from this study indicate that engineering students have a more robust conceptual understanding of statics. The SCI scores revealed that engineering students' performance is higher than engineering practitioners in 24 questions, and engineering practitioners performed better in three questions related to Friction and Rollers. The authors suggest that differences in performance may be impacted by how concepts are situated and applied across these two contexts (Brown et al., 2019). Specifically, Brown et al. (2019) argue that the conceptual representations (i.e., the specific figures, text that make up the problems) utilized in the SCI may not be relevant to engineering practice. Even if engineers use statics concepts in their work, they may not understand these concepts as represented in the inventory. While statics concepts are relevant to civil and structural engineering, their particular representation on the SCI may not be relevant to civil engineering practice. For instance, a couple of the SCI questions are presented in simplistic forms with assumptions that simplify the problem. However, in practice these assumptions may no longer be true. Concepts and representations in the SOMCI may be more relevant than those in the SCI to practicing civil, and particularly, structural engineers. For example, some of the questions in the SOMCI relate to shear, bending moment distributions, and deflections in beams. Structural engineers will likely encounter beam design more so than non-structural engineers; therefore, their experience will help them solve these problems correctly. Arguably, then practicing structural and civil engineers may be expected to perform better than engineering students on some or all of the SOMCI questions.

2.3.3 Situated Cognition

In order to understand how engineering knowledge within the context of engineering academia and practice may affect the difference in performance between practicing engineers and engineering undergraduate students, we make use of situated cognition theory. In situated cognition theory, context plays a role in learning and development. Situated cognition theory suggests that cognition is a social and situated experience in which activity, concept, and culture are interdependent (Brown et al., 1989). In Brown et al. (1989), authors suggest considering conceptual knowledge as a set of tools that can only be understood through the user's view of the context and adaptation of the culture in which these tools are being used. As an example, Brown et al. (1989) describe how knowledge of mathematics is important, but depending on the context and culture, the application may be different, such as how physicists and engineers make use of mathematical formulae differently or carpenters and cabinet makers need to know how to use a chisel, but apply this knowledge differently. Bransford et al. (1999) also discusses the importance of how the context in which one learns contributes to the transfer of knowledge, which draws attention to the need to understand how fundamental engineering concepts transfer to engineering industry.

Situated cognition relevant to experts and novices (practicing engineers and engineering undergraduate students), is associated to features in the individuals work environment, in this case engineering school and engineering industry. Studies of contextual knowledge informed by situated cognition consider the context of the problem and the learner as key factors in learning and development. For instance, conceptual representations may be represented in artifacts which are typically manifested from the sociomaterial contexts of engineering activities in the workplace and engineering academic courses (Barner et al., 2019; Stevens et al., 2014). Barner (2019) discusses how conceptual representations are connected to real-world conditions and engineering tools, providing an additional lens for comparing sociomaterial contexts of conceptual representations that experts (engineers) and novices (engineering undergraduate students) navigate within their respective workplace and academic context. Findings suggest that student (novice) knowledge is more conceptual, academic textbook knowledge, while practicing engineers (experts) knowledge is tied to workplace representations such as design or construction drawings of engineering concepts.

If knowledge is social and situational, practicing engineers through their practice and work experience, may have a different understanding through their practice and it would be expected that engineers will perform better than engineering undergraduate students on certain questions that are relevant to their social situational factors (Industry culture). If knowledge is embedded in context, it is possible that the comparative performance between engineering undergraduate students and engineers may differ depending then, on the relevance and the representation of conceptual content. It may be that engineers perform better on the Strength of Materials Concept Inventory than engineering undergraduate students because their situated knowledge is based on practical experience and not just academic understanding.

Engineering design problem solving may be approached differently from an engineering undergraduate student in comparison to a practicing engineer due to experience and context. In the following beam with a given distributed load example from the SOMCI shown in Figure 2-1, the problem statement addresses understanding of tensile normal stress on a vertical plane. Forces acting on the beam cause axial and shear stress on the cross section of the beam and deflection perpendicular to the longitudinal axis of the beam. Axial stress will vary linearly with distance from the neutral axis and therefore, the maximum tensile normal stress will be located at mid-span and the farthest distance below the neutral axis, which is location F.

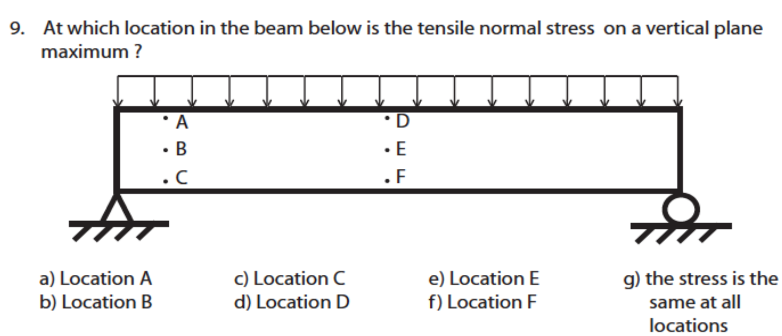


Figure 2-1. SOMCI sample question

A typical beam problem in an academic setting involves establishing the design loads (usually provided by the instructor) to determine the internal forces: Shear Force

(V), Axial Force (P), and Moment (M) at a location of interest. This can be accomplished by developing the shear/moment/deflection diagrams for load cases that the beam will be subjected to, which will show these forces and moments along the length of the beam. As Chi et al. (1981) stated, novices focus on surface features of a problem statement. This would suggest that engineering undergraduate students may memorize the steps required to design or use equations to calculate the stress in a beam, however that does not imply that they have conceptual understanding of the process. In accordance with development of expertise (Ahmed et al., 2003; Litzinger et al., 2011; Song & Becker, 2014), increase in conceptual understanding of expert engineers has been cultivated by informed decision making through their careers. Structural engineers approach problem solving differently based on their professional experience and will have a more developed conceptual understanding of the phenomenon. Therefore, we would anticipate that structural engineers should perform better than non-structural engineers and engineering undergraduate students in these types of conceptual problems.

A typical academic representation of a beam, including the image and notations is shown in Figure 2-2. Students who have taken strength of materials course should be familiar with these representations based on seeing them in textbooks, course notes and exams. Practicing structural engineers who have extensive experience in the field likely understand how tension and compression forces act on a beam and will be able to identify the critical points to keep in mind when designing a beam with a given distributed load such as in Figure 2-2. However, the performance of engineers on the SOMCI may depend on the familiarity of the particular representation of the concept and their use of those concepts and representations in practice.

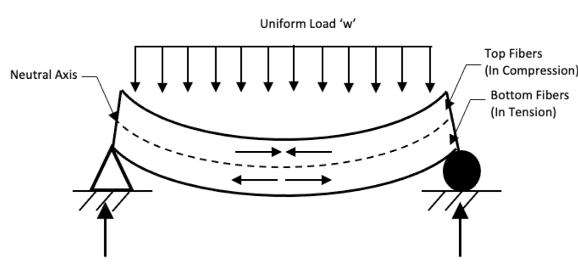


Figure 2-2. Sample beam with distributed load image

In summary, expert novice literature suggest that experts develop conceptual understanding over time and organize their knowledge around large core concepts, allowing them to solve a variety of problems related to the core concepts. Situated cognition theory, however, suggests that context is important, and performance on the SOMCI may hinge on the contextual relevance of the SOMCI questions. The goal of this study is to compare performance of structural engineers, non-structural engineers, and engineering undergraduate students on the SOMCI.

2.4 Method

2.4.1 Participants

Practicing civil engineers who participated were contacted via email and asked if they would complete the SOMCI. If they agreed to participate, they were provided a link directing them to the SOMCI and were also asked to help recruit other engineers from their companies and affiliated engineering societies. Faculty who taught SOM were recruited via email to request that their students complete the SOMCI. Engineering undergraduate student participants were all current students in a strength of materials (SOM) course and completed the SOMCI within the last two weeks of the term, when all content in the SOMCI had been covered in the course. The SOMCI was input into surveymonkey to facilitate gathering responses from engineers and engineering undergraduate students. There was no time limit for completing the SOMCI for students or engineers.

A total of 119 practicing engineers across the United States started the SOMCI, however only 108 fully completed the concept inventory, of which 45 identified as structural engineers and 74 identified as non-structural engineers. Non-structural engineers included transportation, geotechnical, mechanical, and environmental engineering. The practicing engineers' participants consisted of 72% male, 26% female, and 2% identified as other. Participants were asked to provide demographic information including gender, years of engineering experience, highest level of education, and engineering area(s) of expertise shown in Table 2.1. Years of experience in the field varied from 1 year to 39 years. All practicing engineering participants were invited to participate in a $250 raffle drawing as an incentive to participate. Student participation included 153 engineering undergraduate students from different institutions shown in

Table 2.2, with only 129 fully completing the concept inventory. The engineering undergraduate student participants consisted of 84% male and 14% female, and 2% identified as other.

Table 2.1 Demographics of the engineering practitioners

		Gender		Highest education	
Engineering practioner specialization	Total	Female	Male	Bachelor	Master
Structural engineering	45	13	32	20	25[c]
Non Structural engineering[a]	60	15	43	49[b]	11[c]
Other	14	3	11	6	8

[a]Civil engineers who indicated more than one engineering expertise, including geotechnical, environmental, water resources, transportation, construction management, and others.
[b]One engineer reports high school education
[c]One engineer reports PhD.

Table 2.2 Count of student participation by institution

Institution	Participant Count	
	n	%
University of Phoenix	1	1
University of Florida	76	49
Seattle Central College	8	5
Oregon Institute of Technology	14	9
Highline Community College	30	19
Clackamas Community College	22	14
Florida State University	1	1
Unknown	2	2

Note: Number of total participants = 154, number of full responses= 129

Incomplete results were removed from student and engineering practitioner's data. It does not seem plausible to complete this concept inventory in less than 5 minutes and be diligent with responses, therefore all results that had a completion time of 5 minutes or less were eliminated. This process resulted in the final count of participants to be 129 engineering undergraduate students and 108 engineering practitioners.

2.4.2 Instrument

Richardson et al. (2003) developed the initial SOMCI in 2001 and piloted it with approximately 200 students. After applying a psychometric analysis of the instrument, it was determined that the inventory had no internal consistency. Developers indicated that they intended to develop a new version of the SOMCI (Richardson et al., 2001, 2003); however, there is no indication that a second version was ever developed. For a concept inventory to be effective, Jorion et al. (2015) describe an analytic framework with statistical tests necessary to validate a concept inventory. Per Jorion et al. (2015), the five analytic approaches to validate a concept inventory are classical test theory (CTT), item response theory (IRT), exploratory factor analysis (EFA), confirmatory factor analysis (CFA), and diagnostic classification modeling (DCM). Furthermore, in developing and validating the Statics Concept Inventory, Steif and Dantzler (2005) also discuss the importance of evaluating an instrument based on reliability and validity, with both a quantitative and qualitative approach. Steif and Dantzler (2005) state that reliability captures whether the various questions in the test consistently measure the same underlying content and validity refers to whether or not the instrument measures what it was intended to measure. Although reliability can easily be measured using Cronbach's alpha reliability coefficient, Steif and Dantzler (2005) elaborated on how validity is measured using three approaches: content validity, criterion-related validity, and construct validity. Content validity refers to the test items' ability to represent the domain of interest, which was addressed by identifying key concepts, drafting questions, and identifying misconceptions. Criterion-related validity refers to the level of agreement between the test score and an external performance measure, validated by comparing participant total score performance on the inventory. Construct validity refers to how well items measure the instrument's underlying theoretical construct, which was validated by conducting a confirmatory factor analysis. Although Richardson et al. (2003) describe some qualitative approach in identifying concepts, drafting questions, identifying misconceptions, and some psychometric analysis, they do not provide details of psychometric analysis performed on the instrument in order for the concept inventory to be valid and reliable according to other effective concept inventories (Richardson et al., 2001; Richardson et al., 2003; Steif & Dantzler, 2005) . However, the instrument in its current state is a useful to tool to inform possible misconceptions on a question-by-question basis.

The SOMCI consists of 23 multiple choice questions covering concepts centered around stress, strain, buckling, bending, torsion and deflection of members with a variety of characteristics as shown in Table 2.3. The SOMCI was also never validated for practicing engineers, therefore, comparing the performance on a question-by-question basis, as opposed to sets of questions that represent specific concepts provides a unique opportunity to assess validity of the SOMCI on practicing engineers.

Table 2.3 Characteristics of strength of materials concept inventory question statements.

Focus Area	Question	Member Type	Load Type	Question Requirement
Stress, strain, and deflections due to axial forces	Q1	Steel Bar	Tensile Load	Locate highest axial stress
	Q2	Steel Bar	Tensile Load	Select member with highest axial stress
	Q3	Steel Bar	Tensile Load	Select member with highest axial stress
	Q4	Steel Bar	Tensile Load	Select member with largest axial elongation
Axial buckling of slender members	Q5	Slender Steel Bar	Point Load	Select member that will fail first
	Q6	Slender Steel Column	Axial Point	Select member that will buckle
	Q7	Steel Column	Point Load	Select member that will buckle
	Q8	Steel Column	Point Load	Select member that will buckle
Shear and bending moment distributions in beams	Q9	Beam	Distributive Load	Locate max tensile normal stress on vertical plane
	Q10	Beam	Distributive Load	Locate max compressive normal stress on vertical plane
	Q11	Beam	Distributive Load	Locate max shear stress on vertical plane
	Q12	Beam	Distributive Load	Locate max shear stress on horizontal plane
	Q13	Beam	Distributive Load	Locate max shear stress
	Q14	Beam	Distributive & Axial Load	Locate max compressive stress on vertical plane
Stress, strain, and deflections due to shear and bending in beams	Q15	Beam	Point Load	Select member with highest normal stress
	Q16	Beam	Point Load	Select member with largest midspan deflection
	Q17	Beam	Bending Deflection	Select member with largest normal stress
Stress in pressure vessels	Q18	Solid Cylinder	Axial Point	Select inclined plane stress diagram
	Q19	Solid Cylinder	Axial Point	Select max shear stress
Stress transformatio n and failure of ductile and brittle materials	Q20	Steel Cylinder	Axial Elongation	Determine type of failure
	Q21	Steel Cylinder	Axial Elongation	Determine failure plane
	Q22	Concrete Cylinder	Axial Elongation	Determine type of failure
	Q23	Concrete Cylinder	Axial Elongation	Determine failure plane

2.4.3 Data Analysis

Three analyses were conducted to holistically understand differences in performance on the SOMCI. First, in order to determine if a difference in performance (or correct scores) exists between the three groups as a whole, a one-way analysis of variance (ANOVA) was conducted. The ANOVA is reported because the parametric (ANOVA) and non-parametric (Kruskal-Wallis) tests were performed and with similar p-values, which indicated the data is robust to violations to normality (Tabachnick & Fidell, 2007). In addition, in order to determine if a statistically significant difference in performance exists between pair groups, a Tukey post hoc test was conducted on the one-way ANOVA. Second, an independent t test was performed in order to determine which group between pairs had a higher mean correct score on the overall SOMCI with a corresponding Cohen's d effect size in which a "small" effect size is considered 0.20, a "medium" effect size is considered 0.50, and a "large" effect size is 0.80 based on Cohen's guidelines (Cohen, 1992). Third, a chi-square test was performed for each of the 23 questions for three pair comparisons; structural engineers vs non-structural engineers, structural engineers vs engineering undergraduate students, and non-structural engineers vs engineering undergraduate students, to determine if there are any differences or patterns of understanding or relationships comparing performance of the three groups on each individual question on a dichotomous variable (the dichotomous variable being correct or incorrect). These two-way comparisons allow an understanding of which group performed better on each question. P-values are provided for all comparisons with indicators for different levels of significance and corresponding effect size. Statistical significance informs if there is any difference in performance across the groups and the effect size provides information on the magnitude of differences, if any, between the group. In this study $p<0.1$ was used to indicate statistical significance (Gall et al., 2007). Using guidelines from Sheskin (1997), effect sizes suggest that the differences in scores were between "small" (effect sizes are 0.2), "medium" (effect sizes are 0.3), and "large" (effect sizes are 0.5).

2.5 Results

2.5.1 Comparison of overall scores

An analysis of variance (ANOVA) was conducted to determine if any difference in performance among the three groups of participants on the SOMCI scores exists. Results show that there was a statistically significant difference between at least two groups as determined by one-way ANOVA ($F(2,234)=35.062$, $p<0.001$). A Tukey post hoc test revealed that correct score was statistically significantly different between different pair groups: structural engineers and non-structural engineers (p<0.001), structural engineers and engineering undergraduate students (p<0.001), as well as between non-structural engineers and engineering undergraduate students (p=0.002).

2.5.2 Mean correct rate on overall concept inventory

An independent samples t-test was conducted to examine group differences in mean correct scores. Results indicate that structural engineers with a mean correct rate of 15.2 (N= 43, SD= 2.86) performed better than non-structural engineers with a mean correct rate of 12.00 (N= 65, SD= 3.52) and engineering undergraduate students with a mean correct rate of 10.26 (N= 129, SD= 3.45) in the SOMCI. The independent samples t-test associated with a statistically significant effect, t(106)=4.950, p<0.001 between structural engineers and non-structural engineers, a statistically significant effect, t(192)= 3.30, p<0.001 between non-structural engineers and engineering undergraduate students, and a statistically significant effect, t(170)= 8.46, p<0.001 between structural engineers and engineering undergraduate students. Thus, the structural engineers were associated with a statistically significantly larger mean correct score than non-structural engineers and engineering undergraduate students and non-structural engineers were associated with a statistically significantly larger mean correct score than engineering undergraduate students.

When comparing structural engineers and non-structural engineers, Cohen's d was estimated at 0.973 for structural engineers and non-structural engineers, d was estimated at 1.489 for structural engineers and engineering undergraduate students, and estimated at 0.502 for non-structural engineers and engineering undergraduate students, which is large, large, and medium effect size respectively based on Cohen's (1992) guidelines.

2.5.3 Comparison of individual questions

A chi-square test was performed for the 23 questions to determine if there are any differences or patterns of understanding on individual questions and group pair comparisons. On a question-by-question basis, difference in performance across the three groups in 15 questions were statistically significant (p< .05). Figure 2-3 provides an overview of the results of the 23 chi-square tests, showing the percent total of the correct score for each group. The effect size for this finding, was small-large (Cramer's V= .2 to Cramer's V= .5) as proposed by Cohen (1992) on fifteen of the questions.

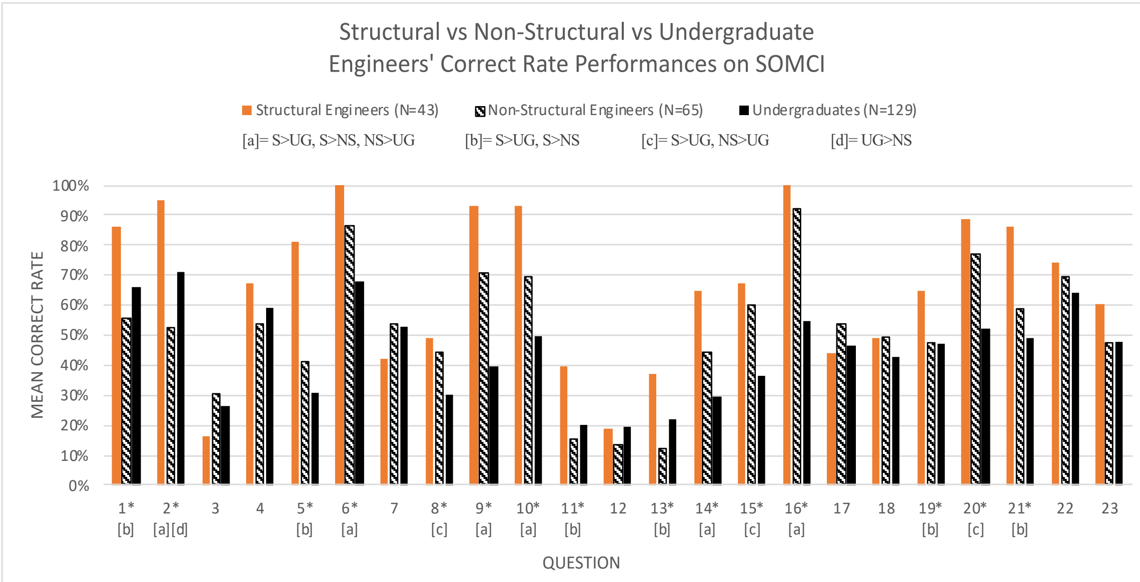


Figure 2-3. Overview of correct score on SOMCI. Symbol (*) denotes that a statistically significant difference exists between structural engineers, non-structural engineers, or engineering undergraduate students with [a]: S>UG, S>NS, NS>UG, [b]: S>UG, S>NS, [c]: S>UG, NS>UG, and [d]: UG>NS.

The pairwise comparison between structural engineers and engineering undergraduate students, difference in performance is statistically significant ($p< .1$) in fifteen questions with structural engineers having the higher correct score on all fifteen questions (Q1, Q2, Q5, Q6, Q8, Q9, Q10, Q11, Q13, Q14, Q15, Q16, Q19, Q20, Q21). The difference in performance between structural engineers and engineering undergraduate students is small (effect size of 0.1 - 0.29) in five questions, medium (effect size of 0.3 – 0.44) in eight questions, and large (effect size 0.45+) in one question. In the group pair comparison between structural engineers and non-structural engineers, difference in performance is statistically significant ($p< .1$) in twelve questions with structural engineers performing better on all twelve questions (Q1, Q2, Q5, Q6, Q9, Q10, Q11, Q13, Q14, Q16, Q19, Q21). The difference in performance between structural engineers and non-structural engineers is small (effect size of 0.1 - 0.29) in three questions, medium (effect size of 0.3 – 0.44) in eights questions, and large (effect size 0.45+) in one question. In the two-group comparison between non-structural engineers and engineering undergraduate students, difference in performance is statistically significant ($p< .1$) in nine questions with non-structural engineers performing better on eight questions (Q6, Q8, Q9, Q10, Q14, Q15, Q16, Q20). The difference in performance between non-structural engineers and engineering undergraduate students is small (effect size of 0.1 - 0.29) in six questions, medium (effect size of 0.3 – 0.44) in two questions, with engineering undergraduate students performing better in one question (Q2) with a small effect size (0.1). The distribution of these questions that show a statistically significant difference are listed in Table 2.4 according to their corresponding effect size. In order to distinguish any patterns across these results based on group participant comparison and performance, the data was reorganized in Table 2.5. Patterns shown in Table 2.5 will be evaluated in the discussion section. Questions in which there is a statistically significant difference between a group comparison are noted with (*) small, (**) medium, (***) large effect size.

Table 2.4 Questions identified as statistically significant and with an effect size among pairwise comparisons

	Effect Size		
Pairwise groups	Small (0.1 - 0.29)	Medium (0.3 – 0.44)	Large (0.45+)
Structural vs Engineering undergraduate students	Q1, Q8, Q11, Q13, Q19	Q2, Q5, Q6, Q10, Q14, Q15, Q16, Q20, Q21	Q9
Structural vs Non-Structural	Q14, Q16, Q19	Q1, Q5, Q6, Q9, Q10, Q11, Q13, Q21	Q2
Non-Structural vs Engineering undergraduate students	Q2*, Q6, Q8, Q10, Q14, Q15,	Q9, Q16, Q20	

Note: (*) denotes the only question in which engineering undergraduate students perform better than Non-Structural engineer with a small effect size.

Table 2.5 Results from chi-square test for independence comparing individual responses from structural, non-structural, and engineering undergraduate students.

Question	Total Correct Score			Group Comparison		
	SE	NSE	UG	Structural vs Undergraduates Performance	Structural vs Non-Structural	Non-Structural vs Undergraduates Performance
Q6- Columns under axial load	100%	86%	68%	S>UG**	S>NS**	NS>UG*
Q16- Beam with point load at midspan	100%	92%	55%	S>UG**	S>NS*	NS>UG**
Q2- Rec bar under tensile load	95%	52%	71%	S>UG**	S>NS***	UG>NS*
Q9- Distributed load beam	93%	71%	40%	S>UG***	S>NS**	NS>UG**
Q10- Distributed load beam	93%	69%	50%	S>UG**	S>NS**	NS>UG*
Q14- Axially & Distributed load beam	65%	45%	30%	S>UG**	S>NS*	NS>UG*
Q1- Rec bar under tensile load	86%	55%	66%	S>UG*	S>NS**	-
Q21- Solid cylinder with axial load	86%	59%	49%	S>UG**	S>NS**	-
Q5- Slender bars with point load	81%	42%	31%	S>UG***	S>NS**	-
Q19- Solid cylinder with axial load	65%	48%	47%	S>UG*	S>NS*	-
Q11- Distributed load beam	40%	15%	20%	S>UG*	S>NS**	-
Q13- Distributed load beam	37%	12%	22%	S>UG*	S>NS**	-
Q20- Solid cylinder with axial load	88%	77%	52%	S>UG**	-	NS>UG**
Q15- Beam with point load at midspan	67%	60%	36%	S>UG**	-	NS>UG*
Q8- Columns with point load	49%	45%	30%	S>UG*	-	NS>UG*
Q22- Solid cylinder with axial load	74%	69%	64%	-	-	-
Q4- Rec bar under tensile load	67%	54%	59%	-	-	-
Q23- Solid cylinder with axial load	61%	48%	48%	-	-	-
Q18- Solid cylinder with axial load	49%	49%	43%	-	-	-
Q17- Beam with midspan bending point	44%	54%	47%	-	-	-
Q7- Columns with point load	42%	54%	53%	-	-	-
Q12- Distributed load beam	19%	14%	19%	-	-	-
Q3- Rec bar under tensile load	16%	31%	26%	-	-	-

Note: Questions that are statistically significant are noted with their corresponding (*)small (0.1-0.29), (**)medium (0.3-0.44), or (***)large (0.45+)effect size.

2.6 Discussion

Overall, practicing structural engineers have a more robust conceptual understanding of the strength of materials concepts than non-structural engineers and engineering undergraduate students. The strength of material concept inventory was developed to measure conceptual understanding of stress, strain, buckling, bending, torsion, and deflection of members that consisted of different characteristics. For this discussion, the inventory questions are placed in three categories: beams, columns & rods, and cylinders. Table 2.5 is ordered first by questions where structural engineers’ performance is statistically different from both non-structural engineers and engineering undergraduate students. The second order of organization consists of where non-structural engineers' performance is statistically different from engineering undergraduate students. The third order of organization consists of questions in which there is no statistical difference in performance among any groups. The organization of Table 2.5 allows consideration of the results in terms of the arguments in the background literature. For the purposes of this study, a "well" performance includes a correct score of 80% and above, a "good" performance includes a correct score between 56%-79%, and a "low" performance includes correct scores below 55%.

Expert and novice literature suggests that practicing engineers will perform better on questions if they have broader level of conceptual understanding of the concepts that the questions represent (Bransford, Brown, & Cocking, 2000; Atman et al., 2007; Ericsson, 2007; Jonassen, Strobel & Lee, 2006). Broader conceptual understanding would allow for the transfer of knowledge to different kinds of problems regardless of representations. For example, if practicing engineers employ the concepts of column buckling design in their day-to-day job, then they will perform better on questions utilizing that concept and should be able to do so regardless of representation. As stated earlier, expert and novice literature indicate that experts have acquired a lot of content knowledge organized into familiar patterns (or groups), allowing them to problem-solve with minimal effort in new and unfamiliar contexts. The paired comparison in Table 2.5 revealed that structural engineers performed better than engineering undergraduate students in 15 questions and outperformed non-structural engineers in 12 questions in the strength of material concept inventory. In the column-rod category (Q1-Q8), structural engineers performed statistically different in five questions between non-structural engineers and engineering undergraduate students. Structural engineers outperforming both groups indicates that they have a better conceptual understanding column buckling and axial stress in rods. Similarly, structural engineers statistically outperformed non-structural engineers and engineering undergraduate students in seven questions of the beam-related category (Q9-Q17), indicating a robust conceptual understanding of beams' normal stress behavior. In the cylinder category (Q18-Q23), there is a statistical difference in performance in three questions (Q19, Q20, Q21) covering shear stress, where structural engineers did better than non-structural engineers and engineering undergraduate students. It is evident that structural engineers outperforming non-structural engineers and engineering undergraduate students in 15 of the 23 questions suggest that experience in the profession provides a deeper, more expert-like understanding of the concepts than engineering undergraduate student, indicating some progression of understanding when obtaining field experience as a structural engineer. It is essential to consider that engineering field experience provides practicing engineers with continued learning and the opportunity to solidify understanding of engineering conceptual knowledge gained in their academic coursework.

Although structural engineers performed better overall in more than half of the questions, some inconsistencies remain in concepts targeting stress, strain, buckling, bending, torsion, and deflection of objects. For instance, in beam-related questions, while structural engineers performed better than non-structural engineers and engineering undergraduate students on questions on normal stress and deflection, their performance was low in other questions also addressing normal and shear stress behavior. Although performance is low, results show a statistical difference in four questions (Q11, Q13, Q14, Q15) and no statistical difference in two questions (Q12, Q17). Similarly, results in the four questions addressing buckling in columns, two of these questions have a low performance, with one of the questions having a statistical difference.

In the cylinder category addressing axial load, results show that structural engineers performed better than non-structural engineers and engineering undergraduate students; however, three questions show low performance, and one of the questions has a statistical significance in performance with non-structural engineers. Findings indicate that there is limited evidence that experts have this consistent holistic understanding that the expert-novice literature would suggest because structural engineers do work with beams, columns, and cylinders. Therefore, the difference in performance may be related to the difference in how engineers typically engage with these concepts in their everyday work contexts.

Situated cognition literature suggests that structural engineers may perform better than non-structural engineers and students on questions relevant to their social situational factors due to concepts being situated and conceptual understanding developed through practical experience and academic understanding (Barner, 2019; Brown et al., 1989; Stevens et al., 2014). For instance, the approach to beam design is fundamentally different. Engineering practitioners use codified approaches for beam design, while in academia, students are provided with figures, loads, and equations to determine stress values at a certain location. If the approach to beam design differs between these two contexts then the approach to problems in the concept inventory would not be familiar. For instance, engineering practitioners use codified approaches for beam design, while in academia students are provided with figures, loads, and equations. The problem statements in the concept inventory are similar to textbook problems which is not the typical type of problems practicing engineers engage with in practice (Jonassen, 2006). Situated cognition would indicate that since the concept inventory design is more like an academic test, engineering undergraduate students perform better than practicing engineers. For example, Brown et al. (2019) discussed that the difference in performance in the statics concept inventory in which engineering students outperformed practicing engineers could be due to how conceptual representations utilized in the statics concept inventory may not be relevant to civil and structural engineering practice. On the other hand, situated cognition would also support the fact that since concepts and representations in the SOMCI are more relevant to practicing structural engineers than those in the SCI, structural engineers will most likely perform better than non-structural engineers and engineering undergraduate students. For example, since beam analysis is heavily incorporated in building design, structural engineers would better understand the normal and shear stress phenomenon in beam design. However, that wasn't the case with the beam-related questions in the SOMCI. Although structural engineers outperformed non-structural engineers and engineering undergraduate students in the beam category, results show low performance in six of the nine beam questions (Q11, Q12, Q13, Q14, Q15, Q17). Even though practicing engineers and engineering undergraduate students interact with strengths of material concepts through their related activities, the conceptual representations used in the SOMCI may be interpreted differently across engineering practice and academic contexts, indicating that knowledge is contextual and related to features in a work environment (Bransford, Brown, & Cocking, 1999).

The difference in interpretation would indicate that the question's conceptual representation would affect performance depending on the level of familiarity with how the problem is presented. This would imply that a poor response is expected if the question is being asked in an unfamiliar format. In the same way, if the problem is being asked in a familiar format, then the correct response to the question is expected. Studies have demonstrated the importance and difference between visual representations of concepts in different contexts (Chamorro-Koc et al., 2008), explaining these questions' low performance results. Low performance in beam questions covering shear stress behavior indicates that there isn't a good understanding of shear stress, but this also contradicts the assumption that a structural engineer understands beam design since an understanding of shear stress is essential in beam design. It would be expected that engineering undergraduate students who have recently taken a mechanics course would better understand the content and perform better than practicing engineers.

However, these questions' poor performance shows that undergraduates also have a minimal conceptual understanding of the content, consistent with previous findings indicating that shear stress is still a challenging concept for undergraduates to understand (Montfort et al., 2009). In order to validate the instrument, there is more work needed to develop the concept inventory, including interviewing practicing engineers to access their understanding and misconceptions, as well as applying the necessary statistical analysis to validate the concept inventory as described by Jorion et al. (2015). Once the concept inventory is validated, this instrument can be implemented in later structures courses or graduate courses, where students would be expected to have a better understanding of strengths of material concepts. Although overall performance is low and practicing engineers performed better among the groups, shear stress is a challenging concept for experts and novices. However, with practicing engineers performing better, this could lead us to an insight on how these concepts might better be presented. Currently, there is limited information we can conclude from the data results, but if we did have practicing engineers reasoning and justification for the answers, we would be able to address the issue. Further knowledge of participants' reasoning behind their answer selection is needed to understand better whether they grasp the concept.

2.7 Conclusion

While most engineering educators strive to provide students with an essential conceptual understanding of fundamental engineering concepts, assessing conceptual understanding remains a challenge. In addition, there are limited studies that focus on the presence and relevance of this knowledge transitioning to the engineering workforce. This study aims to compare the performance of structural engineers, non-structural engineers, and engineering undergraduate students on the SOMCI. By comparing performance between these groups, we gain insight into the influence of situated cognition on conceptual understanding. The SOMCI was administered to engineering practitioners and undergraduates to explore differences in conceptual understanding.

Statistical analyses were conducted on the responses of the SOMCI to understand differences in performance between groups. It is interesting to find that in this SOMCI, structural engineers performed better than both non-structural engineers and engineering undergraduate students in the majority of the questions, which is the opposite to the results in the Statics Concept Inventory findings in Brown et al. (2019). Structural engineers perform better than both non-structural engineers and engineering undergraduate students, indicating that their accumulated time and practice in the field must influence their conceptual understanding of the question statements in the concept inventory. For example, there are nine questions in which structural engineers perform very well and statistically significantly different than non-structural engineers and/or engineering undergraduate students. Two of these questions target normal stress in beams concept, where structural engineers have a correct score of 93%, non-structural engineers have a correct score below 75%, and engineering undergraduate students have a correct score below 50%. Results indicate that both non-structural engineers and engineering undergraduate students have misconceptions about normal stress in beam concepts. Considering that structural engineers have a broader conceptual understanding of the normal stress in beams concept, it would be beneficial for researchers to understand better structural engineers' logic in approaching the correct answer to incorporate in instructional materials. By understanding this logic better, educators can create learning opportunities that simulate the professional engineering practice, providing students with authentic situations that can support students in developing practice-oriented skills and be better prepared for the workforce.

Results demonstrate how practical experience in the field correlates to how well structural engineers responded to conceptual questions, providing a better understanding of the importance of how field experience offers practicing engineers continued learning and the opportunity to solidify engineering academic conceptual knowledge. This information is helpful, providing insight on students' conceptual understanding of the content, and can be used to develop assessments to improve instruction and prepare students for the field. For instance, there are eight questions in which participants have a correct score lower than 55%. Within these questions, three target shear stress in beams, in which all participants have a correct score lower than 40%, and two target buckling, in which all participants have a correct score lower than 55%. Given the results found here, participants do not understand shear stress in beams and are still struggling to grasp the buckling of columns. Although the incorrect responses can identify misconceptions, we can better understand how participants approach the question by conducting interviews to understand their logic in problem-solving that leads them to the selected response. Conducting enough interviews to understand this logic can be used to design instructional materials that explicitly address these misconceptions and improve students understanding of that particular concept. Different instructors might have different perspectives on addressing these misconceptions, so it may be beneficial for a group of instructors to collaborate in designing instructional materials.

The use and meaning of concepts vary across contexts, indicating that the differences between the work and academic context might explain why structural engineers outperformed other practicing engineers and engineering undergraduates. From a situated perspective, it is essential to consider how concepts are represented. It may also be that the content is more relevant in the structural engineering field than in a non-structural or academic context, indicating that knowledge is contextual and related to features in a work environment. However, shear stress in beams is also a relevant concept in engineering practice, but the performance in these related questions was poor, which indicates that structural engineers may understand these concepts differently than it is represented in the SOMCI.

Assessing conceptual knowledge is still a challenge in the engineering education community. The SOMCI was administered to practicing engineers (structural and non-structural) and engineering undergraduate students to explore differences in strengths of material conceptual understanding. Statistical analysis was performed on both accuracy and pattern of response to various questions. There seems to be no apparent consistency in concept areas. Results suggest that engineers understand strength of materials better than students; however, such an interpretation might overlook differences in how these two groups interpret the concepts within the SOMCI. Future work should explore the assessment of conceptual knowledge in engineering through a qualitative approach such as interviews, asking participants about their thought process on their approach to solving the questions. Exploration should also include links between the use of concepts in school and work contexts and assessing the complex relationship between conceptual knowledge and corresponding representational modes in engineering. Previous interview-based qualitative research (Brown et al., 2018; Urlacher et al., 2015) has provided researchers with additional explanations and reasonings on practicing engineers' conceptual understanding while solving problems, supporting their quantitative findings. Obtaining this information can provide the engineering education field with an understanding of the engineering field and help align educational practices to prepare students for the engineering workforce. Future research efforts would benefit from including a qualitative interview approach to target participants' reasoning on problem-solving through SOMCI questions.

Chapter 3- Comparison of conceptual knowledge of shear stress in beams between civil engineering undergraduates and practitioners.

3.1 Abstract

Shear stress is an essential concept for engineering undergraduates to understand and apply in civil engineering problem-solving. This exploratory study compares undergraduate engineering students' and practicing civil engineers' conceptual knowledge of shear stress in beams utilizing a concept inventory. Concept inventories have been used in engineering disciplines as a form of assessment of student conceptual understanding and are presumed to be important for measuring conceptual growth towards successful engineering practice. It can also provide insight into how to enhance undergraduate engineering education to focus on concepts most relevant to engineering practice. The 23 question strengths of materials concept inventory was implemented, resulting in responses from 153 undergraduate engineering students and 119 practicing civil engineers. Three questions that focused on shear stress in beams were analyzed. Although overall results indicate that practicing engineers perform better than students, performance from all participants is low in the three shear stress beam questions. Undergraduates had a higher presence of misconceptions related to the location of maximum shear stress in a bending beam while practicing civil engineers demonstrated a misconception that the maximum shear stress is located at the ends or support of the bending beam. Both groups were challenged with locating where the maximum shear stress is located depending on the type of plane. Outcomes from this study suggest more work may be needed when addressing conceptual understanding related to shear stress concepts.

3.2 Introduction

Aligning engineering education with engineering practice is essential to prepare students for the professional field. Graduate engineers continue to be challenged when connecting their engineering courses to "real" engineering, which has led to concerns about whether engineering undergraduates are adequately prepared (Goold, 2015). Investigations examining the disconnect between academic engineering preparation and professional practice in engineering education research are ongoing (National Academy of Engineering, 2005; Shuman et al., 2005). In some cases, this education to practice gap has been connected to misaligned preparation between undergraduate engineering education that focuses on fundamental conceptual knowledge to structured problems and engineering practice where design challenges are more ambiguous (Barner et al., 2019). To further examine this issue, studies have focused on assessing student's conceptual knowledge of engineering concepts.

Concept inventories in many topics have been developed and implemented to engineering undergraduates as an assessment tool to measure conceptual understanding of engineering concepts. The Foundation Coalition was established to facilitate the development of concept inventories for engineering education (Creuziger & Crone, 2006). Concept inventories have since been developed for core engineering topics such as Statics (Steif & Dantzler, 2005), Thermodynamics (Midkiff et al., 2001), Heat and Energy (Prince et al., 2012), and Materials (Evans et al., 2003; Krause et al., 2003). Concept inventories have been used broadly in engineering education for many reasons, including assessing the efficacy of an educational intervention, identifying misconceptions, and providing information about the strengths and weaknesses of individuals' conceptual understanding of the material. Concept inventory questions have one correct answer and two-four incorrect answers. The incorrect answers represent misconceptions or a form of incorrect prior knowledge or preconceptions and previous experience that may impede learning (Bransford, Brown, Suzanne Donovan, et al., 1999; Evans et al., 2003; Krause et al., 2009; Montfort et al., 2009). Richardson et al. (2003) developed a concept inventory measuring the understanding of the strength of materials concepts such as normal and shear stress and strain, axial buckling, shear, bending, and stress transformation. Shear stress, a concept found in all strength of materials courses, is an important concept commonly used in civil and mechanical engineering and structural engineering design. Studies researching conceptual understanding of shear strength have shown that it is a challenging concept for undergraduates to grasp (Creuziger & Crone, 2006; Montfort et al., 2009). While concept inventories have been used to assess engineering undergraduates' conceptual knowledge, very few have been implemented to assess practicing engineers. The purpose of this study is to compare engineering undergraduates and practicing engineers (structural and non-structural) on three shear stress questions from the Strength of Materials Concept Inventory (SOMCI).

Having engineering practitioners take a concept inventory can provide information on how conceptual knowledge compares in an academic setting to industry. Since shear stress is an important foundational concept and a standard part of civil and structural engineering practice, it would be expected that practicing engineers would perform better on conceptual shear stress questions in the strength of materials concept inventory (SOMCI). Implementing a concept inventory to assess engineering practitioners' and undergraduate engineers' conceptual knowledge can provide engineering educators and researchers with the opportunity to investigate conceptual understanding and misconception patterns.

3.3 Shear stress

Strength (or mechanics) of materials is a fundamental course for civil and mechanical engineers and is typically taught during the undergraduate engineering program's sophomore year. The content covered includes topics such as normal and shear stress and strain, axial buckling, shear, bending, and stress transformation. It is essential to understand how applied loads affect material deformation and failure of a member. Generally speaking, the designer will determine which loading conditions control (result in the worst combination of internal stresses or deformations) and which stress(es) are considered to determine the controlling design criteria. One of these design considerations is shear stress. The magnitude of shear stress varies depending on the loading conditions and the material's geometry. In structural design, the shear stress magnitude is important when designing beams because they can fail while bending. A beam is a structural member primarily designed to support loads perpendicular to the member's length. Bending basically results in the beam going from a straight line when unloaded to a curve when loaded (Figure 3-1) and can produce both normal stress and shear stress.

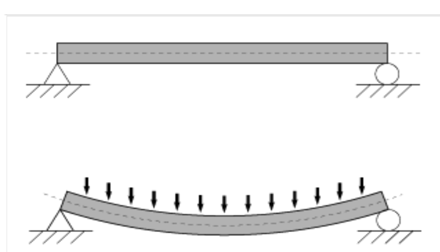


Figure 3-1. Bending stress in beams

The shearing stress in a beam is defined as the stress that occurs from the beam's internal shearing due to shear force (Hibbeler, 2008). Shear stress is distributed on the beam's cross-section, represented by a parabolic curve where the maximum shear occurs at the geometric centroid (or neutral axis) of the beam (Figure 3-2). Shear stress is an essential concept in material science, and it would be expected that practicing engineers who utilize this concept in their daily work would have a better conceptual understanding of shear stress than engineering students. In addition, performance in the SOMCI reveals shear stress misconceptions that participants may have.

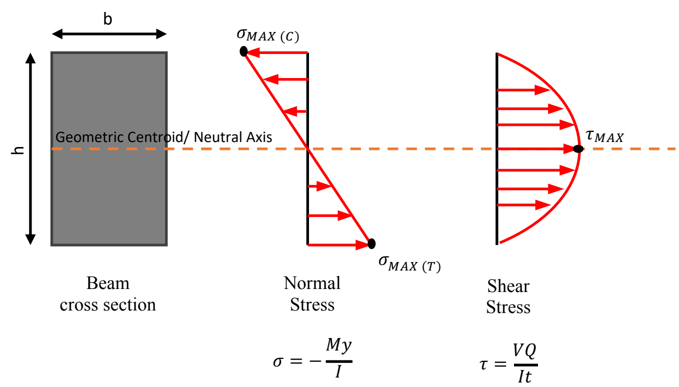


Figure 3-2. Normal and shear stress distribution in a rectangular beam.

3.4 Misconceptions

Concept inventories have been used as an assessment tool to evaluate a students' understanding of a particular core concept (Hestenes et al., 1992; Krause et al., 2003; Richardson et al., 2003). Applications of concept inventories fall into three main categories: a diagnostic tool, evaluation of instruction, and placement exam (Hestenes et al., 1992). A concept inventory can be used to identify individual questions' strengths and weaknesses and of participants' knowledge. Identifying students' strengths, weaknesses, and conceptual misunderstandings provide the opportunity to intervene and clarify misconceptions and areas where a course needs to be modified (Montfort et al., 2009; Yilmaz, 2010). In the case of this research, implementing the CI to practicing engineers and undergraduates allows us to compare performance and misconceptions on a small set of questions and begin to understand how engineers understand shear stress.

Research on conceptual understanding of the strength of materials has focused on the development of a concept inventory (Evans et al., 2003; Midkiff et al., 2001) and on investigating the level of students' conceptual understanding (Montfort et al., 2009) through interviews. Findings have shown that students have difficulty understanding relationships relating to loading and stress distribution and other fundamental concepts (Brown et al., 2018; Montfort et al., 2009). The strength of materials concept inventory is used in this study to investigate differences in understanding of students and engineers on three questions about shear stress in beams.

Conceptual understanding has been used to differentiate between students' abilities to perform calculations and understand the content. Having a conceptual understanding of the material implies knowing more than isolated facts and methods, such as transferring their knowledge into a new situation and applying it to a new context. Learning can be impeded by shortcomings in conceptual understanding, also described as misconceptions. Krause (2009) defines misconceptions as students' mental models not aligning with the scientific community's consensus and suggests that misconceptions are formed from personal experience or incorrect knowledge development from previous courses. Krause (2009) further states that misconceptions can create two types of impediments to future learning, null impediment, which refers to missing information, and substantive impediment, which refers to faulty concept models. Misconceptions have also been described as alternative views of a student that develops aside from scientifically accepted facts or obstacles that prevent students from learning and applying concepts properly and maintaining the learning process's efficiency (Evans et al., 2003; Yilmaz, 2010).

While there is an abundance of literature (Evans et al., 2003; Krause et al., 2003; Midkiff et al., 2001; Prince et al., 2012; Steif & Hansen, 2007) devoted to conceptual understanding and efforts on how to address misconceptions, very few investigate the presence of misconceptions and how patterns may differ between students and engineering practitioners. Concept inventories can be administered to practicing engineers and undergraduates to further this research agenda. This would also highlight if and how misconceptions differ between practicing engineers and engineering students. One of the viewpoints in the book, How People Learn: Brain, Mind, Experience, and School (Bransford et al., 1999), highlights how novice learners (undergraduate engineers) are unlike expert learners (practicing engineers) in that experts have developed the learning skills to build a deep content understanding and organization of their subject that facilitates their retrieval and transfer to new and different applications. This would imply that if a concept inventory were to be provided to both of these groups, practicing engineers would perform better than students and have minimal misconceptions about the strength of materials concepts.

3.5 Methods

3.5.1 Instrument

The strength of materials concept inventory consists of 23 multiple choice questions covering concepts centered around normal and shear stress and strain, buckling, bending, torsion, and deflection. Each question was designed to include one correct answer and several incorrect answers, which are identified as "distractors" and which are based on common student misconceptions (Richardson et al., 2003). An essential quality of a concept inventory is its reliability. The SOMCI has been through two iterations, with the most recent one in 2003. After the first implementation of the SOMCI, the developers applied a psychometric analysis of the instrument, in which they found that the inventory had no internal consistency (Richardson et al., 2003). Although the instrument's reliability is not validated, it is still a valuable tool to inform possible misconceptions participants may have on a question-by-question basis. The SOMCI needs to be validated to function as an overall instrument analyzing particular concepts, however in its current state, we can look at individual question performance.

3.5.2 Sample

Undergraduate engineering students and practicing engineers were recruited, via email, from across the nation to take the concept inventory (CI) through surveymonkey.com voluntarily. Participants who agreed to participate were provided a link to the SOMCI and were asked to help recruit other engineers from their companies and affiliated engineering societies. A link was emailed to faculty to recruit undergraduate participants. No class time was used for the CI, and students were not penalized if they elected not to take the concept inventory. All participants were provided with information and terms regarding the research study.

A total of 119 practicing engineers volunteered to take the SOMCI, which included 108 completed responses. Participants were asked to provide demographic information, including gender, years of engineering experience, the highest level of education, and engineering area(s) of expertise shown in Table 3.1.

Table 3.1 Demographics of the engineering practitioners

		Gender		Highest education	
Civil engineering specialization	Total	Female	Male	Bachelor	Master
Civil engineering	36	8	27	30	6
Structural engineering	28	8	20	13	15
Civil engineering + other [a]	24	7	16	19[c]	5[d]
Structural engineering + other [b]	17	5	12	7	10[d]
Other	14	3	11	6	8

[a]Civil engineers who indicated more than one engineering expertise, including geotechnical, environmental, water resources, transportation, construction management, and others.
[b]Structural engineers who indicated more than one engineering expertise, including civil, geotechnical, environmental, water resources, mechanical, and others.
[c]One engineer reports high school education
[d]One engineer reports PhD.

Practicing engineers' years of industry experience varied from 1 year to 39 years, and the sample consisted of 26% female, 72% male, and 2% identified as other. As an incentive to take the concept inventory, the engineers were invited to participate in a $250 raffle. A total of 153 engineering undergraduates elected to take the concept inventory, with 129 complete responses. The students who took the concept inventory came from 8 institutions ranging from community colleges to four-year institutions. The undergraduates had already taken an introductory strength of material course prior to taking the SOMCI, but the academic level at the time they took the survey was not gathered. The gender make-up of the engineering undergraduate sample was 14% female, 84% male, and 2% identified as other. In examining time completion in entries, it did not seem plausible to complete this concept inventory in less than 5 minutes; therefore, all results that had a completion time of 5 minutes or less were eliminated. Incomplete entries were removed from student and engineering practitioner's data. This process resulted in the final count of participants being 129 undergraduates and 108 engineering practitioners.

3.5.3 Data Analysis

The SOMCI was used to examine the differences in conceptual understanding between the three groups, practicing structural engineers, practicing non-structural engineers, and engineering undergraduates. A one-way ANOVA was performed to determine if an overall difference in performance exists between the structural engineers, the non-structural engineers, and the students. An independent samples t-test was conducted on the overall results to determine if the difference in performance is significant and the effect size between pair groups, structural vs. undergraduate, structural vs. non-structural, and non-structural vs. undergraduate. A chi-square test of independence was performed on each of the 23 questions to determine if there are any differences or patterns of understanding or relationships between these three groups. The confidence intervals for effect sizes are included because they are a measure of the precision of the analysis (Borenstein et al., 2009; Tabachnick & Fidell, 2007). A parametric and non-parametric test was conducted for the t-test and the one-way ANOVA; no discernable difference in *p*-values was found, indicating that the data is robust to any normality violations (Tabachnick & Fidell, 2007).

3.6 Results and Discussion

Results from a one-way ANOVA on the overall SOMCI show that there is a statistically significant difference between the three groups ($F(2,234)=35.062$, $p<0.001$). In pairwise comparisons, an independent samples t-test revealed that structural engineers (M=15.62 N= 43, SD= 2.86) performed better than non-structural engineers (M=12.00 N= 65, SD= 3.52) and better than engineering undergraduates (M=10.26 N= 129, SD= 3.45) in the SOMCI with a significant level of difference in performance, $t(106)=49.50$, $p<0.001$ and $t(170)=8.46$, $p<0.001$ respectively. An independent samples t-test indicates a significant level of difference in performance $t(192)=3.30$, $p<0.001$ between non-structural engineers and engineering undergraduates.

The pairwise comparisons of the three individual questions shown in Table 3.2 indicate a significant difference between structural vs. undergraduates and structural vs. non-structural in Q11 and Q13. Results show no significant difference in performance between non-structural and undergraduates in all three questions and no difference in performance between any of the three groups in Q12. Questions in which there is a statistically significant difference for each group pair comparison is bolded and asterisks are used to indicate the level of significance, small(*), medium(**), and large(***) with the corresponding effect sizes (0.1-0.29), (0.3-0.49), and (0.5+) respectively.

In order to better understand this difference in performance among participants, the discussion will focus on three beam-related questions from the SOMCI. A description of the correct answers are provided so that someone unfamiliar with the content can follow the results. In addition, a discussion of one or more misconceptions will be reviewed. Table 3.2 summarizes statistical analysis results from beam-related questions Q11, Q12, and Q13. Each question in the SOMCI consists of multiple-choice responses. Table 3.3 includes the percent of respondents who selected multiple-choice options from A-G, in which ABCDEFG are options of answers to SOMCI questions.

Table 3.2 Statistical Analysis Results for Structural, Non-structural, and Undergraduate Engineers SOMCI performance

	Total Correct Score (%)			Chi-Square			Independent t-test (Pairwise comparison)					
							S vs UG		S vs NS		NS vs UG	
Question	SE	NSE	UG	X2 (df)	*p*	Effect Size (V)	*p*	Performance	*p*	Performance	*p*	Performance
Q11	40%	15%	20%	9.488 (2)	0.009	0.200	**0.011***	S>UG	**0.005****	S>NS	0.420	-
Q12	19%	14%	19%	0.936 (2)	0.626	0.063	0.911	-	0.506	-	0.339	-
Q13	37%	12%	22%	9.379 (2)	0.009	0.199	**0.044***	S>UG	**0.002****	S>NS	0.112	-

Note: In pairwise comparisons, questions that are statistically significant (p<0.05) are bolded and noted with their corresponding (*) small (0.1-0.29), (**) medium (0.3-0.49), or (***) large (0.5+) effect size.

Table 3.3 Compare Structural, Non-Structural, and Undergraduate Engineer Responses

		A	B*	C	D	E	F	G
Question 11	Structural	16%	40%	26%	0%	5%	2%	12%
	Non-Structural	14%	15%	28%	8%	11%	8%	17%
	Undergraduate	11%	20%	7%	6%	25%	10%	21%
Question 12	Structural	0%	19%	19%	5%	19%	7%	33%
	Non-Structural	14%	6%	6%	3%	17%	9%	37%
	Undergraduate	5%	4%	4%	5%	23%	8%	36%
Question 13	Structural	14%	33%	33%	2%	5%	9%	-
	Non-Structural	15%	25%	25%	8%	20%	20%	-
	Undergraduate	6%	10%	10%	9%	28%	25%	-

Structural engineers' participants (N=43). Non-Structural engineers' participants (N=65). Undergraduate participants (N=129). Values represent the percent of respondents who selected multiple-choice options from A-G. ABCDEFG are options of answers to multiple-choice questions. Symbol (*) denotes correct answer.

The three selected beam questions all ask participants to identify the maximum shear stress on a specified plane. Essentially, the maximum shear stress location is the same in all three questions. In order to facilitate the discussion on the selected misconception response in each question, it would be helpful to first walk through the correct response. The shear force distribution along the beam's length begins at a maximum value, decreases linearly along the length of the beam passing through zero at the geometric center, and ends at the maximum shear value, as shown in Figure 3-3. The shear force is higher at the plane where A, B, and C are located and is zero at the plane where D, E, and F are located. The distribution of shear stress at the beam cross-section is parabolic, with zero values at the top and bottom of the cross-section and maximum at the vertical geometric center (Figure 3-4). Therefore, with the given loading conditions, the maximum shear stress is at location B.

The problem statement and results of question 11 are shown in Figure 3-5. In question 11, 40% of the structural engineers, 15% of non-structural engineers, and 20% of undergraduates selected the correct answer. The most chosen incorrect answer by undergraduates (25%) in Q11 is choice E, in which participants believe that the maximum shear stress is located at the center of the beam. This selection indicates that undergraduates may have recognized that the maximum shear stress is located at the geometric center of the beam but didn't consider that the shear force is zero at the center of the beam. The first most common selection for non-structural engineers (28%) and the

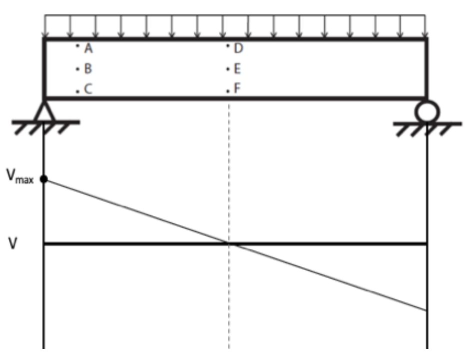


Figure 3-3. Shear diagram for beam with distributive load.

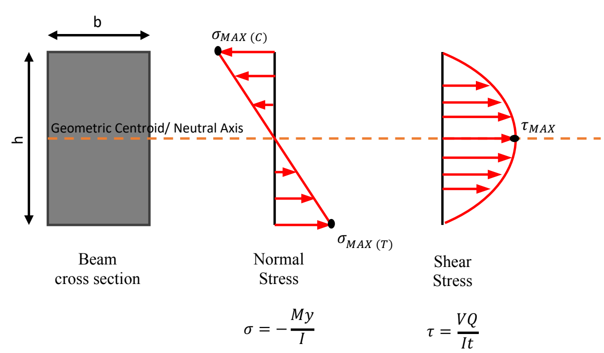
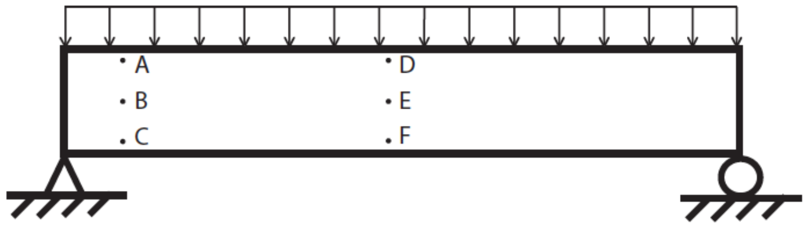


Figure 3-4. Shear stress distribution in rectangular beam cross section.

second most common selection for structural engineers (26%) is choice C. Although location C has a larger shear force than the plane where D, E, and F are located, the shear stress is lower than at location B. We can speculate that the engineers recognized that the location of the maximum shear force is at the end of the beam but didn't recall the shear stress distribution in the cross-section.

11. At which location in the beam below is the shear stress on a vertical plane maximum ?



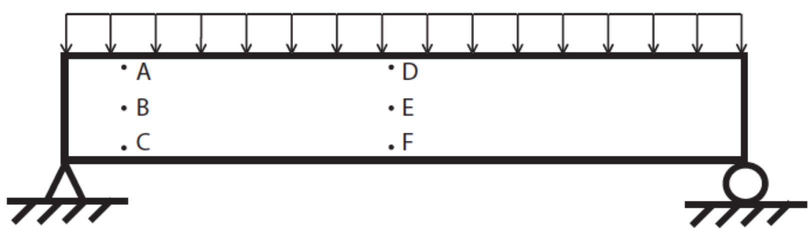
a) Location A
b) Location B
c) Location C
d) Location D
e) Location E
f) Location F
g) the stress is the same at all locations

Question 11	A	B*	C	D	E	F	G
Structural Eng (N = 43)	16%	40%	26%	0%	5%	2%	12%
Non-Structural Eng (N=65)	14%	15%	28%	8%	11%	8%	17%
Student (N = 129)	11%	20%	7%	6%	25%	10%	21%

Symbol (*) denotes correct answer.

Figure 3-5. SOMCI question 11 problem statement and results.

12. At which location in the beam below is the shear stress on a horizontal plane maximum ?



a) Location A
b) Location B
c) Location C
d) Location D
e) Location E
f) Location F
g) the stress is the same at all locations

Question 12	A	B*	C	D	E	F	G
Structural Eng (N = 43)	0%	19%	19%	5%	19%	7%	33%
Non-Structural Eng (N=65)	14%	14%	6%	3%	17%	9%	37%
Student (N = 129)	5%	19%	4%	5%	23%	8%	36%

Symbol (*) denotes correct answer.

Figure 3-6. SOMCI question 12 problem statement and results.

The results for question 12 shown in Figure 3-6, seem to be similar for all participants. Correct score percentages are as follows, 19% for structural engineers, 14% for non-structural engineers, and 19% for undergraduates who selected the correct answer. Many participants believe G is the correct answer, with 33% of structural engineers, 37% of non-structural engineers, and 36% of undergraduates selecting G as the correct answer. Selecting G implies that respondents believe that the stress is the same at all locations. The shear force is a single value across any particular cross-section of a beam. Respondents may believe the question is asking about shear force. Even in this case, the shear force is different at the cross-section where A, B, and C are located compared to the cross-section where D, E, and F are located. Participants may also believe that the shear stress is zero at all locations, because they may be thinking about a shear stress element, in which all four shear stresses have equal magnitudes, are pointed toward or away from each other at opposite edges of the element, and therefore canceling out (Figure 3-7).

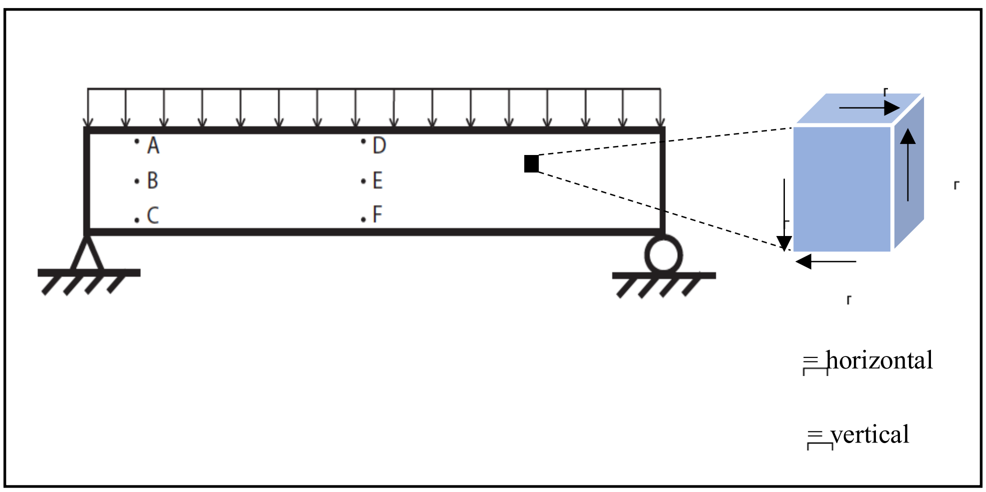
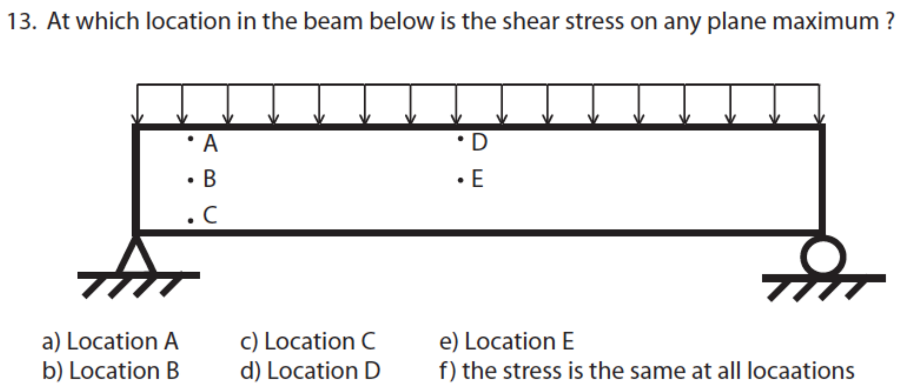


Figure 3-7. Shear stress element



Question 13	A	B*	C	D	E	F	G
Structural Eng (N = 43)	14%	37%	33%	2%	5%	9%	-
Non-Structural Eng (N=65)	15%	12%	25%	8%	20%	20%	-
Student (N = 129)	6%	22%	10%	9%	28%	25%	-

Symbol (*) denotes correct answer.

Figure 3-8. SOMCI question 13 problem statement and results.

The problem statement and results of question 13 are shown in Figure 3-8. Structural engineers have a higher correct score percentage than non-structural and undergraduates in Q13, with 37% of the structural engineers, 12% of non-structural engineers, and 22% of undergraduates selecting the correct answer. The first most common selection for non-structural engineers (25%) and second most common selection for structural engineers (33%) is choice C. Similar to Q11, participants believe that the maximum shear stress is located at the bottom left of the beam. It seems that just like in Q11, the same misconception is present in Q13, in which practicing engineers recognize that the location of maximum shear force is at the end of a beam, but didn't consider the shear stress distribution at the beam cross-section. It is possible that practicing engineers are thinking about shear failure in beams. Shear failure occurs when the shear stress is maximum at a 45 degree cross-section, causing a diagonal crack at the end of the beam (Figure 3-9). This may explain why practicing engineers selected C. The most selected incorrect answer in Q13 by undergraduates (28%) is choice E, in which they believe that the maximum shear stress is located at the center of the beam. Since the wording of the question has changed, we can speculate that undergraduates may be thinking about the location of the maximum bending stress. The maximum stress can be found using the flexure formula (Figure 3-10) that requires the maximum moment located at the center.

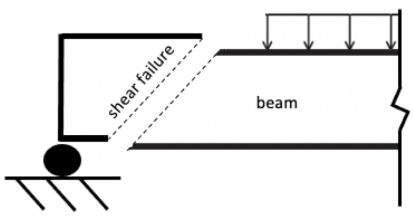


Figure 3-9. Image of beam shear failure

$$\sigma_{\max} = \frac{cM_z}{I_z}$$

$$\sigma_x = -\frac{yM_z}{I_z}$$

Figure 3-10. Flexure formula

Overall, results show that practicing engineers performed better than non-structural engineers and undergraduates, which may be because structural engineers use these concepts more than non-structural engineers and undergraduates. However, the results revealed that shear stress continues to be a challenging concept for all participants. Concept inventory questions are designed to be answered without calculations, using basic conceptual knowledge and revealing common misconceptions. In some cases, on the strength of materials, it is possible to visualize the relation between loads and stresses. For example, the distributive load exerted on the beam will deflect into a "smile" shape, resulting in the bottom of the beam getting longer and the top getting shorter. This change in length directly results from the bending stresses. The maximum compressive normal stress from bending would occur at the top of the beam and the maximum tensile normal stress from bending would occur at the bottom of the beam. The "smile" shape corresponds with these stresses. However, when analyzing shear stress in planes, it may not be that intuitive because it can be challenging to imagine shear stress relationships. The deflected beam shape in the previous example does not give any apparent hints about the distribution of shear force and stress across the beam. Determining shear stress then arguably occurs in the abstract with no visual cues to assist the learner, affecting the concept inventory shear stress-related questions.

3.7 Conclusion

The results from this exploratory study may be beneficial to strength of materials educators since it reveals shear strength misconceptions from students and practicing engineers. Statistical analysis results indicate that practicing structural engineers performed better than non-structural engineers and engineering undergraduates, as predicted. However, the low performance on the reviewed beam shear problems demonstrates misconceptions of shear stress. It may be that shear stress design is not used in the field as much as we anticipate, or these concepts are implemented in codes and standards such that it is more procedural and requires less conceptual understanding for use on a day-to-day basis. Perhaps, the conceptual representation of shear stress in the problem statement is different than what practicing engineers see in their daily activities, which may also explain their poor performance. In addition, a large portion of respondents selected the same incorrect answer, revealing shear stress misconceptions. For example, practicing engineers are thinking about beam shear failure, or undergraduates are thinking about bending stresses, in which the maximum stress is found using the flexure formula that requires the use of the maximum moment, or they could be considering an individual shear stress element, in which the shear stress will be the same in the vertical and horizontal plane.

Research has shown that concept inventories are assessment instruments to help identify student misconceptions, understand misconceptions, help enhance learning instruction and advance the engineering education field. There is minimal literature analyzing practicing engineers' conceptual understanding of engineering concepts. A unique aspect of this research study is that the strength of material concept inventory was implemented with different groups, undergraduates, and practicing engineers to understand the difference in performance in three questions related to shear strength conceptual understanding. As with the Force Concept Inventory, used in physics to comprehend student's misconceptions of physics concepts, the SOMCI may be one tool in investigating change in engineering misconceptions that may help improve students' conceptual understanding of engineering concepts. Future work could involve a qualitative approach such as interviewing undergraduates and practicing engineers to help enhance problem statements and track their reasoning as they work through SOMCI items. Further research is needed to comprehend how conceptual understanding of engineering concepts transfers from an academic context to the professional engineering field. Investigating how practicing engineers interact with and make sense of various concept inventory items can provide a better understanding of engineering work and offer tools to align educational practices. This may help students develop a strong conceptual understanding of engineering concepts and adequately prepare them for the engineering workforce.

Chapter 4- Conclusion

While the benefits of concept inventories in engineering undergraduate research have been fairly well studied, little is known about how engineering practitioners apply conceptual understanding to address problem-solving in industry. Concept inventories have been used as evidence of learning and conceptual change (Steif & Hansen, 2007; Streveler et al., 2008). Findings from this study indicate that structural engineering practitioners performed better than non-structural engineers and engineering undergraduate students. Results demonstrate how field experience offers practicing engineers continued learning and the opportunity to solidify engineering academic conceptual knowledge.

Engineering undergraduate student performance on the SOMCI shows that students develop misconceptions from studying the strengths of materials. One common misconception when analyzing shear stress in planes is that it may not be intuitive because it can be challenging to imagine shear stress relationships. Another common misconception is relating normal and shear stress to load direction. Shear stress in beams is a relevant concept in engineering practice; however, participant performance in these related questions was poor. This poor performance indicates that structural engineers may understand these concepts differently than represented in the SOMCI.

The differences between industry and academic context may contribute to the different interpretations of the concepts in the SOMCI, explaining why structural engineers outperformed non-structural engineers and engineering undergraduate students. This thesis offers significant contributions to engineering education by exploring differences in conceptual understanding between engineering practitioners and engineering undergraduate students, highlighting the importance of experiential learning, and bringing real-life applications into the classroom. As discussed in chapter 2, this information is helpful and can improve instruction and prepare students for the engineering industry. One way to do this is further investigating how participants approached the selected response through interviews. Conducting enough interviews to understand their thought process can be used to design instructional materials that address misconceptions. Furthermore, educators can create learning opportunities in which applied concepts in the concept inventory questions are aligned with professional practice type problems.

In moving this conversation forward, I have offered several insights, including taking a qualitative research method such as interviewing participants to inquire about their thought process on their problem-solving approach through SOMCI items. Prior interview based qualitative concept inventory studies has provided additional reasonings on engineer's practitioners conceptual understanding while solving problems (Brown et al., 2019; Urlacher et al., 2015). Obtaining this information can provide the engineering education field with an understanding of how knowledge transfers to the engineering industry and help align educational practices to prepare students for the engineering workforce. Currently, the SOMCI has distractions as multiple-choice wrong answers consist of misconceptions that have not been identified. It would be beneficial for future work to include exploring misconceptions and identifying specific misconceptions as distractors in the SOMCI. Targeting misconceptions can lead to a revision of the SOMCI that can target understanding across different contexts and take it to the next step in validating the instrument. Such research can provide the engineering education community with a better understanding of how engineering content knowledge transfers to a different context, providing educators with the tools for aligning educational practices and creating learning opportunities that align with professional practice, therefore preparing engineering undergraduate students for the engineering workforce.

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