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The purpose of this thesis is to explore civil engineering students' and professional civil engineers' understanding of concepts within statics and fluid mechanics. The studies described herein begin to examine theories of situated cognition utilizing concept inventories, which are sets of multiple-choice questions where the incorrect answers are based on common student misconceptions. Situated cognition theory suggests that knowledge is contextual and experiential based on know-how, and less so, on abstract concepts, and that engineers would not necessarily perform better on abstracted conceptual questions than students. Two separate studies were done in order to explore this proposition. In this first study, practicing civil engineers took the statics concept inventory. The participants, on average, answered 13 questions (out of 27 questions) correctly or a score of about 50%. Previous research that was conducted with 1378 students had similar results with the same average score of 50%.

In the second study, semi-structured interviews were conducted with professional civil engineers and students using questions from the fluid mechanics concept inventory. For the second study, there were 29 engineers and 22 students that participated. The PE's average score was 73% with a range from 46% to 100% and the student's was 84% with a range from 46% to 100%. PE's performed the worst on pressure changes in horizontal pipes and for

students, it was pressure drops in smooth pipes. The question for which the engineers and students scored the highest on was the concept of velocity change in horizontal pipes.

Both studies indicate that practicing engineers perform about the same as students on concept inventories and questions. The second study began to explore the difference between the conceptual knowledge of professional civil engineers and students within fluid mechanics. The results from both studies question the common assumption that student performance on concept inventories is an indicator of their preparedness for upper division engineering courses and for engineering practice and, begins to validate theories of situated cognition that suggest knowledge is related more to experience than abstract ideas and concepts.

Civil Engineering Students' and Practicing Civil Engineers' Understanding of Engineering Concepts

by
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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.

Mark A. Urlacher, Author

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CONTRIBUTION OF AUTHORS

Drs. Brown and Steif along with Ms. Bornasal assisted in the writing and interpretation of the data collected from the online surveys for the statics concept inventory. Drs. Brown and Beddoes assisted in the writing and interpretation of the data collected from the fluid mechanics interviews.

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DEDICATION

This is dedicated to my Grandpa John Urlacher who always believed that I could accomplish anything as long as I worked hard at it and always remembered to have a smile on my face, but was not able to see me accomplish this goal because he was taken too early from this world.

Civil Engineering Students’ and Practicing Civil Engineers’ Understanding of Engineering Concepts

Chapter 1: General Introduction

Within engineering education research there is very little work that focuses on professional engineers, particularly with a focus on how they understand core engineering concepts. Yet, there is a need for this research to better align engineering practice with undergraduate and graduate engineering education. Situated cognition theories suggest that knowledge is very contextual and that students should engage in activities during their education that allow them to learn concepts within a context they will find in their professional work. It is for this reason that the following research explored civil engineering students’ and professional civil engineers’ understanding of concepts within statics and fluid mechanics.

Literature Review: Situated Cognition and Education

Situated cognition is a theoretical framework that describes how people think about and store concepts within situations and experiences. It attempts to discern the difference between knowing what a concept is and knowing how to apply that concept to a particular situation or context (J. S. Brown, Collins, & Duguid, 1989). It assumes that there is no separation between knowing and doing. This generally lies in contrast with other theories of cognition (e.g. behaviorism, cognitive information processing, etc.)

that assume if a person knows a concept they will be able to use that concept in a multitude of contexts (J. S. Brown et al., 1989). These other theories of cognition suggest that cognition exists within one's self and that knowledge is an input that is then stored for later use. One of the most important pieces to situated cognition is that knowledge, while it can exist within a person, it also can exist *externally*. For the purposes of this research, it is important to understand that it can exist not only within inanimate objects outside of a person, but also within other people, especially within communities of practice (E. Wenger, 2000; Etienne Wenger, 1999). The following literature review is framed to describe the important aspects of situated cognition as it applies to the research found in Chapters 2 and 3 of this thesis.

Context and Concepts

Situated cognition is based on the foundation that knowledge is highly dependent upon context. Context, according to the Oxford Dictionary, is the circumstances that form the setting for an event, statement, or idea, and in terms in which it can be fully understood and assessed; more specifically, the immediate physical and social surroundings (Dunham & Banaji, 2010; Harper, 1989; Mesquita, Barrett, & Smith, 2010; Richardson, Steif, Morgan, & Dantzler, 2003; Smith & Semin, 2004) and the sociocultural environment (Kitayama & Park, 2007; Salter, 2008). The similarities for each of these is that the thoughts, actions, and feelings are emergent results of multiple trans-active processes (Mesquita et al., 2010), meaning that no one source builds context, but rather, each of these sources is a part of the context (L. W. Barsalou et al., 2010).

It is important to distinguish what the term concept means and how they are acquired. There are two types of concepts: Those acquired by experience and those established by means of productivity and reasoning (L. Barsalou, 2003; L. W. Barsalou, 1999, 2008; Yeh & Barsalou, 2006). Concepts acquired by experience are of the most importance to this study and can be defined as accumulated information in memory, extracted for a category, which is a set of things perceived as the same type for many possible reasons (L. Barsalou, 2003; L. W. Barsalou, 1999). For example, the concept of a chair may simulate many different things depending on the situation that it is brought up in; a dining room chair, a recliner, an office swivel chair, etc. All of these conceptualizations of chair share common attributes, although they each vary when compared to each other. Additionally, individuals have different conceptualizations of what a chair is used for and a set of memories of their interactions with chairs. A situated conceptualization is a representation of people's entrenched knowledge of repeated situations (Andersen & Chen, 2002). Once these situated conceptualizations become entrenched in one's memory, they provide background content needed for deduction while reasoning (Johnson-Laird, 1986).

Communities of Practice

Within situated cognition, it is theorized that knowledge exists within communities of practice and that the knowledge they share is highly contextualized (E. Wenger, 2000; Etienne Wenger, 1999). Sharing experiences within a community allows the members of that community to not only learn about concepts from others, but also allows them to contextualize the concepts within each other's experiences. Brown and Duguid (2002) describe how Xerox repairmen collaborate in order to share knowledge and solve difficult problems that even manuals could not help with. The experiences that the repairmen had with the machines had given them insight beyond that of the manual. The manuals were limited because they only describe common problems and the correct repair procedures to follow. When complications arose that did not have instructions for repairs within the manuals they were required to find new methods to complete the repairs. By sharing these experiences they were allowing the rest of their community to use the knowledge and *context* in order to complete repairs in the future. In addition to helping each other the most experienced repairmen trained the new repairmen using their knowledge gained through experience. This knowledge passed through the community and was shared from professional to professional creating a community with shared situational knowledge.

In another study it was observed that navigators that had finished a school program were not qualified for their first assignment despite the school training that they had received (Hutchins, 1993, 1995; Lave & Wenger, 1991). The context that they learned the concepts in school was different than the context that they were expected to perform those same concepts in during their professional duties and needed training from seasoned navigators in order to perform properly on the job. Again, like the Xerox repairmen, the more experienced ones shared their knowledge within their community of practice. These communities of practice are important for novice learners, such as college students, because it illustrates how professionals in their field draw upon their experiences in order to make decisions (Zimitat, 2007). Students actually become part of the community as students by exploring social ties within the community, being exposed to the culture of the profession, and learning about the roles of the full participants, or professionals, within the community. However, not until they have experience within their field do they become full legitimate members of their profession (Lave & Wenger, 1991; Zimitat, 2007).

Further Literature Discussed in Later Chapters

There are three situated cognition terms that will be used within chapters 2 and 3 that will be described in greater detail within those chapters. The embodied, embedded, and extended mind are theories within situated cognition that describe ways that our minds use situational context when performing conceptual tasks. Table 1 presents a brief definition of each theory, a description of how it ties into the greater situated cognition theory, and an example of what it means.

Table 1: Brief introduction to the embodied, embedded, and extended mind with ties to situated cognition theory.

Theory	Definition	Ties to Situated Cognition	Example
Embodied Mind	The mind triggers situation specific responses based on experience with the current context (L. W. Barsalou, 1999; Niedenthal, Barsalou, Winkielman, Krauth-Gruber, & Ric, 2005).	Concept use can be triggered in different ways depending upon the person and their experience with the situation.	A carpenter and cabinet maker are both given a chisel. Each of them proceeds to perform a different task with the chisel based off of their experience using them (J. S. Brown et al., 1989).
Embedded Mind	The use of commonly encountered situations to process information in order to not burden one's own cognitive function (Kirsh & Maglio, 1994).	Based on the repetitiveness of using a concept within a situation eases the application of that concept in that situation each time it is needed	Given a cart of groceries to bag experienced grocers can properly and rapidly pick which item to bag next in order to pack the groceries properly (Kirsh, 1995).
Extended Mind	Thought processes are not limited by the flesh of the human body. The mind extends to physical objects and beings that assist in the processing of data (Clark & Chalmers, 1998).	Information may not reside within a person but can be accessed by the physical surrounding or situation.	Alzheimer patients using a notepad to remember their list of places to go on a particular day (Clark & Chalmers, 1998).

These descriptions are not in the following chapters because the target readers for the journal they will be published in will have more experience with these terms and will not require a primer within the article to understand what they mean. However, for this thesis since there will be a greater variety of people with different backgrounds this table will serve as a reference for the following chapters.

Summary of this research

The current education system encourages and focuses on learning concepts and assumes implicitly and explicitly that a student will be capable of applying the concepts within the proper context as professionals if they know the theory. With the main focus of engineering programs being on the theoretical knowledge instead of the practical knowledge there are limited methods for introduction of concepts within an authentic context. Medical doctors must have a residency before completing school and lawyers have case studies, but engineering schools do not generally require students to have practical experience for graduation. One of the benefits to the practical approaches is that they prepare the students for the professional workplace.

In other fields, as an attempt to enhance student learning and in order to better prepare them for the professional workplace, research on students' conceptual knowledge has been a focus for over 20 years. One tool that has been used within the educational community, as a method of determining conceptual understanding within student bodies (Hestenes & Halloun, 1995; Hestenes, Wells, & Swackhamer, 1992), is called a concept inventory. Concept inventories are comprised of multiple choice questions that have incorrect answers, which are based on common student misconceptions. Misconceptions are viewed as attempts to interpret information within an existing framework theory that also contains contradictory information to that scientific view (Vosniadou, 1994). The Force Concept Inventory (Hestenes et al., 1992) was the first tool to reliably test for misconceptions within a population. It laid the groundwork for other concept areas to address misconceptions by following the same format and administering the questions to students before, during, or after to assess their conceptual knowledge (Hestenes et al., 1992; Huffman & Heller, 1995). Conceptual knowledge goes beyond merely identifying a concept and spans into the understanding of interrelationships and application of fundamental ideas within some domain (Bransford, Brown, & Cocking, 1999; Perkins, Meyer, & Land, 2006). The Statics Concept Inventory (Steif, 2004) and the Fluid Mechanics Concept Inventory (Martin, Mitchell, & Newell, 2003) are both tools that have been developed for the use of determining misconceptions of concepts within those content areas. However, until now, they have been most commonly administered to students. The concept inventories were made for students and the context of the questions has not been the focus of the development of these tools. This research investigates engineers performance and reasoning with concept inventory questions to understand their relevance to engineering practice.

Previous research investigated the importance of context in student responses to questions and associated student contextualization (S. Brown, Lewis, Montfort, &

Borden, 2011; Baghdanov, 2013). Concept inventories were used as a means to ask questions that would then facilitate discussions about the process used to answer the question. One of the limits to these studies was the lack of comparison to professional engineers to determine similarities and differences between the two groups. Another gap that this thesis attempts to address is the comparison between students' and engineers' concept knowledge and contextualization of that knowledge.

In order to understand conceptual understanding of professional engineers, insight is needed in how they conceptualize and contextualize engineering concepts. This thesis includes four chapters that represent the beginning efforts to determine how and why professional engineers respond to conceptual questions about civil engineering concepts.

Chapter 1 is a review of the relevant literature within situated cognition that frames Chapters 2 and 3. Situated cognition is appropriate because it is based upon theories and research of practitioners across a variety of fields.

Chapter 2 is research focused on engineers who participated in the statics concept inventory (Steif & Dantzler, 2005). This paper has been accepted to the American Society of Engineering Education June 2015 conference. The results collected from the engineers was compared to results from previous research that utilized students that were finishing or had recently finished their undergraduate statics course. This comparison was important to understand the difference between the two groups and to determine why there was or was not any difference in between the two data sets. The purpose of this study is to gather data on practicing civil engineers' performance on the statics CI and to compare how they differed from previous research conducted with students (Steif & Hansen, 2006).

The article presented in Chapter 3 will be submitted to the Journal of Engineering Education in May of 2015. It utilized a small subset of questions and images from the fluids concept inventory in a semi-structured interview format. This allowed the engineers and students to explain how they came to solutions. The reasoning processes and concepts that participants used were compared between students and engineers to examine what role, if any, did context have in the their answer. The purpose of this study is to investigate how students and engineers differ in their conceptual knowledge as it relates to questions of core concepts in fluid mechanics. This study progresses towards a larger goal of understanding how practicing engineers operationalize and utilized concepts in the design process.

Chapter 4 is a conclusion, which summarizes the results from Chapters 2 and 3. Then using the results and discussion from those chapters suggestions for future research and instruction are presented in order to encourage the continuation of this research. It continues by explaining why this research is important and explaining how it has allowed a discussion about how to improve the education of future engineers to better prepare them for engineering practice. From this it concludes with possible implications of future research in this area.

Practicing Civil Engineers' Understanding of Statics Concept Inventory Questions

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Abstract

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

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

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

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

Conclusions: Our results provide insights into professional civil engineers understanding of statics concept inventory concepts. Although the data set is not necessarily indicative of the larger community of professional engineers, it provides

early evidence that not all concepts from the statics concept inventory may be relevant for practicing civil engineers. More research is needed to understand how and why academic concepts are important to civil engineering practice.

Introduction

The goals of most engineering analysis courses is to empower students to apply established principles and methods to understand and quantify new unfamiliar situations (Steif & Hansen, 2006). Oregon State University's civil engineering department's mission statement states that its goal is to *"prepare students for professional and responsible engineering and constructor positions*. (OSU C&C Engineering, 2015)" Many other universities including Washington State (WSU), University of Washington (UW), Virginia Tech (VT), and Purdue (PU) have similar goals for graduating engineers within their mission statements. WSU's mission statement notes its goal is to "*prepare our graduates to contribute effectively to the profession and society, for advanced study, and for life-long learning (WSU C&E Engineering, 2015),"* while Purdue lists its goal to *"prepare graduates to successfully pursue their professional career objectives in a civil engineering-related field (P U C. Engineering, 2015)".* Reflective of these mission statements, there exists common desire for classes and material covered within the education plan of civil engineering students to prepare them for the profession after they graduate.

Universities generally undergo ABET certification because, as noted in the ABET website, "*accreditation is proof that a collegiate program has met certain standards necessary to produce graduates who are ready to enter their professions (ABET, 2015).*" For students, accreditation of a program means that the school *"knows their profession's dynamic and emerging workforce needs, they review academic programs to ensure these programs provide students with the technical and professional skills they need to succeed (ABET, 2015)."* For the general public, a school being accredited *"enables academic institutions to demonstrate to the public that they are serious about advancing the quality of their programs. It is recognition by the technical professions that these programs are preparing students well, and it encourages 'best practices' in education through formal, continuous quality improvement (CQI) processes (ABET, 2015)."*These suggest that accredited universities have an obligation to prepare graduates for the workplace and continuously understand and evaluate their process for doing so.

These expectations from regulating agencies, students, and the general public inherently link educational experiences and successful pursuit of professional work. As such, identifying fundamental areas of content knowledge that may be tracked between academia and practice must be addressed. Additionally, means to assess such knowledge must be identified and implemented. Currently, one of the foundational classes during the education of a civil engineer is statics. Steif's (Steif & Dantzler, 2005) statics concept inventory is used to measure the ability of a person to use fundamental concepts of statics to answer questions. This has been used to evaluate students' abilities. This study probes its use in measuring professional engineers' knowledge of these concepts in order to understand how these fundamental ideas in statics are used and understood in the professional engineering field.

Concept inventories (CI) have been defined as, "Multiple choice instruments designed to evaluate whether a person has an accurate and working knowledge of a concept or concepts (Lindell, Peak, & Foster, 2007)." For the purposes of this project, this is the best suited definition because, unlike other definitions of CIs, it states "person" rather than "student." Note that this project does not focus on students, but rather on licensed civil engineers.

Engineering CIs have been broadly used to assess student conceptual knowledge and evaluate the effectiveness of educational innovations (Streveler, Litzinger, Miller, & Steif, 2008). Conceptual knowledge goes beyond merely identifying a concept and spans into the understanding of interrelationships and application of fundamental ideas within some domain (Bransford et al., 1999; Perkins et al., 2006). CI questions were developed to isolate concepts, and CIs typically include common misconceptions as possible incorrect answers (Steif & Dantzler, 2005). Traditional perspectives on application of CIs as assessment of conceptual knowledge, such as those investigating misconceptions, have come from the lens of individual cognitive theories (Prince, Vigeant, & Nottis, 2012; Streveler et al., 2008).

Situated cognition theory generally lies in contrast with some cognitive approaches that suggest that if a person knows a concept well, they will be able to apply it in a multitude of contexts (J. S. Brown et al., 1989). Situated cognition theory suggests that knowledge is very contextual; to prepare students to do something, they should engage in that practice in as authentic a manner as possible (Hutchins, 1995; Lave & Wenger, 1991). Therefore, student's ability to answer questions about isolated concepts may not be a good measure of the ability of an engineer to be productive in the engineering workforce. We began to examine this proposition by implementing the statics CI to practicing civil engineers.

The *purpose* of this study is to gather data on practicing civil engineers' performance on the statics CI. To do this, the statics CI was used as an online instrument to collect responses from professional civil engineers.

Literature Review

Misconceptions have mostly been investigated in engineering education through the development of CIs including statics, fluid mechanics, mechanics of materials, and many more (Evans et al., 2003; Hutchins, 1995; Jacobi, Martin, Mitchell, & Newell, 2004; Steif, Dollár, & Dantzler, 2005) which were all spurred by the Force Concept Inventory (Hestenes et al., 1992). CIs have been widely used to assess student's deeper understanding of important concepts and to measure the effectiveness of curriculum (Hake, 2002). These CIs are partially based on an implicit assumption that the concepts that are tested and the way in which they are tested, are in fact relevant to the engineering profession. However, there is no research that explores how practicing engineers perform on the CIs. Additionally, the assumption of concept inventories' relevancy to the engineering profession has not been examined. If that implicit assumption is true, then it would be useful to compare how professional engineers and students differ on their answers or if they differ at all.

Situated cognition theory suggests that knowledge is not from a single person, but rather that knowledge resides within the group of people who share common goals and practices (Lave & Wenger, 1991). Situated cognition may suggest that the degree of relevance of these concepts to the job of an engineer could question the validity of this assumption since situated cognition experts contend that knowledge only exists in context and has very limited meaning and usefulness when taught out of context (Chaiklin & Lave, 1996; Lave & Wenger, 1991; NRC, 1999). As an example, according to Hutchins (Hutchins, 1993), apprentice navigators aboard ships needed practical training before they could become full navigators even if they had proper training at a school that taught them terminology needed for the tasks they would perform, but gave them no experience doing those same tasks. Although they were trained, they needed time actually performing the tasks of a navigator to be able to perform them by themselves without the supervision of another more experienced navigator. The context in which they learn the skills is important to the ship and its crew. The skills learned in school were the same as those learned on the ship, but disconnected from the situations encountered whilst practicing those skills made them much less useful than learning them in the context of how they are used on the ship. The statics CI includes problems that should be relevant to practical engineering systems (Steif, 2004). However, as shown in the study done with navigators, the context of the concepts that were utilized is very meaningful in terms of the way they are understood. Also, engineering is a field that can require technical coordination to complete tasks where engineers influence each other to perform work (Trevelyan, 2007) making the individual nature of the CI another aspect to consider. Situated cognition theory is not tied to the methodology of this study, but it is a theory that may be useful in facilitating a discussion about the interpretation of why engineers perform as they do on concept inventories.

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

Methods

Participants

Recruiting participants for this study was done in multiple ways. First, emails were sent to professional civil engineers that had helped in research projects before and were willing to help recruit other engineers from their companies and engineering societies that they belong to. After reaching out to known contacts the American Society of Civil Engineers, Section 8 officers and their branch presidents were contacted to recruit via social events and newsletters put out by the separate areas. The total number of participants was 25, all of whom were practicing civil engineers from 20 different firms and government offices. The average number of years of experience as a practicing civil engineer for the participants was 11.4 yrs. 17 participants had bachelor's degrees, 7 had master's degrees, and 1 had a doctorate degree, all in civil engineering. When asked about what they would consider their area or areas of expertise 5 responded structural, 5 responded environmental, 19 responded civil, 7 responded water resources, 2 responded geotechnical, 3 responded management, and 1 responded waste water management. All of them worked for companies or offices employing fewer than 100 employees. 20 of the participants were males and 5 were female.

Data Collection and Analysis

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

Results

Table 2 shows the sub discipline of the participants. The engineers that associated with the water resource discipline had a slightly lower average than the rest of the participants. The other three groups of engineers scored within 4% of the average of 48%.

Table 2: Participants score and experience by sub discipline.

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

Figure 1 shows how the engineers that participated in this study scored on separate concept areas compared to an earlier study conducted with N=1378 students from 10 different statics classes at 7 different universities (Steif & Hansen, 2006). The students were either finishing their statics class or had recently finished it when they took the concept inventory. Of the nine concepts that are being assessed, static equivalence over the three questions had the lowest average for engineers at 23%. The lowest scoring question across all engineers fell under that same category. 12% of the engineers that answered question 9 answered it correctly. In the highest scoring category, the questions focused on slots and over the three questions that covered this concept, an average of 68% answered correctly. The single highest scoring question was question 11 which is in the section about rollers and was answered correctly by 80% of the engineers.

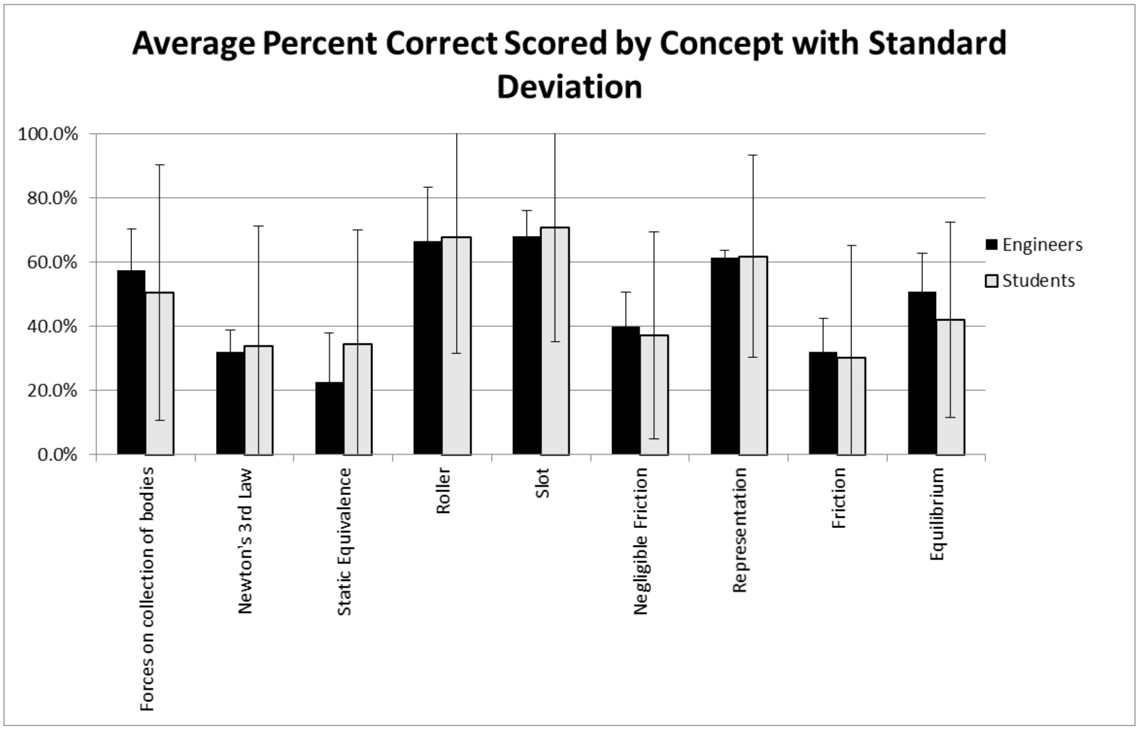


Figure 1: Concept Difficulty: Percent of engineers answering a set of questions about a single concept correctly.

Discussion

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

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

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

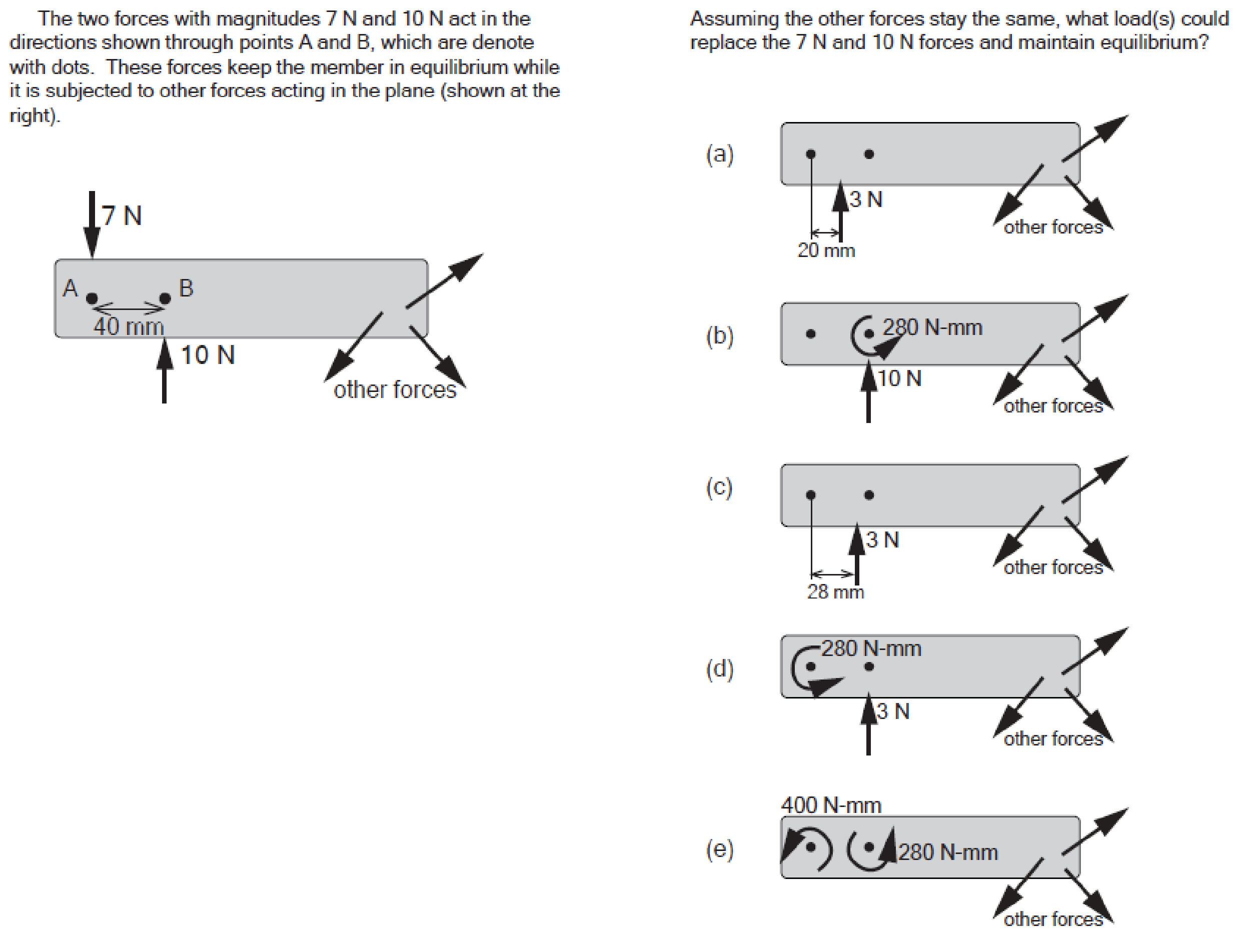
The next possibility is that these concepts may be relevant as foundational to other concepts that are built upon these concepts, but are foreign compared to the more complex concepts which then caused the engineers to not score well on the CI. Statics is generally taken in the second year of a civil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

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

Situated cognition offers an explanation for each of these possibilities. The engineers were asked to take the CI without using reference material to help them remember how to use concepts if they felt they needed it or in order to verify that their answers were correct before submitting them. The theory of the extended mind is an important piece to situated cognition and may explain why asking engineers to not use reference materials could cause them to not perform well on the inventories. The extended mind is a theory that claims that the boundaries of a cognitive system lie outside of the envelope of an individual person and extends to the physical environment (Clark & Chalmers, 1998; M. Wilson, 2002), which would include books and reference material used by engineers. Clark and Chalmers (Clark & Chalmers, 1998) proposed that an Alzheimer's patient that uses a notebook to remember important facts is only superficially different than a person that has a perfectly functioning memory that looks up information and stores it internally. Engineering reference books are used by many engineers as a part of their day to day routine that, considering the extended mind theory, if they are not allowed access to this information then they are almost being asked to not use part of their mind which may be extended into these reference materials. Engineers may also be *embedding* their minds in the reference material and the situations they commonly encounter at work in order to travel "informationally light" (Clark, 1997). If engineers use reference material to embed and extend their minds, then not allowing them to access it could cause them to not perform as well as expected.

Situational availability provides an explanation for the second point about statics concepts being foundational to other concepts more commonly used by civil engineers. Situational availability suggests that it is difficult to retrieve situations for abstract concepts (Schwanenflugel, Harnishfeger, & Stowe, 1988). The concepts in the statics CI may be considered abstract by engineers if they are not rooted in situations related to their work. The concepts themselves may not be abstract, but how they are presented may make it difficult for engineers to retrieve the concepts because those situations are abstract.

It is theorized that concepts are stored situationally and engineers may have difficulty recalling the concepts as situated in the form the questions take in CIs. According to Yeh and Barsalou (Yeh & Barsalou, 2006), a concept produces different conceptualizations in different situations, with each form relevant to the current situation. According to this theory, concepts are not represented as generic, highly abstracted data structures, but rather their content is tailored to the current situation. The concepts in the statics CI might be presented to the engineers in a different situation than how the concepts might generally be presented. As a computer might be thought of as an instrument used for work when depicted in an office, it might be thought of as an entertainment device when depicted in the home. Statics concepts can be situated differently in the workplace compared to the classroom. Along with this idea that concepts are stored differently for each situation, it is important to consider that people may not store and retrieve surface stimuli, such as images and words, in the way that cameras and audio recorders do (L. W. Barsalou, 1999). It is possible that the images presented in the statics CI trigger the same stimuli in practicing engineers as it does in students, but for students this imagery may be recent retrieval rather than long term retrieval which may explain why they did not score better than the students. Although engineers have more experience and schooling, if they are expected to answer questions about abstract concepts then that experience would not be as useful to them as what was learned in school, giving them the same capacity as the students to answer the questions correctly.



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

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

Figure 2: Question 3 of 3 on static equivalence.

Conclusions

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

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

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Students' and Practicing Civil Engineers' Understanding of Fluid Mechanics Concept Inventory Questions

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Introduction

One of the stated goals of university engineering programs is to prepare graduates for the engineering workplace. However, various reports, research findings, alumni surveys, and graduate anecdotes suggest that students are immediately faced with tasks that they are unable to complete; they are not prepared technically to conduct the open-ended design problems that are commonplace in the workplace. Learning theories of situated cognition may help explain this shortcoming. Situated cognition theory suggests that knowing is an interaction between knower and context and that the best way to prepare individuals for a job is to engage them in authentic activity that represents that job.

There is a large body of research examining students' knowledge of engineering concepts, but very little similar research with practicing civil engineers. In this study, professional civil engineers and civil engineering students were interviewed about fluid mechanics concepts to attempt to understand similarities and differences in student and engineer responses and logic to these questions.

Literature Review

Situated cognition theory suggests that knowledge resides within groups of people that share common goals and experiences and is associated with context (Lave & Wenger, 1991). This is in contrast to other cognitive theories that suggest cognition resides within the mind (J. S. Brown et al., 1989). The immediate physical or the social surroundings can serve as the context (Dunham & Banaji, 2010). Phase of life and socioculture environment can also serve as context (Salter, 2008). Both of these also share the common idea that thoughts, actions, and feelings are emergent results of multiple trans-active processes between the individual and the context (Mesquita et al., 2010). Our bodies optimal processing is often associated with simple processing and both reflect context specificity, in which simple processing is retrieving situation specific patterns stored in memory from previous experience (L. W. Barsalou et al., 2010). In practice these processes are much different than in education. A seminal work on situated cognition says that the breach between learning and use, which is captured by the folk categories “know what” and “know how,” may well be a product of the structure and practices of our education system. Many methods of didactic education assume a *separation between knowing and doing*, treating knowledge as an integral self-sufficient substance, theoretically *independent of the situations* in which it is *learned and used* (J. S. Brown et al., 1989).

Examples from the situated cognition literature help clarify the important role of situational context in preparation for work. Lave and Wegner (1991) observed that apprenticeship was an effective form of learning for practical purposes. Tailors, midwives, and other professions utilized apprenticeship to ensure that those entering their profession would not only be qualified, but also capable of performing their duties. This was the foundational work in communities of practice and the idea that knowledge is contained within a group of practitioners and was followed by others including

Hutchins (quartermasters) (1993) and Brown and Duguid (Xerox repairmen) (2002; Zimitat, 2007).

Hutchins (1993) conducted a study using quartermasters (or navigators) that shows this difference between knowing and doing. This study showed that apprentice quartermasters, although they had finished programs of study when they were assigned to a ship, they were not allowed perform in their duties before having an apprenticeship under an experienced quartermaster. The reason was because the experienced quartermasters did not find that new quartermasters had the correct *context* for the information learned in school programs to effectively perform at their positions until they had training on the ship or in the correct *context* for their position. Brown and Duguid (2002) documented experiences from Xerox repairmen that had to problem solve difficult problems every day with machines in which they had access to all of the reference material they needed. They found that instead of the reference manuals, other Xerox repairmen were the source they would turn to when a solution was needed because of the context that was offered along with the knowledge. As a community of practice, their knowledge seemed to surpass the reference books because they each brought unique experiences that the books did not have. More importantly, the new repairmen were able to learn from the more experienced ones, which allowed them to see how experts drew upon past experiences to repair the machines.

Theories of Situated Cognition and Relevance to Studies of Students and Practitioners

Two permutations of situated cognition theory are particularly relevant to, including the pieces referred to as the embodied and the embedded mind.

Within situated cognition, embodiment of knowledge is important as it helps us to determine how representations acquire meaning (Anderson, 2003; Niedenthal et al., 2005). Within a field that has experienced workers, unexperienced workers, or even students, embodiment can explain any difference there might be between how each group approaches problem solving when given the same task. For instance, in a study conducted with weight watchers, experienced members used multiplication to determine what measuring cup to use, but newer members used the original measuring cup, dumped the full amount onto a plate, and then removed the appropriate amount off in order to end with the appropriate reduced serving (J. S. Brown et al., 1989). The newer members had expereince with higher level math and were capable of multiplying fractions but fractions and cooking were situationally different and therefore had no connection, which led to the overly involved method of measuring a fraction of the portion size. This may be similar to how engineering students and engineers approach enginering questions. Although this study utilized pieces from the fluid mechanics concept inventory, the statics concept inventory was used in another recent study, which hypothesized that how the concepts are presented may be abstract because the situations are abstract to engineers (Urlacher, Brown, Steif, Bornasal, 2015).

The embedded mind is a theory of situated cognition that says, “rather than attempt to mentally store all of the relevant details about a situation, [cognitive agents] physically store and manipulate those details out in the world, in the very situation itself" (M. Wilson, 2002 p. 629). According to Clark (1997), this allows agents to “travel informationally light” meaning, that instead of memory being the only information processor that agents can use, the very situation they learn in can help them process information. Kirsch conducted a study that observed how grocers bagged groceries. The more experienced grocers were capable of bagging groceries very quickly and in a specific order: Heavy items on bottom, less fragile groceries in the middle, and fragile items on top. The more experienced they were the more quickly they performed their task, but seemingly without any more stress on their thought processes because they were more familiar with the specific situation. The less experienced grocers also sorted the groceries, although they were not as efficient as the more experienced ones, and occasionally did not bag the groceries in the optimal order, but the more they encountered the situation the more efficient they became at bagging (Kirsh, 1995; Kirsh & Maglio, 1994). By embedding a concept over numerous encounters with that specific situation the more easily a task can be completed but it has to be the same situation, the same context (Ballard, Hayhoe, Pook, & Rao, 1997). Students continually encounter concepts within situations that are contextualized within homework, tests, and lectures.

Engineers encounter them within the context of their work, which is a different than how students encounter them meaning that depending on the context of the question embedding could affect how they might answer the question.

The embodied and embedded mind theories have never been used to describe the differences between engineers and engineering students and their processes while answering conceptual questions. Since the theories can explain the differences between how people with differing levels of experience operationalize concepts in specific situations they are ideal for explaining the differences between students and professionals conceptual understanding.

Concept Questions and Inventories

Previous research has attempted to identify students' understanding of fluid mechanics that utilized the FMCI and computer applications to determine if scores improved after using the applications (Fraser, Pillay, Tjatindi, & Case, 2007). Three simulations were done with two of them being successful and one unsuccessful, but the two successful simulations had the participants take the posttest with less delay between the computer applications than the one unsuccessful simulation. Additionally, participants still had trouble with applying what they learned from the computer simulations to problems that were in slightly different context. This finding was less prevalent with the horizontal pipe problems, than when the participants tried to apply the concepts to vertical pipes. The research described in this paper used the same questions, but without the multiple choices, to not potentially constrain participant thinking to the provided choices, but instead get their holistic thinking about the concept(s) in the question.

In order to further the research in this field, research is needed on practicing engineers and their knowledge of civil engineering concepts taught during the education of engineering students. Previous research within situated cognition has utilized professionals to determine if knowledge is contextualized and research has been conducted with students in engineering to determine conceptual understanding of engineering topics. However, no studies have utilized interviews with engineers to not only determine if engineers can answer questions correctly, but to also study the process they use to respond to the questions about engineering concepts. The embodied and embedded mind will serve as tools for describing why the participants responded to questions in specific ways during their interviews. This study is meant to probe that gap and lay groundwork for further research into this area.

Purpose of Study

The purpose of this study is to investigate how students and engineers differ in their conceptual knowledge as it relates to questions of core concepts in fluid mechanics. This study progresses towards a larger goal of understanding how practicing engineers operationalize and utilized concepts in the design process. The research questions addressed are:

1. How does student and professional engineer conceptual knowledge of fluid mechanics differ?
2. Are there similarities within the student and engineer groups that might be indicative of the larger community?
3. Is the context of the questions important to participants when answering conceptual questions?

Methods

In an attempt to achieve these goals and answer the research questions, qualitative interviews were conducted and analyzed. Interviews were conducted with both professional civil engineers and with students that were currently enrolled in Fluid Mechanics at Oregon State University in the civil engineering program. The interview questions were structured around the concepts of equilibrium and the conservation of mass, energy, and momentum, which are traditionally believed to be important concepts to civil engineering education and practice. The interviews were coded using the constant comparative method (Patton, 2002) for reasoning processes and reasons given while answering the questions for both of the different participant groups.

Participants and Recruitment

The criteria for selecting engineers to participate was they have an engineer in training certificate or professional civil engineering license[1] and work as a practicing civil engineer. 28 of the engineers that participated were water resource engineers or engineers that worked closely with water resource engineers for their project designs. A group of 29 professional civil engineers with an average of 19 years of work experience as a civil engineer participated. Employees from three civil engineering firms were interviewed with at least 75% of their water resources civil engineers in that office participating in the interviews. A snowball sampling technique was used to recruit the participants for this group. A snowball or chain referral sampling (Biernacki & Waldorf, 1981; Penrod, Preston, Cain, & Starks, 2003) refers to a method of sampling where the researchers must first identify individuals who meet the requirements for the study and then ask for referrals of other individuals that they know that would be interested in also participating in the research. Snowball sampling is particularly popular among researchers in studying deviance, sensitive topics, and difficult-to-reach populations. In this case professional engineers are a difficult to reach population because they are being asked for a significant amount of time in a one-on-one setting from an individual they likely do not know. Referrals from one participant to another are critical to

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[1] Engineer in training and professional engineering licenses are issued by each state to individuals that have passed state administered tests and in the case of the later have worked as an engineer for a specified amount of time which is determined by state.

recruiting a sample. While this sample might not be able to be generalized to engineering community as a whole because the sample from each of the firms had a large portion of the their water staff interview it is representative of that at least the offices that participated and will likely extend to offices that deal with design work similar to these offices.

The second group of participants in this study consisted of 22 students from Oregon State University who were enrolled in the junior level fluid mechanics course. In order to recruit students for this study, a sample of convenience was used. Convenience sampling, also known as availability sampling (Babbie, 2015; Mutchnick & Berg, 1996; Polit & Beck, 2013), is a method that uses subjects that are close at hand and easily accessible. Since the researchers are located at Oregon State University, students from there are a convenient sample. In order to recruit the student participants, announcements were made twice in the two different junior level fluid mechanics classes held during the fall of 2014 term. At the time of recruitment, the students had at least been introduced to all of the concepts used in the interviews. The distribution of students was 54% above average students, 32% below average, and 14% average students, which was representative of the two classes. Above average students were considered to be half a standard deviation or more above the class average grade and below average were half a standard deviation or more below the class average. Although this sample was from convenience it still was stratified according to the classes the students were recruited from. The students that participated are representative of a group of comparable students from other universities. The ability to generalize to other students depends some on whether their interview responses are based on the content of their fluids course and/or their personal experience.

Data Collection

The interview consisted of eight sets of questions with each set associated with a different figure. These figures and questions were used from the Fluid Mechanics Concept Inventory (FMCI) (Martin et al., 2003) (The figures and descriptions used from the FMCI were used with permission from the developers of the instrument, John Mitchell and Jay Martin). The FMCI is 33 questions, and was developed to assess student understanding of these concepts, and not specifically for professional civil engineers. The 8 questions were chosen because they best represented concepts commonly used in advanced civil engineering classes and in professional civil engineering. Questions that were not used were considered to be less relevant to civil engineering. For example, questions about fluids with varying density, shear flow, and moving plates on fluids were not used because civil engineering work generally does not involve these conditions according to civil engineers that participated in trial interviews. It was also necessary to reduce the number of questions used in the interviews in order to shorten the amount of time required for the interviews. Companies that agreed to allow their engineers to participate in the interviews asked that they only last around 30 minutes, which corresponds to about eight interview questions. Table 3 shows the questions that were asked during each interview. The figures associated with each of the questions can be found in the results section in Figures 3– 8.

Table 3: Questions participants were asked during each interview.

Question Number	Question text
Question 1-4	What happens to velocity and pressure from point 1 to 2?
Question 5	Is the pressure drop the same or different in Pipe 1 and 2? If it is different which pipe has a higher pressure drop?
Question 6	What can you tell me about forces F_1 and F_2?
Question 7	What can you tell me about forces F_1 and F_2?
Question 8	Which figure shows the correct fluid levels at equilibrium?

The interviews were conducted in a semi-structured clinical format (Fraser et al., 2007). For each interview, the subject was given a packet that showed the images that they would be referencing for each question and then the text and questions associated with each question was read to them. The interviewer asked probing questions when needed, but after the question was asked, the subject was allowed to answer, explaining their reasoning without interruption. The probing questions were used to elicit complete responses from each participant to help determine understanding of the material and concepts that were used. Although participants were allowed to write on their handouts, most of them opted to not write anything more than a few terms on any one piece of paper.

Data Analysis

All interviews were recorded with a digital audio recorder and were either transcribed professionally or by research assistants. The transcriptions were coded using the Dedoose quantitative analysis program (SocioCultural Research Consultants, 2014) using the constant comparative method. The constant comparative method compares new data to all existing data trends (Maykut and Morehouse, 1994). Each question was named with a specific code to allow for easy identification of the question and concept.

Table 4: Identification codes for each of the interview questions.

Question	Identification code
Questions 1-4 on velocity	Q1-Q4-Velocity
Questions 1-4 on pressure	Q1-Q4-Pressure
Question 5	Q5-Pressure Drop
Question 6	Q6-Momentum
Question 7	Q7-Momentum
Question 8	Q8-Equilibrium

Each transcript was read by the coder without applying any codes, then read a second time, this time applying existing codes or creating new ones. As per the constant comparative method, if new codes were created, then all existing data had to be reanalyzed to determine the presence of these codes in previously analyzed data. At the end of this phase, there were over 25 different codes for types of reasons that engineers and students used while explaining their answers. The codes were examined within the context of each use and from this, analysis were combined where appropriate to make a more concise list. This list was shortened to a list of 13 codes, which can be seen in Table 5.

Table 5: Overview of concepts and terms used codes.

Concepts and Terms	**Code Definition**
Bernoulli Equation	Participant used the Bernoulli equation or terms commonly associated with the equation while explaining their answer.
Continuity	Participant mentioned continuity, constant flow, or terms commonly associated with continuity while explaining their answer.
Water column	Water columns and the effect they have on pressure was mentioned as a force that affected velocity or pressure change in a pressurized pipe system.
Flow and pressure drop	The more discharge or velocity in a pipe, the higher the pressure drop will be.
Frictionless pipe	Participants talked about the relationship between headloss and frictionless pipes.
Flow direction change	The change in the flow direction of the fluid stream was used to explain an answer.
Sum of forces	A summation of forces was used or mentioned in order to explain an answer.
Momentum	The concept of Momentum was mentioned during an explanation.
Cart movement	The direction a cart was moving in the figure for question 7 was used to explain which force was higher.
Equilibrium	The concept or a description of Equilibrium was used while explaining the chosen figure for question 8.
Atmospheric pressure	Participant used the fact that the water is exposed to the atmosphere to explain their choice in question 8.
Shapes not equal	Participant explained their choice in question 8 by using the shapes of the containers.
Instinct	Participant explained that their answer was instinctual and did not provide information related to the other codes in this list.

After coding the concepts and terms used in the explanation of each question, another set of codes was made in the same fashion for what was called “reasoning processes". "Reasoning processes" was a term that the researchers used to define the way in which a participant talked through their reason(s) for how they answered the question. Analyzing and comparing engineers and reasoning process during their helps understand how the groups differ in their conceptualization of fluid mechanics. Seven reasoning process codes resulted, shown in Percentages of each reasoning process and concept or term used was calculated for each group in each question. In the results when making comparisons between the two groups there were three categories for used for the comparisons. If percentages were within 10% of each other the comparison was assumed to be the same. If difference in percentages was between 10% and 25% they were comparison was assumed to be similar but with some variance. Anything more than 25% was assumed to be different.

Table 6 shows the reasoning process codes and the application criteria for each one. These codes were more difficult to apply than the concept codes since there were some processes that had little difference between them and sometimes multiple processes were coded within one interview because a participant changed their method for explanation during the interview. Two of the processes are very different from the others; One describes when participants linked their reasoning to a previous answer and did not explain themselves again, while another was used for short answers that the interviewer was unable to attain more information from because the participant wished to move on instead of answering probing questions which made it difficult to place in any other category.

Percentages of each reasoning process and concept or term used was calculated for each group in each question. In the results when making comparisons between the two groups there were three categories for used for the comparisons. If percentages were within 10% of each other the comparison was assumed to be the same. If difference in percentages was between 10% and 25% they were comparison was assumed to be similar but with some variance. Anything more than 25% was assumed to be different.

Table 6: Overview of reasoning process codes.

Reasoning Process Code	Code Definition
Applied concept/equation	A specific concept, term, or an equation was not used to explain an answer.
Logical Process	Used a step by step process often utilizing non engineering terminology or multiple concepts in one explanation to either eliminate it then as an option or conclude if it was usable in the situation.
Experience	A personal experience was used to explain an answer. For Engineers this was generally from their work and from students it was generally from a lecture or homework.
Example	A scenario made up by the participant was used to explain an answer.
Link to previous reasoning	Participant linked their reasoning to a previous answer. This code was used but not reported in the results. Instead the previous reasoning code was reported.
Short confident response	Participant gave a reason that was fewer than 5 words, but needed no further explanation.
Guess	Participant had no other reason or verbally said that they were guessing at the answer.

Engineers and students used the terms energy equation and Bernoulli's equation interchangeably during the interviews. This is in contrast to the way in which it is sometimes presented in fluids courses and textbooks. One form of the Bernoulli equation, when used to compare two separate points on a streamline, is similar to the energy equation. The difference between the two is that there is no headloss (h_L) term in the Bernoulli equation. Another term for headloss is energy loss. The distinction between head and energy is that head is measured in terms of length as it is the fluid's energy per unit weight. There is no evidence to conclude that the participants meant anything different when using one term or the other. For reference, Bernoulli's equation and the energy equation can be seen below:

Equation 1: Bernoulli equation comparing two points on a streamline.

$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + z_2$$

Equation 2: Energy equation comparing energy between two points in a system (includes headloss, h_L, term)

$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + z_2 + h_L, \quad where\ h_L = f\frac{L}{D}\frac{v^2}{2g}$$

Results

The results are organized by the questions asked during the interview with questions 1-4 in the same section due to the similarities of the questions. The distribution of participants that answered a question correctly and incorrectly is reported, along with common reasoning processes that participant groups used, and what terms or concepts they utilized in their process. Some participants used more than one reasoning process or used multiple terms and concepts within their explanations leading to uses of multiple codes per answer. This is why some questions show more codes than participants.

The engineers that participated in this research study answered on average 73% of questions correctly with a range from 46% to 100% and a standard deviation of 14.4%. The students that participated in this research study answered on average 84% of questions correctly with a range from 42% to 100% and a standard deviation of 15%.

When comparing the two groups, there were three categories for comparison. If percentages were within 10% of each other, the comparison was assumed to be the same. If difference in percentages was between 10% and 25%, the comparison was assumed to be similar, but with some variance. Anything more than 25% was assumed to be different.

Words or phrases that represent codes discussed above are bolded in the quotes to clarify the code they are associated with and to emphasize the important features of the quote.

Questions 1 - 4

Questions 1-4 used for different figures, as seen in Figure 3 and 4, but for each figure the same questions were used. The first four questions asked participants if they could identify how velocity and pressure would change from point one to point two in the figure. There are two concepts needed to solve Questions 1-4. One each, for correctly answering how velocity and pressure will change. The concept of conservation of mass, when appropriately applied to these questions, relates the change in velocity to the change in area and the concept of conservation of energy relates the change in velocity to the change in pressure. The correct answers for questions 1-4 are:

1. Velocity increases and pressure decreases.
2. Velocity decreases and pressure increases.
3. Velocity decreases and pressure increases.
4. Velocity increases and pressure decreases.

For each of the answers, the explanation is the same. The changes in velocity are inversely proportional to the cross sectional area change. This relationship is from the continuity equation as seen in Equation 3:

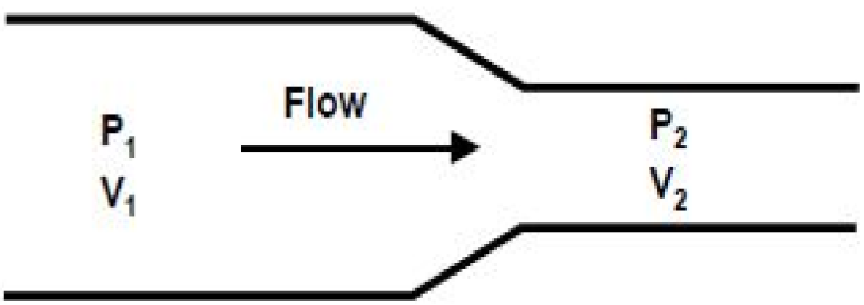
Equation 3: Continuity Equation

$$Flow\ rate = Velocity * Area$$

Pressure change is directly proportional to the cross sectional area change. This relationship is from Bernoulli's equation as seen in Equation 1. See Table 15 for the percentage of engineers and students that answered the questions 1-4 correctly. Table 7-10 show the different reasoning processes and concepts or terms that participants used during the interviews to justify their answers and what percentage of the two groups used each with their answers.

Question 1

Water flows through a pipe and enters a section where the cross sectional area is smaller. Viscosity, friction, and gravitational effects are negligible. Flow is from left to right.



Question 2

Water flows through a pipe and enters a section where the cross sectional area is larger. Viscosity, friction, and gravitational effects are negligible. Flow is from left to right.

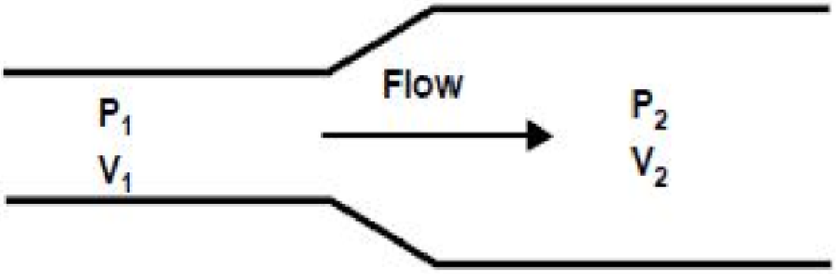
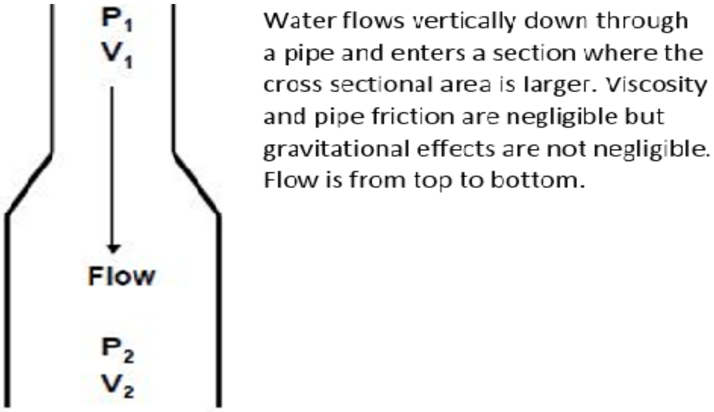


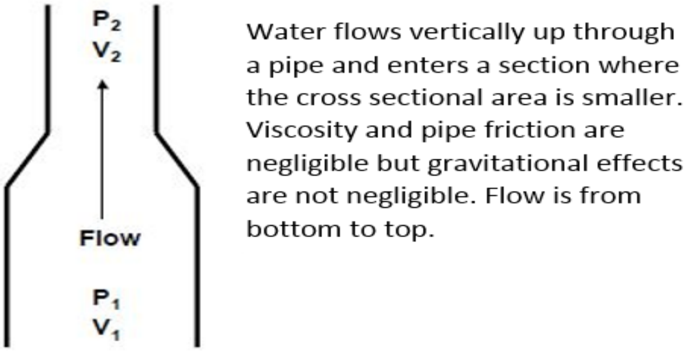
Figure 3: Figures for Questions 1 and 2 on velocity and pressure changes in pressurized pipe systems.

Question 3



Water flows vertically down through a pipe and enters a section where the cross sectional area is larger. Viscosity and pipe friction are negligible but gravitational effects are not negligible. Flow is from top to bottom.

Question 4



Water flows vertically up through a pipe and enters a section where the cross sectional area is smaller. Viscosity and pipe friction are negligible but gravitational effects are not negligible. Flow is from bottom to top.

Figure 4: figures for Questions 3 and 4 on Velocity and pressure changes in pressurized pipe systems.

Questions 1-4 Students

For Q1 and 2-Velocity, all 22 students answered correctly. During the explanations of their answers, each of them applied concepts and equations relating the question to continuity, except for 5% during Q2-Velocity that related it to the Bernoulli equation. The quotes from students in Q1 and 2-Velocity are similar to Student 205:

> *Student 205: Because of **V1A1 equals V2A2 and using continuity equation** and because the area of the first one is larger than the area of*

> *the second one is smaller, the velocity in the second pipe has to increase to make up for it.*

For questions Q3 and Q4-Velocity, the students score was lower, with 86% correct for both of the questions. During the explanations of their answers for Q3- Velocity, the reasoning was split into 75% applying concepts, 15% applying a logical process, and 10% either guessed or used experience to explain their answers. Along with the 95% that talked about continuity during their explanation, 15% also talked about how gravity would have some effect on the water's velocity. The quote below from Student 205 is an example of how the concept or equation of continuity was applied to these questions. A quote from Q3-Velocity where a student tried using gravity to explain their answer showed that they considered the question without gravity, but determined that with gravity not being negligible V1 would equal V2:

> *Student 203: So V1 would be greater than V2 supposedly,* ***but if gravity is put into play, I don't know if it would be the same****. If V1 would be equal to V2. Um, hmm, or it could be near that. I don't know if one would be greater or not. But that's probably would be my answer. Or at least velocity.*

When asked about pressure during Q1-Q4-Pressure, student scores varied less than Q1-Q4-Velocity. For each question, at least 90% answered correctly and applied concepts or equations while answering. During their explanations for Q1 and Q2-Pressure, the students used Bernoulli's equation 90% of the time with continuity accounting for the other 10%. For Q3 and Q4-pressure, 75% of students referred to Bernoulli's equation in their reasoning for each question. Q3-Pressure had 40% of students use the concept of pressure gradients in static water columns in their explanations and 30% of students used this same concept in Q4-Pressure. When talking about pressure gradients in static columns, the students answered in similar fashions to Student 206:

> *Student 206: Also, I think that you could say that pressure would increase because* ***as you go vertically down in a column of water, the pressure increases****.*

Questions 1-4 Engineers

For Q1 – Q4-Velocity, over 90% of the engineers answered correctly except on Q3-Velocity when only 72% answered correctly. For Q1 and Q2-Velocity, 95% of the engineers applied concepts and equations with 15% of those applying them with short, confident answers. The short, confident answers were generally no more than 10 words and were similar to PE 112 who answered by saying "*velocity will increase because of continuity"* and when asked if they could elaborate, used the same quote. The remaining 5% used a logical process for explaining their answer. Over 80% of engineers used equations and a specific concept when explaining their reasoning for Q3 and Q4-Velocity. Q3 and Q4-Velocity saw an increase in logical processes to 10% and 20%, respectively.

When asked about pressure during Q1-Q4-Pressure, engineers' answers varied between the Q1/Q2-Pressure and Q3/Q4 Pressure. For Q1 and Q2-Pressure, the engineers scored 25% and 15%, respectively. While answering Q3 and Q4-Pressure, the engineers score increased to 64% and 72%, respectively. Q1-Pressure had engineers using 6 reasoning processes to explain their answers; 60% used a single concept or equation, 30% used a logical process. Experience, short, confident answers, and guesses each accounted for 10% and 5% used an example. Experience, examples, and short, confident responses were no longer used for Q2-Q4-Pressure by the engineers. The most used process during each of the pressure questions was applications of concepts and equations, followed by logical processes, and a small selection (<10%) guessed at each of the answers. Although the engineers used Bernoulli's equation or terms from the equation for their explanations in Q1 and Q2-Pressure, which should have produced the correct reasoning if applied correctly, at least 60% of engineers used it incorrectly. Similar to PE 123 who mostly works with open channel systems where pressure is the same through a system, the other engineers that responded similarly also, mainly worked with open channel systems.

> *PE 123: You've got your velocity head, your elevation head and your pressure head and without sort of-- yeah, by just constricting the area, you're not going to affect-- I don't think at least that you're going to affect the pressure. I think that you will just increase the velocity.*

Questions 1-4 Comparison of Groups

For Q1, Q2, and Q4-Velocity, both groups scored within 10% of each other, with the majority using the concept or equation of continuity to explain their answers. For Q3-Velocity, the groups were considered to be slightly different with a difference in scores of 14%, but like the other three, the majority of explanations came from the use of continuity. Pressure answers for Q1 and Q2 were considered to be different between the two groups, but Q3 and Q4 were in the similar category. This trend is the same for the reasoning processes for each of the questions. The concepts and terms used for explanations was the same for Q1 and Q2-Pressure, but different for Q3 and Q4-Pressure. Both students and engineers used appropriate concepts during these questions, but familiarity with the use of the concepts seems to be linked to how appropriately it was used while answering the questions.

Table 7: Percent answered correctly/incorrectly, the reasoning processes, and the terms and concepts used while explaining the answer for both engineers and students on Q1 and 2-velocity. [2]

		Reasoning Processes			**Concepts and Terms**	
Question 1 and 2 Velocity Change	**% Answered**	Applied concept/equation	Logical process	Short confident response	Bernoulli equation	Continuity
Students						
Q1-Velocity-Correct	**100%**	100%	-	-	-	100%
Q1-Velocity-Incorrect	**-**	-	-	-	-	-
Total	**100%**	**100%**	**-**	**-**	**-**	**100%**
Q2-Velocity-Correct	**100%**	100%	-	5%	5%	95%
Q2-Velocity-Incorrect	**-**	-	-	-	-	-
Total	**100%**	**100%**	**-**	**5%**	**5%**	**95%**
Engineers						
Q1-Velocity-Correct	**93%**	90%	5%	15%	-	95%
Q1-Velocity-Incorrect	**7%**	5%	-	-	-	5%
Total	**100%**	**95%**	**5%**	**15%**	**-**	**100%**
Q2-Velocity-Correct	**100%**	95%	5%	15%	-	100%
Q2-Velocity-Incorrect	**0%**	-	-	-	-	-
Total	**100%**	**95%**	**5%**	**15%**	**-**	**100%**

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[2] The percentage of participants that correctly or incorrectly is reported in all tables to the nearest 1% because it was a clear distinction between the answer either being correct or incorrect. The reasoning processes and concepts and terms are reported to the nearest 5% because some of the explanations could be interpreted in different ways.

Table 8: Percent answered correctly/incorrectly, the reasoning processes, and the terms and concepts used while explaining the answer for both engineers and students on Q3 and 4-velocity.

		Reasoning Processes				**Concepts and Terms**		
Question 3 and 4 Velocity change	**% Answered**	Applied concept/equation	Logical process	Experience	Guess	Bernoulli equation	Continuity	Gravity
Students								
Q3-Velocity-Correct	**86%**	65%	15%	5%	-	-	85%	-
Q3-Velocity-Incorrect	**14%**	10%	-	-	5%	-	5%	15%
Total	**100%**	**75%**	**15%**	**5%**	**5%**	**-**	**90%**	**15%**
Q4-Velocity-Correct	**86%**	80%	-	-	5%	10%	80%	5%
Q4-Velocity-Incorrect	**14%**	10%	5%	-	-	-	-	15%
Total	**100%**	**90%**	**5%**	**-**	**5%**	**10%**	**80%**	**20%**
Engineers								
Q3-Velocity-Correct	**72%**	70%	-	-	-	-	70%	5%
Q3-Velocity-Incorrect	**28%**	10%	10%	-	5%	-	10%	20%
Total	**100%**	**80%**	**10%**	**-**	**5%**	**-**	**80%**	**25%**
Q4-Velocity-Correct	**90%**	75%	20%	-	-	10%	90%	10%
Q4-Velocity-Incorrect	**10%**	10%	-	-	-	-	-	10%
Total	**100%**	**85%**	**20%**	**-**	**-**	**10%**	**90%**	**20%**

Table 9: Percent answered correctly/incorrectly, the reasoning processes, and the terms and concepts used while explaining the answer for both engineers and students on Q1 and 2-Pressure.

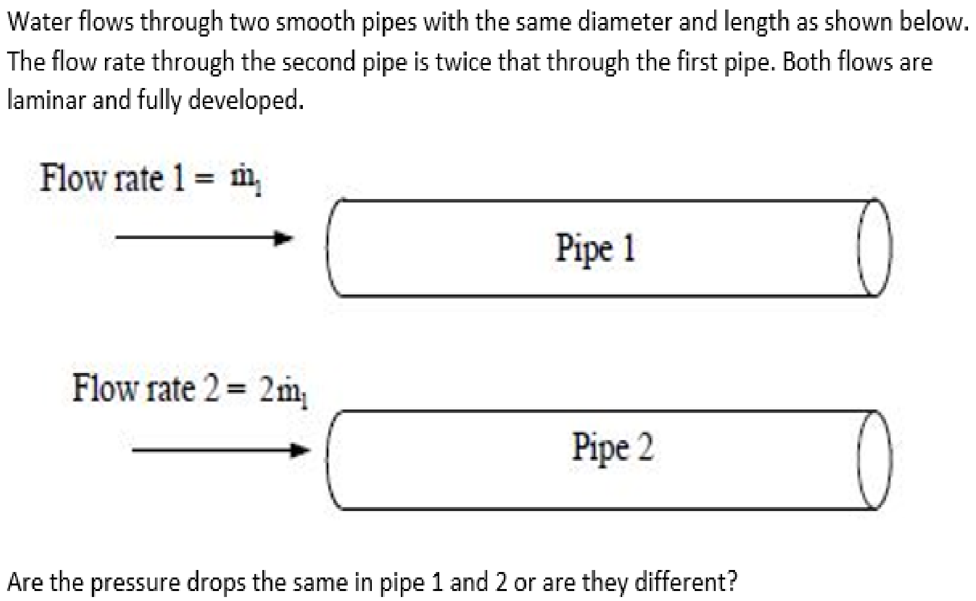
		Reasoning Processes						**Concepts and Terms**	
Question 1 and 2 Pressure change	**% Answered**	Applied concept/equation	Logical process	Experience	Example	Short confident response	Guess	Bernoulli equation	Continuity
Students									
Q1-Pressure-Correct	**90%**	85%	-	-	-	-	5%	90%	-
Q1-Pressure-Incorrect	**10%**	5%	-	-	-	-	5%	-	10%
Total	**100%**	**90%**	**-**	**-**	**-**	**-**	**10%**	**90%**	**10%**
Q2-Pressure-Correct	**95%**	95%	-	-	-	-	-	90%	5%
Q2-Pressure-incorrect	**5%**	5%	-	-	-	-	-	-	5%
Total	**100%**	**100%**	**-**	**-**	**-**	**-**	**-**	**90%**	**10%**
Engineers									
Q1-Pressure-Correct	**34%**	25%	10%	5%	-	5%	-	35%	-
Q1-Pressure-Incorrect	**66%**	35%	20%	5%	5%	5%	10%	60%	5%
Total	**100%**	**60%**	**30%**	**10%**	**5%**	**10%**	**10%**	**95%**	**5%**
Q2-Pressure-Correct	**21%**	15%	5%	-	-	-	-	20%	-
Q2-Pressure-incorrect	**79%**	35%	35%	-	-	-	10%	70%	5%
Total	**100%**	**50%**	**40%**	**-**	**-**	**-**	**10%**	**90%**	**5%**

Table 10: Percent answered correctly/incorrectly, the reasoning processes, and the terms and concepts used while explaining the answer for both engineers and students on Q3 and 4-Pressure.

		Reasoning Processes			**Concepts and Terms**		
Question 3 and 4 Pressure change	**% Answered**	Applied concept/equation	Logical process	Guess	Bernoulli equation	Continuity	Water column
Students							
Q3-Pressure-Correct	**91%**	90%	-	-	70%	-	40%
Q3-Pressure-Incorrect	**9%**	10%	-	-	5%	-	-
Total	**100%**	**100%**	**-**	**-**	**75%**	**-**	**40%**
Q4-Pressure-Correct	**95%**	90%	5%	-	70%	-	30%
Q4-Pressure-Incorrect	**5%**	5%	5%	-	5%	-	-
Total	**100%**	**95%**	**10%**	**-**	**75%**	**-**	**30%**
Engineers							
Q3-Pressure-Correct	**66%**	60%	15%	5%	10%	10%	60%
Q3-Pressure-Incorrect	**34%**	25%	10%	-	5%	15%	15%
Total	**100%**	**85%**	**25%**	**5%**	**15%**	**25%**	**75%**
Q4-Pressure-Correct	**72%**	55%	15%	-	20%	5%	65%
Q4-Pressure-Incorrect	**28%**	10%	10%	10%	-	25%	5%
Total	**100%**	**65%**	**25%**	**10%**	**20%**	**30%**	**70%**

Question 5

Question 5, as seen in Figure 5, asked the participants if they could say whether the pressure drops were the same or different in Pipes 1 and 2 and if they were different if they could identify which one had a higher pressure drop. For Question 5, the concept of conservation of energy (Equation 2), when appropriately applied to this question, relates the change in flow in the same pipe to the change in headloss, which is then directly related to pressure drop. To reiterate what headloss is, it is the energy loss within the system measured in units of length. It is in units of length because it is the fluid's energy per unit weight. The correct answer for questions 5 is that the pressure drop will be twice that through Pipe 2 than it is through Pipe 1. This is because headloss is directly proportional to velocity and from the conditions it is known that the velocity in pipe 2 is twice that of the velocity in pipe 1. If there is twice the headloss, there is twice the pressure drop under this set of conditions. 90% of engineers and 50 % of students answered question 5 correctly. Table 11 shows the different reasoning processes and concepts or terms that participants used during the interviews to justify their answers and what percentage of the two groups used each with their answers.



Water flows through two smooth pipes with the same diameter and length as shown below. The flow rate through the second pipe is twice that through the first pipe. Both flows are laminar and fully developed.

Are the pressure drops the same in pipe 1 and 2 or are they different?

Figure 5: Figure used for question 5 on pressure drops in smooth pipes.

Questions 5 Students

For Q5-Pressure Drop, 50% of the students answered the question correctly. During the explanations of their answers, 60% applied a single concept or equation, 30% used a logical process, 20% guessed, and the remaining 5% used short, confident answers. Of the 60% that applied a single concept or equation, half of them applied it incorrectly and 65% of those that used a logical process had incorrect answers. The terms and concepts that were used by students were in two main categories; The Bernoulli equation was used by 60% of students and 30% related the flow rate to the pressure drop. Of the 60% that mentioned Bernoulli's equation, only 30% of them answered correctly. In contrast to this, all of the students that related flow to pressure drop answered correctly. Of the 40% that said there would be no pressure drop in either pipe, 10% mentioned the pipe being frictionless:

> *Student_0219: I would think that these would be P1 equals P2. I think if, because we'll be neglecting friction, we'll be neglecting or is that safe to say because it says smooth pipes? **Water flows through 2 smooth pipes so there's no friction in the pipes.***

Although the other 30% did not specifically mention that being smooth meant that it neglected friction, there was no mention of friction being important in their explanations.

Questions 5 Engineers

For Q5-Pressure Drop, 90% of the engineers answered correctly. During the explanations of their answers, 55% of the engineers used a single concept or equation, 35% used a logical process, 20% related to some experience they had, and 5% either guessed or had short, confident responses. 85% of the engineers talked about how, in this situation, there would be a greater pressure drop in the pipe with a higher flow rate. When talking about how flow and pressure drop related, the engineers used similar terms and language as PE 118:

> *PE 118: Water pressure drops. Pressure drops. Same smoothness in the pipes. I would think the-- well, if the flows were equal I think the pressure drop would be the same, but the flow is greater in the second pipe. I think that the pressure drops are going to be different and so **I think the pressure drop is going to be greater in Pipe 2 because you're trying to push more water through Pipe 2**.*

15% talked about Bernoulli's or the energy equation. All of the engineers that related pressure drop to the flow rate and 5% of engineers that used Bernoulli's equation answered correctly. Two examples of how experience was used in explanations can be seen below. The first one is an engineer that used experience and answered correctly:

> *PE 119: Well,* ***when we calculate pressure drop*** *through, like, a water meter, you want to-- the bigger the meter gets, the less pressure drop you have through it at a certain flow. So,* ***correspondingly, you would think that the more flow through a same-sized pipe would result in a higher pressure drop.***

This is in contrast to an engineer that used their work experience, but answered incorrectly. In this example, they mention that pressure losses will be independent of friction losses and that those are not dependent on velocity:

> *PE 112:* ***I'm relating this to open channel*** *that we do and it's not necessarily, I mean these are higher velocities, but um, your roughness is not dependent on velocity. In an open channel situation, it's dependent on, you know, sizes of roughness of the material or size of the material that's exposed in the flow and things like that, so it's independent and so your pressure loss is going to be the result of friction losses or roughness in the pipe.* ***Yeah I would think that they would be the same.***

Questions 5 Comparison of Groups

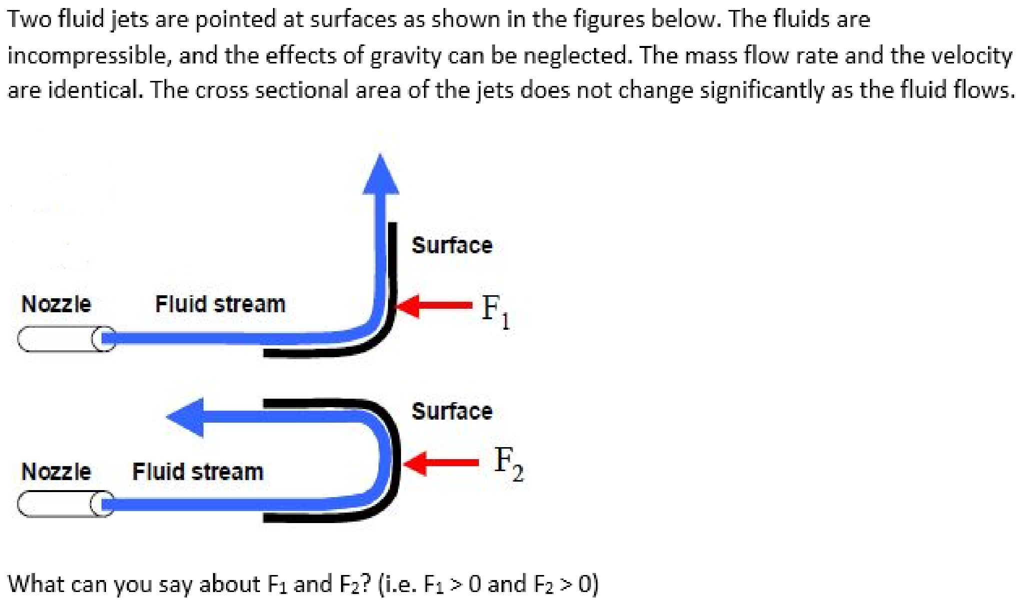
For Q5-Pressure Drop, both the difference in group scores and concepts and terms utilized was at least 40%, which means these were classified as being different. For the reasoning processes, the groups were within 10% in every category excluding guessing and experience, for which there were no students in the category. The difference came from which concept was used for explaining. The students had only one lecture on headloss before participating in the interviews and Student 213 even mentioned after deliberating on the problem, *“Well we haven’t covered head loss necessarily in lecture so that’s, we saw it like one time.”* This is in contrast to the engineers who have more experience with headloss.

Table 11: Percent answered correctly/incorrectly, the reasoning processes, and the terms and concepts used while explaining the answer for both engineers and students on Q5- Pressure Drop.

		Reasoning Processes					**Concepts and Terms**			
Question 5-Pressure Drop	**% Answered**	Applied concept/equation	Logical process	Experience	Short confident response	Guess	Bernoulli equation	Continuity	Flow and pressure drop	Frictionless pipe
Students										
Q5-PD2 > PD1-Correct	**50%**	30%	10%	-	-	15%	20%	-	30%	-
Q5-PD1 > PD2-Incorrect	**10%**	5%	5%	-	-	-	10%	-	-	-
Q5-PD1 = PD2-Incorrect	**40%**	25%	15%	-	5%	5%	30%	5%	-	10%
Total	**100%**	**60%**	**30%**	**-**	**5%**	**20%**	**60%**	**5%**	**30%**	**10%**
Engineers										
Q5-PD2 > PD1-Correct	**90%**	50%	30%	5%	5%	5%	5%	-	85%	-
Q5-PD1 > PD2-Incorrect	**5%**	5%	-	-	-	-	5%	-	-	-
Q5-PD1 = PD2-Incorrect	**5%**	-	5%	5%	-	-	5%	-	-	-
Total	**100%**	**55%**	**35%**	**10%**	**5%**	**5%**	**15%**	**-**	**85%**	**-**

Question 6

Question 6, as seen in Figure 6, asked the participants if they could say anything about the Forces F_1 and F_2. In order to solve Question 6, the concept of conservation of momentum relates forces one and two to the redirection of the fluid streams. The correct answers that were given for question 6 were that $F_2>F_1$ and that $F_2=2F_1$. For this question, engineers correctly answered 67% of the time and students answered correctly 59% of the time. Table 12 shows the different reasoning processes and concepts or terms that participants used during the interviews to justify their answers and what percentage of the two groups used each with their answers.



Two fluid jets are pointed at surfaces as shown in the figures below. The fluids are incompressible, and the effects of gravity can be neglected. The mass flow rate and the velocity are identical. The cross sectional area of the jets does not change significantly as the fluid flows.

What can you say about F_1 and F_2? (i.e. $F_1 > 0$ and $F_2 > 0$)

Figure 6: Figure used for question 6 on Conservation of Momentum.

Questions 6 Students

For Q6-Momentum, 59% of the students answered the question correctly. During the explanations of their answers, 45% applied a single concept or equation, 50% used a logical process, 15% used experience, and 10% guessed. Of the 45% that applied a single concept or equation, a third of them applied it incorrectly and half of those that used a logical process had incorrect answers. The students used a summation of forces 55% of the time, related the flow direction change 35% of the time, and only 10% specifically stated momentum in their explanation. Of the 55% that utilized a force summation 35% of those answered correctly. Those that answered incorrectly talked about how there was no acceleration and since there was no acceleration in the streams, the forces would have to be equal.

> *Student_0211: Force equals mass acceleration and it's not going to depend on the direction or how the streams going to go after it hits that point. So as long as they're hitting at the same point and they're following the same path to that force where it's interjecting.*

All of the students that talked about the flow direction change answered correctly and half of those that used momentum used it correctly. All 15% of the students that talked about their experiences also talked about flow direction change:

> *Student_0217: So F1 is only deflecting it, deflecting this fluid stream in one direction but F2 is completely like redirecting the fluid flow in both. I had a problem very similar to this in the homework.*

Questions 6 Engineers

For Q6-Momentum, 67% of the engineers answered correctly. During the explanations of their answers, 40% of the engineers used a single concept or equation, 55% used a logical process, 15% related to some experience they had, 10% used an example they thought of, and 5% guessed. 55% of the engineers talked about the flow direction change, 35% used a summation of forces, and 15% used momentum in their explanation. When talking about flow direction change, the 10% of engineers that also used experience used examples of thrust block design:

> *PE 102: I think that it would be because if I was to ah, draw a force diagrams on this if* ***I was thinking like thrust restraint*****.** ***If I was going to draw a thrust restraint on F1,*** *I would say that you've got pressure and are going this way and pressure and area going that way. Well, you know from the pipes perspective and then on F2, you have it twice and if it's on the same surface, then it's gonna be opposite and you have it twice.*

Similar to the students, the engineers only used a summation of forces correctly less than half of the time they used it.

Questions 6 Comparison of Groups

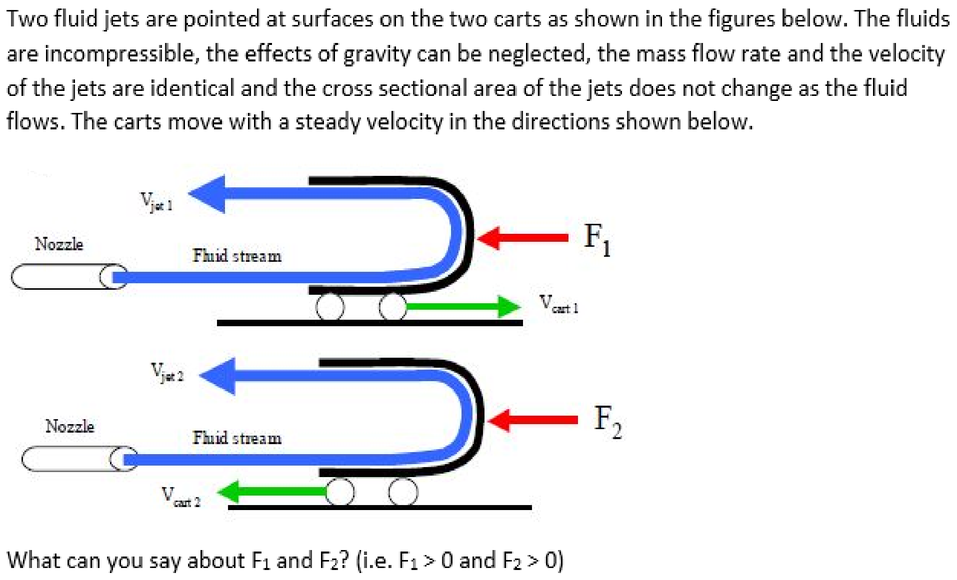
For Q6-Momentum, both the differences in group scores and reasoning processes was less than 10%, which means these were classified as being the same. The concepts and terms used were classified as similar since the difference between the two main concepts used was 20%. An important similarity found in the responses to this question was when the participants used experience in their reasoning process. The students talked about homework assignments, where they had encountered a similar question, while the engineers talked about designs that they had encountered in their work. So although they each used experience, it emphasized the difference in experiences between each group.

Table 12: Percent answered correctly/incorrectly, the reasoning processes, and the terms and concepts used while explaining the answer for both engineers and students on Q6- Momentum.

		Reasoning Processes					Concepts and Terms		
Question 6-Momentum	**% Answered**	Applied concept/equation	Logical process	Experience	Example	Guess	Flow direction change	Sum of forces	Momentum
Students									
Q6-F2>F1-Correct	**59%**	30%	25%	15%	-	10%	35%	20%	5%
Q6-F1>F2-Incorrect	**5%**	-	5%	-	-	-	-	5%	-
Q6-F1=F2-Incorrect	**36%**	15%	20%	-	-	-	-	30%	5%
Total	**100%**	**45%**	**50%**	**15%**	**-**	**10%**	**35%**	**55%**	**10%**
Engineers									
Q6-F2>F1-Correct	**67%**	25%	35%	10%	10%	5%	40%	15%	10%
Q6-F1>F2-Incorrect	**10%**	5%	-	5%	-	-	10%	-	-
Q6-F1=F2-Incorrect	**23%**	10%	20%	-	-	-	5%	20%	5%
Total	**100%**	**40%**	**55%**	**15%**	**10%**	**5%**	**55%**	**35%**	**15%**

Question 7

Question 7, as seen in Figure 7, asked the participants if they could say anything about the Forces F_1 and F_2. In order to solve Question 7, the concept of conservation of momentum, when appropriately applied, relates the cart movement to the force applied to the cart. The correct answer for question 7 is that $F_1<F_2$. Table 13 shows the different reasoning processes and concepts and terms that participants used during the interviews to justify their answers and what percentage of the two groups used each with their answers. This was the only question that was said to be confusing by both engineers and students and PE 126 said - “I haven’t thought about this problem before and I am having a little trouble understanding it”. Other participants had many questions about the figure because they found it to be confusing, which was not common with the other questions that were asked.



Two fluid jets are pointed at surfaces on the two carts as shown in the figures below. The fluids are incompressible, the effects of gravity can be neglected, the mass flow rate and the velocity of the jets are identical and the cross sectional area of the jets does not change as the fluid flows. The carts move with a steady velocity in the directions shown below.

What can you say about F_1 and F_2? (i.e. $F_1 > 0$ and $F_2 > 0$)

Figure 7: Figure used for question 7 on Conservation of Momentum

Questions 7 Students

For Q7-Momentum, 64% of the students answered the question correctly. During the explanations of their answers, 5% applied a single concept or equation, 90% used a logical process, 10% used experience, and 10% provided an example. None of the students that applied a single concept or equation answered correctly. Those that used a logical process correctly answered 65% of the time. When talking through their reasoning, 70% of the students used the movement of the carts to explain their answer, 20% used a summation of forces, 5% each used momentum and flow direction change. Except for 5% that used a summation of forces to successfully determine the correct answer, all of the correct answers were from students that used the movement of the cart in their explanation. Student 204 was a good example of how students using cart movement in their reasoning:

> *Student 204: F2 is larger than F1 because if the same fluid is being pushed back at the same speed and this one's still moving that way, then the F1 must not be doing as much as the F2 which is pushing it back, so for that reason we'll put F2 as greater than F1.*

This process showed that although students may not be able to apply a particular concept or equation, they still had the capacity to reason through the question to answer the problem.

Questions 7 Engineers

For Q7-Momentum, 79% of the engineers answered correctly. During the explanations of their answers, 40% of the engineers used a single concept or equation, 60% used a logical process, and 15% used an example. 60% of the engineers talked about how the carts were moving, 35% used a summation of forces, and 5% used either Bernoulli's equation or momentum in their explanation. The engineers that used cart movement used a similar process to the students to determine the answer. When they applied concepts, they were using summations of forces that related the forces being exerted on the cart either by the fluid stream or the external force. The examples that the engineers used were similar to the students:

> *PE 124: I'm just thinking of a water hose. Like me shooting my water hose in my backyard. The closer you are to the nozzle, the more pressure you feel, the more force there is. Whereas, the further away you are from my garden hose, there's less force, less pressure.*

Questions 7 Comparison of Groups

For Q7-Momentum, the difference in group scores was less than 15% which means these were classified as being similar. The reasoning processes were different with the exception of the use of examples which was the same between the groups. Although the reasoning processes were considered to be different, if the amount of students and engineers that used a logical process and answered the question correctly are compared, then that category is classified as the same. This is an important distinction because it was the most used reasoning process for each group. Also, the participants that used a logical process also explained their reasoning by talking about the movement of the carts. The other concepts and terms used were also considered to be the same between the two groups. This question showed participants in each group answering questions based on something other than concepts or equations. Whether it be an example or reasoning through the cart movement, participants in both groups showed an ability to logically step through the problem to find a solution.

Table 13: Percent answered correctly/incorrectly, the reasoning processes, and the terms and concepts used while explaining the answer for both engineers and students on Q7- Momentum.

		Reasoning Processes				**Concepts and Terms**				
Question 7-Momentum	**% Answered**	Applied concept/equation	Logical process	Experience	Example	Bernoulli equation	flow direction change	Sum of forces	Momentum	cart movement
Students										
Q7-F2>F1-Correct	**64%**	-	60%	-	5%	-	-	5%	-	60%
Q7-F1>F2-Incorrect	**14%**	5%	10%	5%	-	-	-	-	5%	10%
Q7-F1=F2-Incorrect	**20%**	-	20%	5%	5%	-	5%	15%	-	-
Total	**100%**	**5%**	**90%**	**10%**	**10%**	**-**	**5%**	**20%**	**5%**	**70%**
Engineers										
Q7-F2>F1-Correct	**79%**	25%	55%	-	10%	5%	-	20%	5%	55%
Q7-F1>F2-Incorrect	**14%**	10%	5%	-	-	-	-	10%	-	5%
Q7-F1=F2-Incorrect	**7%**	5%	-	-	5%	-	-	5%	-	-
Total	**100%**	**40%**	**60%**	**-**	**15%**	**5%**	**-**	**35%**	**5%**	**60%**

Question 8

Question 8, as seen in Figure 8, asked the participants if they could identify which figure showed the correct fluid levels in the containers at equilibrium. In order to solve Question 8, the concept of equilibrium, when appropriately applied to this question, relates the height of the fluid in the different containers to each other. The correct answer for questions 8 is “A” where the fluid levels in each container are the same. All five of the choices were given to the participants so they could determine which one was the correct figure and explain why it was correct. Table 14 shows the different reasons and reasoning processes that participants used during the interviews to justify their answers and what percentage of the two groups used each with their answers.

Question 8 Students

For Q8-Equilibrium, 91% of the students answered the question correctly. During the explanations of their answers 80% applied a single concept or equation, 10% used a logical process, and 5% either provided an example or guessed. The 10% that used a logical process were all of the students that answered incorrectly. The concepts and terms used were mostly in the two categories of equilibrium and atmospheric pressure, but 10% used Bernoulli’s equation, and 5% used either water columns or that the shapes were not equal to explain their answer. When talking about equilibrium, students talked about the level in each container needing to be the same as the others regardless of shape:

> *Student_0204: Like even if they're a different shape or anything, if it's the same fluid in it, then **it will all come to the same equal height**.*

When talking about atmospheric pressure, they talked about how the containers were open to the atmosphere, and therefore the pressure on all the water surfaces would be the same. As an example of this when Student 201 was talking about atmospheric pressure they said, *"Because um, if they're all open to the atmosphere, they all have the same pressure exerted, so this is zero, um, zero gauge pressure."*

Questions 8 Engineers

For Q8-Equilibrium, 97% of the engineers answered correctly. During the explanations of their answers, 55% of the engineers used a single concept or equation, 30% used a logical process, and 5% used experience, short, confident responses or guessed. The concepts and terms used were similar to the students where 80% used equilibrium, 45% used atmospheric pressure, 10% talked about water columns, and 5% either used the Bernoulli's equation or that the container shapes were not equal in their explanations. The 5% that talked about the container shapes not being equal were the 5% that answered incorrectly. Engineers that used equilibrium in their explanation mention how the water level is going to be independent of vessel shape similar to PE 129 who said "*There's-- they're all in-- because they are-- the level is independent of the shape of the vessel."* When they were talking about atmospheric pressure, which was combined with equilibrium often, they talked in a similar way to students where they mention it as a separate concept to equilibrium:

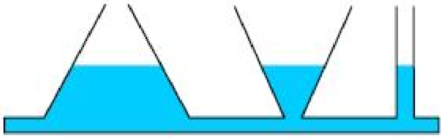
> *PE 110:* ***At equilibrium they should all be about the same****. If there is no flow it's just static right?* ***And they're all open to the atmosphere*** *so it should all just be at the same level.*

Questions 8 Comparison of Groups

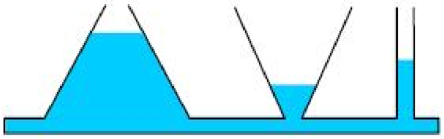
For Q8-Equilibrium, the difference in group scores was less than 10% which means these were classified as being the same. The reasoning processes of applying concepts and logical processes were within 25% difference, and so, were considered to be similar and the same amount from each group guessed. The other three reasoning processes were completely different between the two groups. Equilibrium was used much more by the engineers than students during their explanations, but about the same amount of students and engineers used atmospheric pressure. Although the amount of students that used equilibrium was less than engineers, they talked about the concept in similar ways.

Three containers connected at the base are filled with a fluid. The top of each is open to the atmosphere and surface tension is negligible. The container shapes are all different. Which of the figures shows the correct fluid levels in the containers at equilibrium?

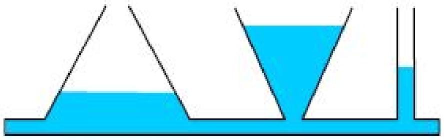
A.



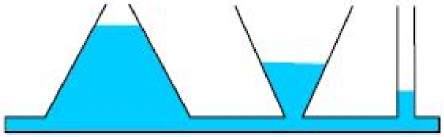
B.



C.



D.



E.

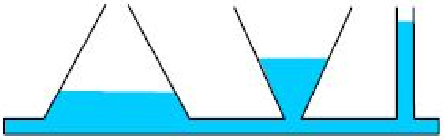


Figure 8: Figure used for question 8 on Equilibrium.

Table 14: Percent answered correctly/incorrectly, the reasoning processes, and the terms and concepts used while explaining the answer for both engineers and students on Q8- Equilibrium.

		Reasoning Processes						Concepts and Terms				
Q8- Equilibrium	**% Answered-Students**	Applied concept/equation	Logical process	Experience	Example	Short confident response	Guess	Bernoulli equation	Water column	Equilibrium	Atmospheric pressure	Shapes not equal
Students												
Q8-A-Correct	**91%**	80%	-	-	5%	-	5%	10%	-	45%	55%	-
Q8-B-E-Incorrect	**9%**	-	10%	-	-	-	-	-	5%	-	-	5%
Total	**100%**	**80%**	**10%**	**-**	**5%**	**-**	**5%**	**10%**	**5%**	**45%**	**55%**	**5%**
Engineers												
Q8-A-Correct	**97%**	55%	25%	5%	-	5%	5%	5%	10%	80%	45%	-
Q8-B-E-Incorrect	**3%**	-	5%	-	-	-	-	-	-	-	-	5%
Total	**100%**	**55%**	**30%**	**5%**	**-**	**5%**	**5%**	**5%**	**10%**	**80%**	**45%**	**5%**

Results Summary

When comparing the two groups they were considered to be the same if the percent being compared was within 10% of each other, they were similar if they were between 10% and 25%, and they were different if there was more than a 25% difference between them. The percent of students and engineers that answered Q1, Q2, and Q4-Velocity, Q6 –Momentum, and Q8- Equilibrium correctly were all considered to be the same. The percent of students and engineers that answered Q3-Velocity, Q3 and Q4-Pressure, and Q7 –Momentum correctly were all considered to be similar. The percent of students and engineers that answered Q1 and Q2-Pressure and Q5 –Pressure Drop correctly were all considered to be different. During 60% of the questions engineers used one reasoning process more than 25% more than any other process and students did the same for 90% of the questions. For 10 of the 12 questions both groups used the same concept at least 25% more times than any other concept during their explanations. For example in Q3-Pressure both groups used Bernoulli's equation at least 90% of the time compared to between 5% and 10% for continuity. Between the groups they used the same reasoning process for 15% of the questions and the same concept for 65% of the questions.

Table 15: Percentage of practicing engineers and students that answered each question correctly.

	Professionals	Students		Professionals	Students
Question 1			**Question 4**		
Velocity	93%	100%	**Velocity**	90%	86%
Pressure	34%	91%	**Pressure**	72%	95%
Question 2			**Question 5**	90%	50%
Velocity	100%	100%	**Question 6**	67%	59%
Pressure	21%	95%	**Question 7**	79%	64%
Question 3			**Question 8**	97%	91%
Velocity	72%	86%			
Pressure	66%	91%			

Discussion

Practicing engineers have scholastic and practical experience with engineering concepts. Since they have more experience with concepts, it might be assumed that they should answer most or all of the questions correctly, or at least more so than students. So why do professional engineers not perform as well with answering some of these questions as students? Situated cognition theory would suggest that they might perform better on questions that deal with concepts that they use more often and are in a similar context to how they encounter those concepts in their work, similar to the research conducted with quartermasters (Hutchins, 1995; Lave & Wenger, 1991) and Xerox repairmen (J. S. Brown & Duguid, 2002). In both of these studies the context was important for the people in that field to perform well at their jobs. For both the quartermasters and repairmen the more experienced ones trained the newer ones until they had passed on not only their knowledge, but also the context in which to use it.

Situated cognition theory then might suggest that professionals and students differ in how they respond to the questions because knowledge within the two groups is based on two different contexts, school and professional work.

The role of context, as it pertains to the interview questions, may have been important for why students and engineers responded to the questions in the way that they did. In the study about the navigators, Hutchins (1995) wrote about how when the navigators were finished with their school program and reported to their first shift, they were supervised by an experienced quartermaster until the experienced quartermaster was satisfied that they could perform their duties. This was important because when they were done with school, they do not have the experience with the concepts that is needed to operate out of the classroom, it was all *contextualized* within the classroom because that is the most familiar setting that the new quartermasters knew. After spending the amount of time they did in school stepping into a new physical and social setting changed the context for them. This made it difficult, or maybe impossible, to transfer the knowledge to the actual job of being a quartermaster. In the same way, engineers generally enter the field licensed with their engineer in training license and must work under the supervision of an experienced engineer in order to become a fully licensed engineer. By the time they are licensed, the engineers will hopefully have experience using the concepts they learned in school in the applications they will be using them in during their careers. This also means that the concepts that they are not using from their school have likely not been used since school and may have less contextualization for these concepts. During the interviews, some engineers mentioned that they did not use particular concepts in their work, especially after they felt that they performed poorly on a question. While this may be true, the concepts may be used within a computer program without the engineers realizing it or a particular question and answer may not be used within design. For example, some of the engineers mentioned that they did not see pipe expansions often in their pressurized pipe design and so that question and answer would not be familiar to them. Questions one and two involved horizontal pipes and only 34% and 21% of engineers answered these correctly (as mentioned in the results), respectively. The following two questions involved pressure in vertical pressurized pipes and the engineers drastically improved their score, except that the reasoning many of them gave involved pressure gradients in a static water column, so it was answered correctly, but due to a misconception rather than an understanding of the concept.

The context in which the questions are given could be the reason that the engineers did not perform better on the interview questions and why students in general did as good, if not better, than the engineers. The physical surroundings would not have been the context since the interviews were held in familiar settings for each group, but the way in which the questions look may not have been familiar to engineers. Students commented on how they had recently finished homework or tests that had similar questions to those being asked, but engineers would often refer to projects they worked on as a way to contextualize the questions. Having the context ready at hand may have given the students an advantage that the engineers did not have. Since the questions were originally designed for students, there is cause to believe that perhaps the engineers and students would have performed differently if asked questions regarding actual engineering projects that would be more familiar to the engineers.

As mentioned earlier in the literature review people can use “embedding” to assist them when solving a problem by allowing them to use the situation itself to process the information for them (R. A. Wilson, 2004). Embedding concepts into a specific situation can help when you need to use a concept for an unfamiliar situation. If you can manipulate the current situation and relate it to a situation in which you have embedded a concept into, you would not have to process information in an unfamiliar way and this could potentially help with the process of utilizing concepts. PE 123 has worked as an engineer for 7 years, is licensed as a PE, and has mainly worked on non-pressurized systems with a little experience with pump selection for pressure mains, which is not normally their main task. They answered questions about the concept of conservation of mass correctly, which is a concept that they said they use often in their work, and that they related the question to when justifying their answer. When they were answering Q1 and Q2-Pressure, they answered incorrectly. When trying to explain their reasoning, they said that by constricting the area, the velocity would be affected, but not the pressure. In an open channel, this would be true, but not for a pressurized pipe system. Their situational knowledge of the concept is impaired by the assumptions they generally work with. This was true of least 66% of engineers during Q1 and Q2-

Pressure. Situated cognition theory would explain this as the embedded mind. The concepts that are used more often are embedded, or stored, in situations and these situations help one recall the concept for use in their current task (Wilson 2002). In contrast to this, students scored a 90% on Q1-Q4-Pressure. They had been in a classroom setting for weeks before they interviewed, learning about the concept needed to properly answer the question. They had also taken a test the same week the interviews started. The questions that were asked in the interview were similar to questions they encountered during their course and they had practiced that type of question in similar contexts for weeks. The concepts that were needed to answer the questions were *embedded* properly for the students to easily process the information and use it during their explanations.

Another instance of embedding within both students and engineers was Q6-Momentum. Student 219 mentioned that the question was very similar to a recent homework problem they had finished for class. They then proceeded to talk through the question, referring back to the homework they had just recently completed for reference. Engineers do not have the same benefit of having recently finished a homework project with the same or very similar problem, but that does not mean they did not have the necessary concept embedded. Some engineers referred to thrust restraint design when they were explaining their answers for Q6-Momentum. According to the engineers that talked about it, thrust restraint was a common part of their normal system design. Although this was not named a thrust restraint question, that is how they contextualized it in order to process the embedded concept easier.

It is theorized that concepts are stored situationally and engineers may have difficulty conceptualizing the questions within the situations presented in the interviews because of the piece of situated cognition called *embodiment*. According to this piece of situated cognition theory, concepts are not represented as generic, highly abstracted data structures, but rather, their content is tailored to the current situation. Fluids concepts can be situated differently in the workplace compared to the classroom, just as the carpenters and cabinet makers used a chisel in different ways (J. S. Brown et al., 1989). The chisel, or in this case fluid mechanics concepts, may not change, but the person utilizing it will tend to use it according to their experience with it. Similar to the study done where engineers participated in the statics concept inventory, it is possible that the images presented during the interviews trigger the same stimuli in practicing engineers as it does in students, but for students, this imagery may be recent retrieval rather than long term retrieval which may explain why they did not score better than the students (Urlacher et al., 2015). During Q3 and Q4-Pressure, engineers' scores increased from the previous two questions, but their reasoning was flawed. They saw a figure that had fluid in a vertical structure and talked about how pressure would change according to the pressure gradient within a water column. The engineers that explained it with this concept work on projects that involve static water at some point in the design. They saw something similar to what they see often in their work and they used a common tool, although for this particular purpose, it was not the right one. Similar to muscle memory, the engineers started using this embodied concept in their explanation. Although it produced a correct answer, if the situation had been different, it may not have had the same result.

Q5-Pressure Drop has another example of embodiment within the participants. Students may have idealized systems without friction embedded into their process for approaching questions like this due to generally neglecting friction in smooth pipes. When Student 219 was talking about the pipes, they said that since the pipe was smooth, the pipe was frictionless. They may have embodied the idea that smooth means frictionless. This could be because of previous experience, either with the word or an idealized homework problem. They were not told it was frictionless and before they went into this part of their reasoning, the interviewer told them that friction was not necessarily negligible when the student asked about it. Although they were told that friction was a possibility, they still chose to use what was *embodied* and decided that a smooth pipe was frictionless. Engineers, however, did not hesitate to assume that a smooth pipe was the same or similar to new pipe that they design for in some of their projects. Embodiment was important for both engineers and students and if a situation arises where an embodied concept is perceived as being useful, then it had potential to either help or hinder the participant in their answer and reasoning.

Lastly, the engineers and students responded in similar ways throughout the interview. From the results we see that within their group, the majority of engineers and students used the same concept for 84% of the questions. While other concepts were used during these questions, these concepts were used by at least 25% more participants within a group for a single question. These concepts were not always the same between groups, but this shows that within these groups, their conceptualization is similar between participants. For the students, about half of them were enrolled in one class and the other half enrolled in another, each taught by different professors. These classes followed the same tentative class schedule and the concepts were supposed to be covered for the same amount of time, giving each class about the same exposure to each concept. Also, since the classes were at the same university, the professors have the opportunity similar to the Xerox repairmen to talk about common problems amongst their student groups. This could is a form of the community of practice talked about by Lave and Wegner (1991), where the professors are the experts and the students are the novices in the field. Since they have a unique relationship with each other, which is entwined with the learning of new concepts, they share similar ideas, conceptualizations, contextualization, embodiment, and even embedding is probably similar. The engineers work in three firms within close proximity to each other. They may interact on occasion because they are in the same geographic area and the projects they work on probably have many of the same issues that arise from being in that particular area of the world. They also form a community of practice which would share similar ideas, conceptualizations, contextualization, embodiment, and even embedding which is similar to the students' community of practice. The overlap that does happen between the groups may be concepts that are important to both communities. Eventually, students will likely become part of the greater engineering community of practice and when that happens, they will likely change to conform to their new community's ideas, conceptualizations, contextualization, embodiment, and embedding natures.

Summary/Conclusion

This study utilized professional engineers and students in an attempt to begin to understand how conceptual knowledge is different between the two groups. Engineers and students seem to use their experiences to relate concepts to problems. It is also possible that they embed knowledge in situations which are different for each group. Students embed their knowledge in the classroom, homework, and tests because that is what is important in their life at the moment, while engineers embed their knowledge in engineering design projects. This could account for the difference in scores between each question. The questions that both groups scored well on were explained using different types of experiences; students used their experience with school while engineers used their work experience to explain their answers.

The results of this study indicate that engineers and students situate their knowledge within the context they are most comfortable with. This is not to say that their conceptual knowledge of fluid mechanics is any different other than that one group is situated within practice and one is situated within school. This also means that there might be a difference between the context that concepts are taught and learned in during school and the context in which they are used in engineering practice. Within each group, participants seemed to share the contextualization of the concepts in the same way as the others within their group, but not with the participants of the other group. This study, therefore, contributes evidence to a body of research on the ways in which cognition is situational and is not limited to a person, but can be embedded in situations specific to each individual.

During the first four questions of the interview, with very few exceptions, the students interviewed seemed to use the same approach to problem solving. The group of students used many of the same reasons with a few differences when the pipe changed from horizontal to vertical, but mostly it was consistent throughout the first four questions for both velocity and pressure. The engineers were not as consistent with their answers all through the first four questions, although they were more consistent when responding about velocity than pressure. Between the questions involving horizontal pipes and vertical pipes, there did not appear to be much change in how a particular participant or group changed in their reasoning based on whether the flow in the pipe was going into an expansion or a contraction. The fifth question showed greater variety in students reasoning, but more consistency by the engineers. This question was the only one that students scored much lower than engineers did. The engineers seemed to have a better understanding of some of the terms such as “smooth” and were more knowledgeable in the topic than the students were since the students had only had exposure to the topic in one lecture and the engineers seemed to have more experience in their jobs with the concept.

Future research that uses interviews of professional engineers should be conducted to verify and enhance this study on a larger scale. Specifically, this could be done by using interview questions that were situated in engineering work rather than questions contextualized as they were in this study.

This study gave insight into the shared cognitive mind of the larger community of practicing engineers and students. In order to verify and expand on the findings in this paper, a larger study utilizing more engineers and possibly a different concept set would be a logical next step to understanding more about shared cognitive models amongst engineers. Also, by using another set of questions that are more situated within engineering practice, it could show the reversal of this study where engineers perform better than students due to the context of the questions being rooted in what engineers are familiar with rather than what students are familiar with. Would there be a difference in how students and engineers perform in the interviews?

If other studies hold true to the results found in this paper, then it could suggest that a change in the current education system needs to happen to allow for a more professionally contextualized system that allows students to learn concepts within the same contexts that they will use them in their professional careers. More specifically, using more interactive approaches of teaching and having class design input from the professional community. This would allow professors to tailor their classes to the needs of the professional community rather than some other goal.

Finally, this study supports the claim that there is an urgent need for research utilizing professional engineers. There are differences between students and engineers and, although there is a vast amount of research that studies students, it cannot necessarily be used to extend the findings to professional engineers because of the differences that were discussed in this paper. The purpose would not be to invalidate the previous research done with students, which is invaluable for the perception it gives on students conceptual knowledge, but rather to expound upon it in order to more completely understand conceptual knowledge within the engineering profession.

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Chapter 4: General Conclusion

The research efforts described throughout the previous two chapters begin to address the gap of research on professional engineers' knowledge of engineering concepts. The first paper, described in Chapter 2, utilized the statics concept inventory to determine professional engineers' conceptual knowledge of statics. It was the first study of its kind and will hopefully lead to future research utilizing concept inventories to determine engineers' concept knowledge within specific fields of engineering. The second paper, described in Chapter 3, focused on engineers' conceptualization of fluid mechanics concepts commonly used within civil engineering practice and showed how the contextualization of questions may affect how participants answer.

The first study, described in Chapter 2, was conducted utilizing 25 practicing civil engineers from 20 different firms. This was first study done utilizing the statics concept inventory and practicing engineers. Comparing the data to previous studies done with students, not much difference was found between the two groups. Although this may be initially concerning, the implications that the concepts are highly contextualized is a possible cause of why there is little difference between the professionals' scores and the students' for most of the questions. The professionals may use the concepts from statics concept inventory, but they may use them in different contexts, making it difficult to properly apply them to the specific situations that the concepts are presented in as a concept inventory question. Since the concept inventory questions are in a format more familiar to students, this suggests that the professionals do not encounter these concepts in the same context that students do while in school. If engineers are using the concepts, but not in the same way they learned them in school, then perhaps the context that the concepts are taught in needs to change in order to better prepare students for the engineering profession.

The second study, described in Chapter 3, included interviews with 29 practicing civil engineers and 23 students. The students and engineers both answered questions with varying processes and concepts. The students exceled at questions that they were familiar with because of the similarity to class assignments, projects, and tests, but had a more difficult time answering questions with which they had very little practice with from their experience in the fluid mechanics class. The engineers showed similar tendencies and exceled at questions that were related to concepts that they felt were used often in their work. Within each group, there was consistency in the concepts used during the explanations to the problem. Engineers and students both answered questions in a way that suggests they embody and embed fluid mechanics concepts, especially those that they encounter often in their work or class. This suggests that at least knowledge within fluid mechanics is highly dependent on context. This means that traditional teaching methods may not be enough to meet the needs that the NRC would like to see addressed in the engineering curriculum.

Future Research

These studies will serve as a benchmark for discussion about professional engineering situated contextualization of engineering concepts. The relatively small sample sizes are large enough to draw preliminary conclusions from the communities that they represent. It is important to investigate other subject areas to examine the contextualization of concepts, and to determine if these results are generalizable for the larger engineering community. There are concept inventories for physics, heat transfer, electricity, biology, statics, fluid mechanics, transportation, and strength of materials, all of which should be used to study concept knowledge within these areas of engineering as well. Along with the concept inventories, a good accompaniment to these studies would be more in depth studies that involve interviews with engineers that can help determine similarities and differences in the way students and engineers process their answers. Specifically, as discussed in Chapter 3, this could be done by using interview questions that were situated in engineering work rather than questions contextualized as they were in this study. When this research is conducted questions that should attempt to be answered are:

1. Do the implications made in Chapter 3 hold for fluid mechanics across a larger sample size or are they specific to the engineers that were interviewed in this that study?

2. Do the implications made in Chapter 3 of this thesis cross over to other concept areas or is it isolated to fluid mechanics?
3. If there are similarities between the different concept areas, are there suggestions for change within the education of engineers in order to bring the context needed for professional engineering work into the education of future engineers?

Another approach to this research that might be important is to change the context of the questions. If new concept inventories could be developed that were more situated in engineering design rather than in context familiar to students, would the results of these studies change? Currently, engineers do not do particularly any better than students do, with few exceptions where the students had very little interaction with the concepts within their education at the time of participation. If engineers perform better than students on questions that are contextualized within familiar situations, this would further solidify the idea that engineering knowledge is highly dependent on context.

Educational Implications

The purpose of this research was to begin a discussion about the context that concepts should be taught within the engineering education system to enrich the education of future engineers. Each of these studies discussed how context was very important to how engineers and students answered the questions. From the research discussed in Chapters 2 and 3, it was determined that context is important when applying concepts to problems. The engineering office is a collaborative work space that needs collaboration between engineers of different disciplines. Why are engineering classes taught independent of each other? If course work was changed from individual classes separated by subject content a curriculum that breaks down the barriers of our current system where concepts are not mixed is suggested. Focusing on authentic design under the supervision of practicing engineers may bring the concepts into the correct context first, instead of learning them in one context and having to practice them in another. This may be the most difficult piece to implement because engineers are not primarily educators and expecting that they spend their time helping in the education process is difficult. They may not need to spend physical time in the school and the time commitment could be minimized to twice or three times a term: First meeting, midterm check in, and final evaluation. This interaction would benefit both the students and the professional engineering community by allowing each group to integrate with each other. For students this could help them integrate into the professional community easier after graduation. For engineers it could help them by focusing energy into the students' conceptual development before they reach the professional office.

Closing Thoughts

The work presented in this thesis needs to not be the end of this discussion, but rather the beginning. Larger sample sizes and more concept areas are the most important areas to focus on. With these two areas as the focus of future research, validation of this data could help initiate discussions about how it could facilitate changes in the current education design within engineering programs. It could create ideas for how to bring the context of the professional engineer to the student to allow them to learn the concept within, instead of apart from, the proper context. Since this is what the National Research Council says is an *urgent need* within the education of engineers, it is paramount that as educators, we turn our attention to it and collaborate to make the future generation of engineers ready for what lies ahead of them.

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