STUDENT UNDERSTANDING OF PRESSURIZED PIPELINE CONCEPTS AND THE APPLICATION TO CONCEPTUAL CHANGE THEORY

By

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Abstract

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Background

Engineering students struggle with fluid mechanics concepts, including flow in pipelines with a changing diameter.

Literature

There are competing theories on how to identify and address students' misconceptions, like those that exist in fluid mechanics for pipeline flow. Limited research exists on student understanding of fluid mechanics, and research is notably lacking in identification of students' misconceptions in fluid mechanics and the application of broadly accepted conceptual change theories.

Research Goals

Research was conducted to explore students' understanding of fluid mechanics concepts. Specifically, the purpose of the research is to (1) investigate student understanding of pressurized pipeline flow, (2) evaluate the consistency of misconceptions between two different interview protocols exploring similar fluid mechanics concepts, (3) evaluate the misconception consistency between two participant groups with varying levels of experience in fluid mechanics, and (4) apply prominent conceptual change theories to the identified misconceptions.

Methodology

The participants were interviewed using two distinct interview protocols: one consisted of questions from the Fluid Mechanics Concept Inventory and the other was an open-ended pressurized pipe system. The participants had varying levels of experience in fluid mechanics.

Results & Discussion

Research showed that students easily understood velocity changes in pressurized pipelines with a changing diameter, but frequently were unable to accurately predict how pressure would change. Furthermore, the data showed that students approached vertical pressurized pipelines differently than horizontal ones, even though they are conceptually the same problem. Two prominent theories on conceptual change were identified to be applicable to the data. Though these theories are appropriate they are individually incomplete in fully explaining the data. The ontological shift theory explained the existence of the two major misconceptions identified in this paper; however, it was unable to explain why both misconceptions are utilized separately for conceptually similar problems. A combination of an ontological shift theory and framework theory provides a more complete understanding of students' misconceptions in fluid mechanics.

Conclusions

Using both the ontological shift and framework theory approaches to conceptual change, suggestions on how to implement schema training and active learning are given with the goal of achieving conceptual change in the classroom.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. Introduction

Water distribution systems consist of pipes and pumps, including many kinds and sizes of pipe material and fittings. Understanding relationships between elevation, pressure, velocity, and system characteristics is fundamental to the design and modification of these systems. The introduction to concepts of flow and energy loss is sometimes covered in sophomore level physics courses and always in junior level fluid mechanics courses. Results from the Fluid Mechanics Concept Inventory (FMCI) indicate that students have basic misconceptions related to pipe size, elevation, velocity, and pressure. While FMCI results are useful for knowing how students responded to individual questions and groups of questions related to the same concept, they provide little or no insight into students' thinking about concepts related to the questions. Additionally, multiple perspectives from conceptual change theory suggest that the context of interview questions influences students' responses. The purpose of this study is to explore student understanding of the fundamental fluid mechanics concepts of pressure and velocity in relation to pipe geometry and the consistency of misconceptions in different contexts. Two different approaches to the interview protocol were utilized: one was a selection of FMCI questions and the other was an open-ended pressurized pipe system. Data from two different participant populations were used. Participants had varying levels of experience in fluid mechanics, allowing for a broad transferability of the research results.

2. Literature Review

Concept Inventories (CIs) were created as an assessment tool to provide feedback to instructors on what fundamental concepts students understand and to evaluate teaching effectiveness [1, 2]. When the Force Concept Inventory (FCI) was developed, physics professors deemed the CI questions "too trivial to be informative," but their students responded poorly to the questions [2, p. 2]. Researchers found, using the FCI, that students who did well on exams and homework performed poorly on the FCI questions [2].

While CIs are a good assessment tool [3], they are still a structured questionnaire that does not allow researchers to fully understand the thought process of the participants unless paired with an interview, and are not specifically tied to learning theories.

2.1 Research in Fluid Mechanics

All previous published work located in relation to student understanding of pipeline flow used the Fluid Mechanics Concept Inventory (FMCI). An extensive search through engineering education journals such as the ASCE Journal of Professional Issues in Engineering Education and Practice, the Journal of Engineering Education, and many more yielded no other articles pertaining to student misconceptions in fluid mechanics.

Development of the FMCI was initiated by asking students and faculty to create a list of ten fluid mechanics topics that they understood or believed to be important and ten topics which they did not fully understand or did not believe to be important [4]. The students were also asked to discuss the list they created as well as answer questions from faculty [4]. To assess the validity of the FMCI the developers administered it to approximately 200 fluid mechanics students at the University of Wisconsin at both the beginning and end of their fluid mechanics course [5]. After assessing the students' responses the developers revised the FMCI [5]. The FMCI consists of 30 multiple choice questions that covers a broad spectrum of fluid mechanics concepts, including conservation of mass, conservation of energy, momentum, and viscous flow [4, 5].

The only research identified relating to students' understanding of fluid mechanics that was not a part of the development of the FMCI was by Fraser *et al.* who utilized the FMCI to determine if the application of computer simulations improved students' understanding of fluid mechanics concepts [6]. In this study, an average of only 23.9% of students who took a shortened version of the FMCI that used 22 of the 30 FMCI questions could properly answer questions about fluid flow through a pipeline with changing diameter [6]. Exposing students to computer simulations increased the percentage who properly understood fluid flow through pipes with a changing diameter [6]. The researchers noted that due to the post-test being taken shortly after the computer simulation students may have performed better than if there was a longer delay between the computer simulations and the post-test [6]. It is noted that students still struggled to apply what they learned from the computer simulations to problems that were presented in a slightly different context [6]. The computer simulation depicted a horizontal pipeline, when taking the post-test the number of correct responses improved on horizontal pipe problems; however, when answering questions with a vertical pipeline there was no significant improvement [6]. This research indicates that carefully designed instruction can improve students' performance on the FMCI; however, students will likely struggle to apply their new knowledge to different situations or contexts.

2.2 A Gap in the Literature

The advancement of teaching and learning requires the development and refinement of learning theories [7]. Despite the necessity of fluid mechanics in the civil and environmental engineering curriculum [8] no research was found relating students' understanding of fluid mechanics concepts to learning theories in journals relating to engineering and education. Conceptual change research has been used extensively to address students' learning and understanding of physics [9-11], heat transfer [10], electricity [12], and biology [13]; it is therefore an acceptable tool to address students' conceptual understanding of fluid mechanics.

Conceptual change can be understood as exchange of naïve, incorrect knowledge for scientifically correct knowledge [14].

An absence of work on student's conceptual understanding of fluid mechanics diminishes the opportunities for the co-development of conceptual change theory in engineering education and educational practices to help students more efficiently and effectively learn difficult engineering concepts.

2.3 Conceptual Change Theories

To better understand conceptual change we should briefly explore its connection to learning. There are three situations in which learning can occur: where (1) there is no existing or prior knowledge of a concept, (2) learning fills in gaps of missing knowledge or concepts, or (3) prior knowledge is in conflict with correct knowledge [15]. This last situation is where conceptual change occurs because the prior knowledge must be adjusted and corrected for students to have the proper conceptions. Understanding conceptual change for a particular subject requires an in-depth understanding of how students think about concepts related to the subject. Therefore, previous research on conceptual change has almost wholly utilized interview data [16, 17]. Past research with the FMCI utilized test scores rather than in-depth explanations from participants, inhibiting the application of conceptual change theories [6].

In the learning sciences there are two conflicting approaches to conceptual change: the cognitive and situative perspectives. The cognitive perspective is based on the notion that one's knowledge is organized into structures of information and processes and that knowledge exists in the "minds of individuals" and it "can be acquired, developed, and changed" [18, p. 56]. This perspective focuses on the transferability of concepts to different contexts [19]. From the situative perspective knowledge is a process or "activity that takes place among individuals, the tools and artifacts that they use, and the communities and practices in which they participate" [20, p. 20]. What changes during conceptual change is "the way that tools are used by learners in various contexts" [19, p. 106]. Knowledge in this regard is based on "knowing and doing – in terms of participation in social and cultural activities" [18, p. 56]. Primarily, this perspective focuses on the setting or context as the prominent feature of knowing [19].

Two of the most prominent and widely cited researchers in conceptual change are Michelene T.H. Chi [12, 13, 15, 16, 21-23] and Stella Vosniadou [10, 18, 24, 25]; both incorporate an ontological perspective in their theories of conceptual change and misconceptions, but in different ways. Ontology can be described as the "fundamental essence" [23, p. 28] of a concept that incorporates how we define it and how we associate with other concepts within a larger branch, or hierarchical tree, otherwise known as an ontological category [13, 16, 23, 26].

Chi's stance on conceptual change is from the cognitive perspective [19]. She believes that robust misconceptions, which are misconceptions that persist after formal education, form because concepts have been placed in the wrong ontological category [13, 21-23]. Based on this, conceptual change requires shifting a concept from the incorrect ontological category to the correct one [13, 21-23].

Vosniadou describes her framework theory as a middle ground between the cognitive and situative perspectives and it "avoids many of the criticisms of the classical [cognitive] approach" to conceptual change [18, p. 60]. She believes that misconceptions are formed when individuals try to reconcile "scientific information within an existing framework theory that contains information contradictory to the scientific view" [10, p. 46]. Conceptual change in this situation does not focus on fixing the misconception, but rather on correcting the "naïve, intuitive…theories constructed on the basis of everyday experience under the influence of lay culture” [18, p. 58].

Being able to identify what misconceptions students have and which conceptual change theory is most appropriate will give insight into how to better approach teaching in the classroom. Chi’s and Vosniadou’s approaches will both be used to fill the existing research gap in regards to students’ conceptual understanding of fluid mechanics. A more detailed explanation of Chi’s ontological shift theory and Vosniadou’s framework theory is presented in the discussion section.

2.4 Research Goals

Students struggle with concepts in fluid mechanics, including situations with pipelines with a changing diameter [6]. Even though intervention with computer simulations was able to improve students’ scores on FMCI questions in the study by Fraser *et al.*, those students still struggled to apply their knowledge to similar situations that were presented in a different context [6]. Results from CIs and educational intervention show whether the instruction or intervention was successful, but do not explain why. Therefore, it is worthwhile to explore the misconceptions and reasoning that students have with pressurized pipeline flow. Knowing this will provide insight into an appropriate theory of conceptual change, which will in turn help instructors achieve conceptual change in the classroom.

While CIs are useful assessment tools, they can constrain students’ responses to the available multiple-choice options (it should be noted that a few students sometimes wanted an un-listed answer during this study). Therefore, in addition to having students solve FMCI questions, their verbal responses about their thought process and rationale while solving the problems will be informative and beneficial to understanding their conceptual understanding.

Furthermore, students' responses to an open-ended, pressurized pipe system problem will also be beneficial by providing insight into what misconceptions students still hold when presented with a more practical situation.

Conceptual change theories are helpful as they allow researchers and educators to go beyond just knowing what concepts students struggle with and understand why. Applying conceptual change theories will also provide faculty with a better understanding of what can be done to achieve conceptual change in the classroom and help students better understand course material.

The purpose of this research is to (1) investigate student understanding of pressurized pipeline flow, (2) evaluate the consistency of misconceptions between two different interview protocols exploring similar fluid mechanics concepts, (3) evaluate the misconception consistency between two participant groups with varying levels of experience in fluid mechanics, and (4) apply prominent conceptual change theories to the identified misconceptions.

3. Methodology

Qualitative research has been described as an "intensive study" and as the "interpretations of meanings" [7, p. 5]. Qualitative methods to assess learning include observations, written or oral responses, ratings, and self-reports (questionnaires, interviews, stimulated recall, and think-alouds) [7]. Interviews and think-alouds are particularly useful for qualitative research as interviewers are able to prompt participants in order to collect in-depth responses and think-alouds provide a detailed pathway of a participant's thought process.

This project utilized data from two different groups of participants with varying academic experience and different interview protocols. Data sets were collected independently of each other but provide a unique opportunity to investigate student understanding of fluid mechanics in two very different student populations and with different interview questions. To investigate the misconceptions and appropriate conceptual change theories both sets of data were analyzed together.

3.1 Participants

Within the two sets of data utilized in this study there are three cohorts. Cohort 1 consists of twenty Washington State University (WSU) students who had completed an introductory course to fluid mechanics typically taken during junior year, prior to the interviews.

Cohorts 2 and 3 are either current or former WSU civil engineering students and are part of a three-year longitudinal study tracking their conceptual understanding and epistemology utilizing short, weekly check-in and intensive, twice annual interviews. Cohort 2 is comprised of eight WSU undergraduate students. During their first interview (pressurized pipe system) the students were finishing their sophomore year and had not been taken the fluid mechanics course; however, they had received some exposure to fluid mechanics concepts via physics, which is a prerequisite for the civil engineering program. During their second interview (FMCI problems) they had just completed the fluid mechanics course.

Cohort 3 consists of nine WSU graduates who completed their bachelors of science in civil engineering between the first and second interviews. At the time of their first interview (pressurized pipe system) the participants were in their last semester of their undergraduate program. During their second interview (FMCI problem) the participants had been employed and working as civil engineers for approximately one year. Not all of the participants in cohort 3 had a focus in fluids; their interests covered the entire spectrum of civil engineering.

In total there were 54 interviews; a summary of the interviews each cohort participated in as well as their experience level during their interviews can be seen in Table 1. Previous research has utilized a homogenous population sample [6], while the participants in this study have a diverse range of experience. If a misconception is prevalent across all sets of participants it is likely to be a robust misconception. The number of participants who were interviewed when they had completed fluid mechanics is sufficient for drawing conclusions on a large population [27]. While there are significantly less participants at the pre-fluid mechanics and post-graduation experience levels in cohorts 2 and 3, they are a unique attribute to this study.

Table 1: Tabular summary of what interviews each cohort participated in and their education level both in school and relative to fluid mechanics or graduation

Interviews	Cohort 1	Cohort 2	Cohort 3
FMCI	Juniors, After Fluid Mechanics	Juniors, After Fluid Mechanics	Graduated & Employed
Pressurized Pipe System	- - -	Sophomores, Before Fluid Mechanics	Seniors, After Fluid Mechanics

3.2 Interview Protocol

Two different interview protocols were used, one based on a pressurized pipe system, and the other using FMCI questions.

Participants in cohorts 2 and 3 were given a schematic drawing of a pressurized pipe system (see Figure 1). The interview protocol used was designed to investigate participants' understanding of how pressure, velocity, and energy vary in and are affected by the system utilizing a semi-structured, clinical interview approach [28-31]. A semi-structured interview consists of a set of pre-established questions that are used to guide the interview but allows for the interviewer to add or replace questions as necessary to ensure that participant provides a detailed response that fully expresses their understanding of the material [32]. The purpose of clinical interviews is to determine "the nature and extent of an individual's knowledge about a particular domain by identifying the relevant conceptions he or she holds and the perceived relationships among those conceptions" [33, p. 195]. The pre-established questions were primarily related to pressure, velocity, and energy in the pipeline (see Table 2) and any additional questions were probing questions (e.g. *can you explain why the system will react that way*). Participants were allowed to draw or write anything down on the handout that they felt was useful.

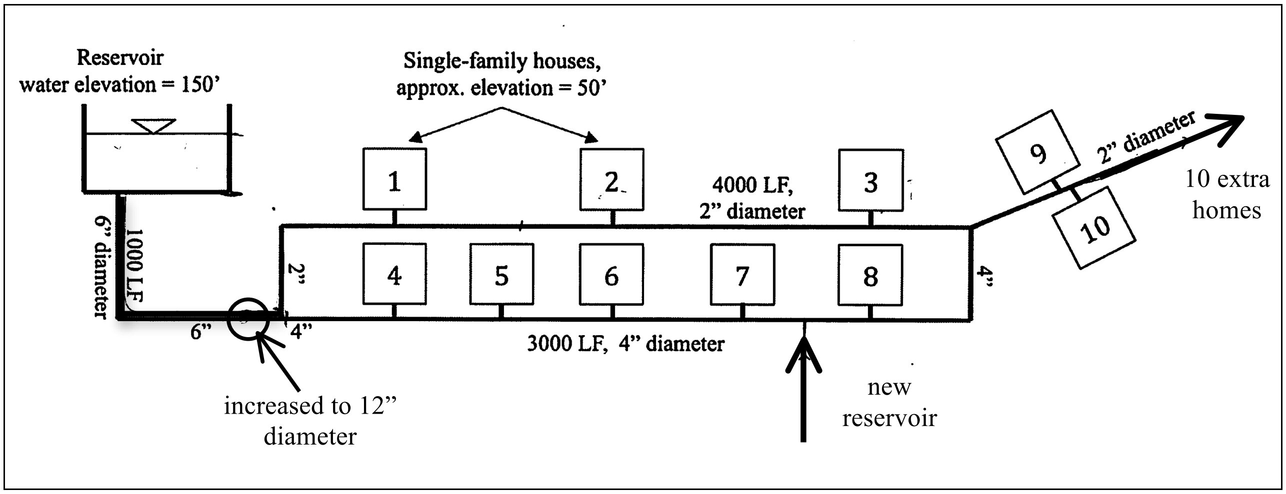


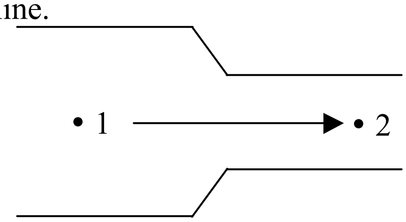
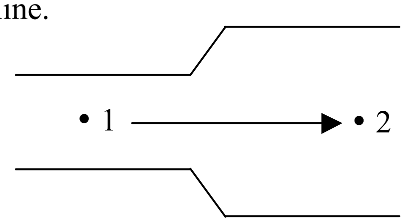
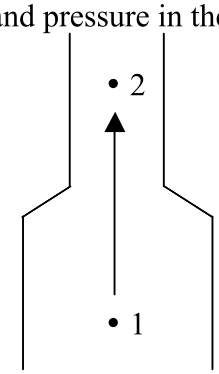
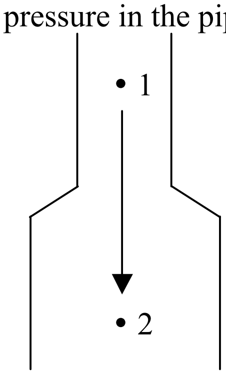
Figure 1: Pressurized pipe system diagram

Table 2: Pressurized pipe system interview questions

• What do you think the source of pressure is in the system?
• Where is pressure greatest?
• Where is velocity greatest?
• Where is energy greatest?
• How would you increase pressure near house 1?
• How would you increase velocity near house 1?
• How might the system change if an extra reservoir is added near house 7?
• How might the system change if 10 new homes were added after house 9 and 10?
• How might the system change if the entire 6" pipe was replaced with a 12" pipe?

Participants from all three cohorts were interviewed using the same three questions (cohort 1 had two additional questions) from the FMCI, which were chosen to help provide insight into participants' understanding of the relationship between pipe diameter, pipe orientation, velocity, and pressure. The original interview protocol used for cohort 1 consisted of twenty questions, only five of which were relevant for this study. For cohorts 2 and 3, three out of five FMCI questions in their interview protocol were relevant. Summaries of these questions can be seen in Table 3 and the original questions are in Appendix A. The interviews were implemented in a semi-structured, clinical format [28-31], similar to the previous interview protocol. Participants were given each problem and approximately two minutes to determine the correct answer. Afterwards participants explained why they selected their answer, during which the interviewer asked probing questions to elicit a complete response from the participant that demonstrated their understanding of the material. Some participants wrote on the handouts of the questions when explaining their reasoning.

Table 3: Questions from the FMCI

<table>
<tr>
<td>Question # 1
Water is flowing in a section of horizontal pipeline in which the pipe diameter decreases. Students were asked about what happened to the velocity and pressure in the pipeline.

</td>
<td>Question # 2
Water is flowing in a section of horizontal pipeline in which the pipe diameter increases. Students were asked about what happened to the velocity and pressure in the pipeline.

</td>
</tr>
<tr>
<td>Question # 3
Water is flowing in a section of vertical pipeline where the pipe diameter increases. Gravitational effects were not negligible. Students were asked about what happened to the velocity and pressure in the pipeline.

</td>
<td>Question # 4*
Water is flowing in a section of vertical pipeline where the diameter increases. Gravitational effects were not negligible. Students were asked what happened to the velocity and pressure in the pipeline.

</td>
</tr>
<tr>
<td colspan="2">Question # 5 *
Select the correct statement about pressure: (a) it is a body force, (b) it acts normal to a surface, (c) it is a frictional force, (d) it acts parallel to the surface</td>
</tr>
</table>

**Only asked to cohort 1*

3.3 Data Analysis

All interviews were conducted in person, except for five from cohort 3 in their FMCI interview. In these instances phone interviews were conducted, as they were more feasible for the interviewer and the practicing engineers. All interviews were audio recorded and professionally transcribed. The interview transcripts and handouts used in the interviews were analyzed utilizing the qualitative data analysis software Atlas TI [32, 34].

Data analysis began with a quantitative analysis of the FMCI data. This consisted of determining how many participants form each cohort chose the correct answers to each question. The problems were also broken down to determine how many participants from each cohort got the velocity and pressure change portions of the answers correct. The intent of this quantitative analysis was to compare the FMCI results across the cohorts.

The qualitative data analysis process followed the guidelines for thematic analysis outlined by Braun and Clarke [35], which is similar to but more detailed than the outlined by Glesne [32]. Thematic analysis focuses on finding patterns or themes within a data set [32, 35]. Like the grounded theory approach to data analysis, it strives to "generate a plausible – and useful – theory of the phenomena that is grounded in the data" [35, p. 80].

Thematic analysis was utilized in this project over six phases. During the first phase, interview transcripts were read in order to become familiar with the data [35]. This was followed by an initial coding phase where codes, such as 'water condenses' and 'more water in a small pipe area,' were applied to "interesting features" in the transcripts [35, p. 87]. In qualitative data analysis coding refers to categorizing the data [32]. Table 4 shows some data extracts along with the codes they were assigned. These codes are the final codes assigned to the data; the initial codes from the previous readings are not shown. During the third phase of thematic analysis codes were collated "into potential themes" [35, p. 87]. In the fourth phase, the themes were reviewed to determine if they were applicable and relevant to the data extracts (the coded sections of the interview) as well as the entire data set [35]. The fifth phase was a continuous analysis of the themes and an iterative process of naming and defining the themes, and the sixth phase involved creating the report [35]. While these last two phases may not intuitively be a part of data analysis, they imply that researchers should continue thinking about and analyzing the data throughout the writing process to ensure that all ideas and interpretations are allowed the chance to sprout and grow before a report is finalized. It is important for qualitative data analysis to reach saturation, which can be accomplished by continually analyzing the data (as stated in phase five of the thematic analysis) to ensure that no new codes can be created to describe the data [35, 36]. This ensures that "a sufficient theory has emerged from the data" and that no new data "contributes to elaboration of the phenomenon being investigated" [37, p. 286].

Table 4: Examples of coded data extracts

Coded Response	**Code**
Student 107: The source of pressure is the fluid pressure that increases as the diameter of the pipe gets smaller. I would assume, I haven't had much to study. I think I've covered that a little bit in statics, but yeah.	• Pressure source is pipe area
Student 12: I know that when it decreases the diameter that the pressure head will increase so it's not A and it can't be B because those both have the pressure decreasing. And...I would guess that...since it got smaller that the water is going to move faster too.	• Pressure opposite of pipe area • Velocity opposite of pipe area
Student 17: Okay, so I know that Q1 has to equal Q2 because constant flow, and it's pressurized pipe, and then Q equals V times A. So since the area of one is greater than the area of two, that means that the velocity of one has to be lower than the velocity of two, so V1 is less than V2. *Interviewer: Okay great.* *Student: And let's see, then we have our energy equation P1 over gamma, plus Z1, plus V1, squared over 2G is equal to the same on the other side, and so the Z1 and the Z2 are the same because it's a horizontal pipe and V1 is squared. V2 is greater than V1 so it's either B or D, and because the V1 is squared I'm going to say that the pressure- so if this is greater and it's squared then this has to be significantly less. I'm going to say P2 is less than P1.*	• Same flow rate • Same elevation • Q=VA • Energy equation (full+correct)

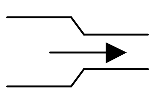
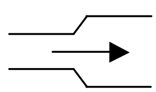
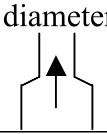
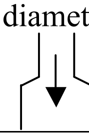
4. Results

Key research findings are: (1) interview results were similar across the participant cohorts and interview protocols, (2) participants used incorrect logic to determine pressure changes, (3) the misconception of water being a compressible fluid in horizontal pipes, and (4) utilizing hydrostatic pressure for pressure changes in vertical pipes.

4.1 Similarity of Interview Results

The three cohorts were relatively consistent in their responses and reasoning to the FMCI questions. The results in Table 5 show a maximum difference between cohorts of 25%. The trend for the percentage of correct responses is inconsistent among the cohorts. Cohort 1 improved on question 2 while the percentage of correct responses from cohort 2 decreased and cohort 3 remained the same. The low percentage of correct responses suggest that many students struggle with flow in pipelines with a changing diameter, even after formal instruction on this concept in a fluid mechanics course.

Table 5: Percentage of participants who correctly answered the FMCI questions

	Question			
Cohort	**1** horizontal, decreasing diameter 	**2** horizontal, increasing diameter 	**3** vertical, decreasing diameter 	**4*** vertical, increasing diameter 
1	40%	50%	45%	45%
2	38%	25%	50%	-
3	33%	33%	56%	-

**Only asked to cohort 1 participants*

Participants from all cohorts often utilized similar approaches and language during both the FMCI and the pressurized pipe system interviews. The majority of the participants who used incorrect logic to determine pressure changes often times used phrases similar to ‘the water squeezes,’ ‘the water compresses,’ and ‘more water goes into a small pipe.’ These intuitive responses contradict the premise that water and other liquids are assumed to be incompressible fluids in the context of the majority of engineering problems [38]. Table 6 displays quotes from participants of each cohort with selected passages of word choice bolded to emphasize the similarity between the cohorts in both the FMCI and pressurized pipe system interviews. Because responses from participants between all the cohorts were comparable the discussion of the results will not have any major distinction between the cohorts.

Table 6: Quotes emphasizing the similarity between cohorts in both the FMCI and pressurized pipe system interviews

Cohort	Interview	Quote
1	FMCI	*Student 1: … with the pressures, because of the sides getting decreased, it's* ***going to squeeze it more that's why the pressure might increase.***
3	FMCI	*Student 213: … You would think that it has to be something like, you think of like as something that smaller,* ***like if you had a balloon and you start trying to push on it and get in that, it's going to increase the pressure.*** *So I guess intuitively, it doesn't make sense, but* ***I guess something constricts. Usually that would like increase pressure****...*
1	FMCI	*Interviewer: Okay. And how come you said that P2 is greater than P1?* *Student 6: Kind of for the same reason, because the contraction, I'm not 100 percent positive about this, but* ***since there's less diameter, or the diameter is smaller, then there's more water flowing through a smaller area, so there's more pressure****.*
2	Pressurized Pipe System	*Student 107: The highest pressure, probably from right here, these two inch pipe or this two inch pipe because it's thinner and* ***there's more water going through it.***
3	Pressurized Pipe System	*Student 204: I feel like that you could* ***increase the pressure by decreasing the size of it so you can fit more water through a smaller area****. So I guess technically you have the same amount of water coming out, but it's coming out faster because it's being constricted, so it's coming out of a smaller area.*
1	FMCI	*Student 8: Okay. Well, if you can't neglect gravity that means V2 is going to be greater. Because the water is going to be speeding up as it falls. Or, is it a pressurized pipe? Yeah, I think it says pressure. Then* ***the pressure on the bottom is going to be greater, it's just a vertical pipe****. So you know that P2 has to be greater than P1…*
2	Pressurized Pipe System	*Interviewer: Okay. All right. So how could you increase the pressure in your house one?* *Student 108:* ***Lowering the elevation of it*** *or getting some sort of pump* ***to increase the water pressure*** *going up that hill, to get it there better.*

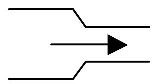
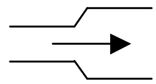
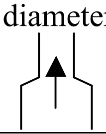
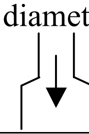
4.2 Logic for Velocity & Pressure Changes

Across all three cohorts, many participants were able to accurately predict how velocity would change in pressurized pipelines. However, they frequently struggled to predict the change in pressure. An example of a single participant using the correct logic for velocity changes and incorrect logic for pressure changes is shown in the following quote. This participant was able to correctly utilize the concept of continuity in pipeline flow, which is shown by his mention of constant flow and the equation relating flow, area, and velocity. To predict the change in pressure, he relied on incorrect, intuitive knowledge.

> *Student 106: Here you have problem where you have-- basically it's a pipe with water flowing through it. You have pressure velocity in one section of the pipe, and then the area decreases to a smaller size. And you have pressure velocity in the second portion of the pipe. And you're asked to find which part of the pipe where pressure's greater, which part of the pipe where velocity is greater basically. So I said that pressure and velocity is greater in the smaller portion of the pipe. Velocity is greater because* ***flow has to be constant****, and so* ***flow is equal to area times velocity.*** *So since they're constant, the area is smaller for section two of the pipe. And then that means that velocity has to be larger to compensate, basically balance out. So that's how I came up with velocity 2's greater than V1. And then for pressure, basically since it's a smaller-- let's see. The way I thought about it is that it's a smaller section but water's still flowing. So pressure's going to have to be greater.* ***Because you have more-- And so it's going to be pushing on the cross section of the pipe more.***
> *Interviewer: Okay. So how do you know that?*
> *Student 106: ...I didn't use a formula for pressure. I just kind of pictured it in my mind how the system would be behaving.*

Table 7 shows that less than half of the participants were able to correctly determine pressure, with an exception of question 3. A large portion of the participants answered the pressure portion of question 3 correctly, but their logic in the interview transcripts was not entirely correct. The wider section of the pipe, where pressure would be larger is also the bottom section of the pipe, where participants think pressure is greatest.

Table 7: Percentage of all participants who correctly got the velocity or pressure component of the FMCI questions correct

	Question			
Component	**1** horizontal, decreasing diameter 	**2** horizontal, increasing diameter 	**3** vertical, decreasing diameter 	**4*** vertical, increasing diameter 
Velocity	95%	84%	76%	38%
Pressure	38%	43%	57%	30%

**Only asked to cohort 1*

4.3 Water is a Compressible Fluid Misconception

To accurately go about solving for pressure changes in pipelines, whether horizontal or vertical, it is necessary for participants to utilize concepts of conservation of mass and energy [38]. The conservation of mass in pipelines with steady flow means that the flow rate along the pipeline is constant [38]. It is used to derive the continuity equation (Equation 1), which describes the volumetric flow rate in pipelines [38]. The conservation of energy means that the total energy in the system is constant, and the energy equation can be written as shown in Equation 2 [38]. Essentially, the energy between two points in a system must balance out. Any energy that is lost is incorporated by the headloss variable. The elevation and pressure components of the energy equation represent the potential energy in the pipeline, and the velocity component represents the kinetic energy.

$$Q_1 = Q_2 \quad or \quad V_1 A_1 = V_2 A_2 \qquad \text{(Equation 1)}$$

Where, Q: volumetric flow rate (ft^3/s)
V: fluid velocity (ft/s)
A: pipe cross-sectional area (ft^2)

$$Z_1 + \frac{P_1}{\gamma} + \frac{V_1^2}{2g} = Z_2 + \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + h_L \qquad (Equation\ 2)$$

Where, Z: elevation (ft)
P: pressure (lb/ft^2)
γ: specific weight (lb/ft^3)
V: velocity (ft/s)
g: gravity (ft/s^2)
h_L: headloss (ft)

The general solutions to selected interview problems are shown in Appendix B. Table B-1 shows the solution to determining the pressure change in the pipeline for question 1 of the FMCI interview where water flows through a contraction in a horizontal pipeline.

In problems with horizontal pipelines, participants commonly expressed a belief that when water travels from a larger to smaller pipe the pressure increases due to more water being 'squeezed' or 'compressed' in the smaller pipe section. This theme of water being a compressible fluid and the codes that support it are shown in Figure 2.

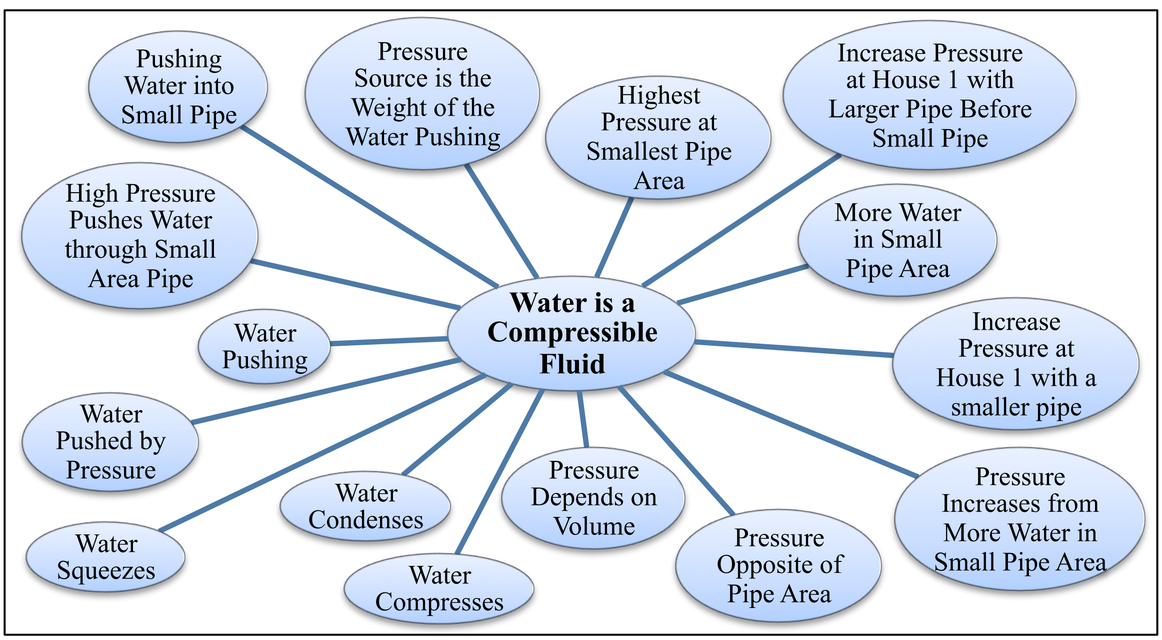


Figure 2: Concept map showing the theme of water being a compressible fluid and the codes that pertain to it

The following quote is a participant's explanation of the pressure change in the third FMCI question, where water flows upward through a contraction. This section of the interview was coded with 'water squeezes.' This response expresses the participant's belief that in the smaller section of pipeline the water will be squeezed, which in turn causes the pressure in this section to increase.

> *Student 1: ... with the pressures, because of the sides getting decreased, it's* ***going to squeeze it more that's why the pressure might increase.***

One of the more common codes was 'more water in small pipe area.' The following quote, in response to the first FMCI question, where water flows through a contraction. The participant states that when water flows into a smaller pipe section, which causes the pressure to increase.

> *Student 216: I said that the pressure and velocity will be greater in the smaller tube than the bigger tube.*
> *Interviewer: Okay. Why is that?*
> *Student 216: Because* ***when it bottlenecks it has less area for the water****. So the pressure will go up. And then it causes the velocity to go faster if it's steady flow.*
> *Interviewer: And why would the pressure go up?*
> *Student 216: Because if they're trying to press the volume, basically, the flow here needs to stay the same here in a smaller area. So with the velocity increasing the pressure* ***So more water has to go in that small area or go through it.***

A participant's response to being asked where pressure is highest in the pressurized pipe system interview was coded as both 'more water in small pipe area' and as 'water condenses.' This quote indicates that more water is able to fit into the smaller pipes because the water must be compressed when it reaches contractions in the pipeline. The pressure in the smaller pipelines increases because, when compared the larger pipeline sections, there is more water.

> *Student 107: The highest pressure, probably from right here, these two inch pipe or this two inch pipe* ***because it's thinner and there's more water going through it****. ...*
> *Interviewer: Okay. And why would it be there?*
> *Student 107: My reasoning is because, actually, because it's going from all this water has to be pumped from six inches or six inch diameter pipe to four inch diameter pipe*

*and then to a two inch diameter pipe. So all the pressure is being**-- all the water's being compressed when it gets to these changes in diameter**, so it has to-- so it experiences more pressure as it goes through the pipe.*

The previous quotations express the theme that as water conforms to the size of the pipeline the volume of water will change, or that water is a compressible fluid. This misconception led the participants to believe that pressure would increase in smaller pipe sections.

The set of codes previously described were placed into a 'compressible fluid' code group. A second code group relating to velocity, which was frequently determined utilizing the concept of continuity, was also created. Codes belonging to this 'continuity' code group are shown in Figure 3.

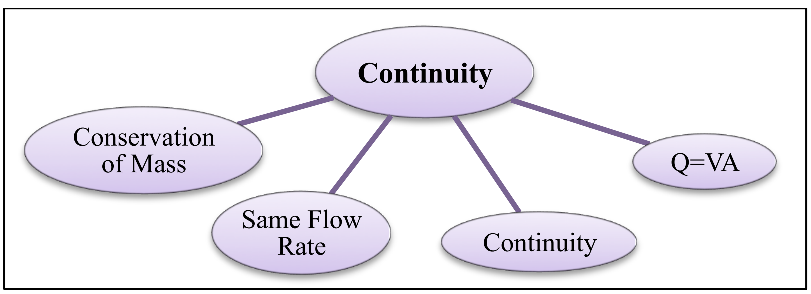


Figure 3: Concept map for the theme of continuity and the related codes

Equation 3 was commonly referred to as the continuity equation by many of the participants and was one of the ways in which participants frequently predicted velocity changes in the pipeline. It is a simple relationship between velocity and pipe cross-sectional area. When participants utilized Equation 3 and stated that the flow rate was same throughout the pipeline it becomes the more appropriate version of the continuity equation that is shown in Equation 1.

$$Q = VA \qquad \text{(Equation 3)}$$

Where,
Q: volumetric flow rate (ft^3/s)
V: fluid velocity (ft/s)
A: pipe cross-sectional area (ft^2)

Participants who had not taken fluid mechanics did not use the continuity equation, however, these same participants used it after they took fluid mechanics. Because it may not be a part of intuitive knowledge about pipeline flow and because it is presented in fluid mechanics courses as a part of the concept of continuity [38] it is included in this theme of 'continuity.' Furthermore, in order to derive the continuity equation an assumption of the fluid being incompressible must be made [38]. This conflicts with how participants described water in the pipeline for determining pressure changes.

Table 8 shows the percentage of participants who made comments belonging to the 'compressible fluid' and 'continuity' code groups. The decrease in 'compressible fluid' codes in the second FMCI question is likely due to the fact that not all participants stated that they would repeat the same process they used in the first FMCI question. In this case, because it was not explicitly known what the student was thinking, there are fewer 'compressible fluid' codes for the repeat question.

Table 8: Percentage of participants who made comments that indicate a belief that water is a compressible fluid or comments related to continuity

	Fluid Mechanics Experience		
Code Group	**Pre-Instruction**	**Post-Instruction**	**Degree Conferred**
All Interviews			
Compressible Fluid	50%	43%	33%
Continuity	13%	68%	78%
Pressurized Pipe System			
Compressible Fluid	50%	11%	-
Continuity	13%	56%	-
FMCI, Question 1			
Compressible Fluid	-	46%	33%
Continuity	-	57%	67%
FMCI Question 2			
Compressible Fluid	-	29%	0%
Continuity	-	57%	67%

The data indicates that the misconception of water being a compressible fluid is likely robust because students who completed fluid mechanics and completed their undergraduate education in civil engineering continued to make comments that indicate this belief.

4.4 Hydrostatic Pressure Misconception

Pressure changes in vertical pipelines with contractions or expansions are due to a combination of changes in potential energy caused by changes in elevation and changes in kinetic energy caused by changes in velocity. Participants often only focused on the elevation changes in the pipeline to predict how pressure would change and did not incorporate kinetic energy changes.

As mentioned earlier, the concepts of conservation of mass and energy are both needed to predict pressure changes in pipelines. The general solution to solving question 3 of the FMCI interview, where water flows upwards through a contraction in a vertical pipe, as well as a brief solution to determining where pressure is greatest in the pressurized pipe system are shown in Table B-2 and B-3 in Appendix B.

In an ideal vertical pipeline with a constant diameter there would be no change in kinetic energy or potential energy. However, potential energy would be redistributed between the elevation and pressure components in the energy equation. This contrasts with an ideal horizontal pipe with a uniform diameter as pressure, elevation, and velocity would be equal throughout the entire pipeline.

Participants often times did not utilize the concept of conservation of energy in the vertical pipelines. Instead, participants often times focused only on hydrostatic pressure. Figure 4 shows the codes that represent this theme.

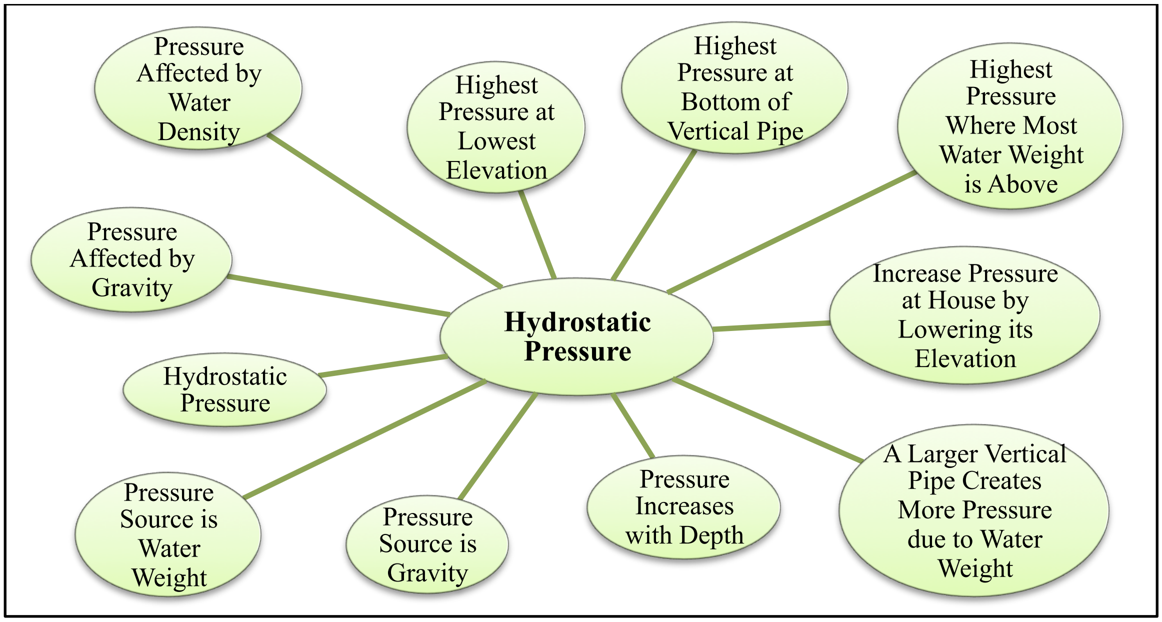


Figure 4: Concept map for the theme of hydrostatic pressure and the codes that codes that pertain to it

The following quotes were made in response to the third and fourth FMCI questions. In the third FMCI question water flows upwards through a contraction and in the fourth it flows downwards through an expansion. In both questions the participant stated that pressure would be greater in the bottom section of the pipelines due to hydrostatic pressure, which was the code assigned to both statements.

> *Student 20: Okay. So Q=VA. Area decreases, velocity increases, so V2 is greater than V1. So I'm going to cross out C and cross out E because they say V2 is less than V1. Then, for the pressure difference, I'm going to go with P1 is greater because of gravitational so-- or* ***hydrostatic pressure*** *and that would be B.*

> *Student 20: Okay. So, again, Q=VA. Area increased, velocity decreased so V2 is less than V1, process of elimination, cross out A, B and D. Then I'm going to go with C as my answer* ***because of the buildup hydrostatic pressure****….*

A participant's response to the fourth FMCI question, where water flows downwards through a pipe expansion, was coded with 'pressure affected by water density,' 'pressure affected by gravity,' and 'pressure increases with depth.' While this participant mentions static and pressure head he does not elaborate on what each of these mean or represent. However, at the end of this quotation he succinctly states that in addition to depth, pressure is affected by other variables: gravity and water density. Depth is the only variable that will change throughout the vertical pipeline.

> *Student 9: Okay. So obviously P2 is going to be greater than P1.*
> *Interviewer: Okay, and why?*
> *Student 9: Gravity, you have the static head and then the pressure head above it. I should write that out. So say there's a point there, you'd have the static head and the pressure head. ... So I'm going to say P2 is bigger and V1 is bigger. V1 is bigger because of the smaller cross-sectional area.* ***P2 being bigger because of the gravitational effects and the pressure head due to the depth and density of the water****...*

An example of the code 'highest pressure where most water weight is above' is exemplified by a participant's response to being asked how the system would change if the 6-inch diameter pipe was replaced with a 12-inch diameter pipe in the pressurized pipe system interview. This quotation expresses the relationship between pressure and the weight of the water that exists in the participant's mind. Expanding on this participant's explanation, pressure would also increase due to depth since more water, and therefore more mass and more weight, will exist above a specific point in the pipeline.

> *Interviewer: How would they system change if the six inch pipe…were changed to 12 inches?*
> *Student 101:* ***Pressure will increase because there's more mass and water weighs a lot*** *so there's more mass coming out of this pipe so there's a lot of mass coming down, and so there's more pressure, yeah. Pressure will increase…obliviously on this system.*

The following quote was made in response to a question in the pressurized pipe system interview about the location of the highest pressure. It was coded with 'pressure increases with depth.' This type of response and code was the most frequently used for problems relating to vertical pipelines. The quotation expresses the belief that pressure is directly related to depth: when depth increases the pressure will increase.

> *Interviewer: What about pressure? Where do you think the pressure would be the highest?*

Student 208: ***The highest pressure is going to be down at these houses as opposed to up here because pressure increases as you go down in elevation.***

It should be noted that while the concept of pressure being dependent on depth is in fact a true statement, it is concerning that participants did not look at the overall energy in the pipeline system to predict changes in pressure. If contractions or expansions in the FMCI interview questions are assumed to be sudden, then changes in velocity will have more of an effect on the pressure change than changes in elevation. In the pressurized pipe system interview where there is a larger pipeline system, elevation will have a significant effect on pressure. The contractions in the pipeline at the lower elevation will also impact where the highest pressure will exist in the system (see Table B-3 in Appendix B).

The elevation component of the energy equation (Equation 2) "represent[s] the change in pressure possible due to potential energy variations of the fluid as a result of elevation changes" and can be referred to as the hydrostatic component [38, p. 75]. Participants are technically correct to relate pressure to depth. However, based on how infrequently participants utilized conservation of energy in their interviews to determine changes in pressure, it is likely that they were not considering the overall energy in the system. Rather they just focused on the simple relation of pressure and depth. This simple relation is also seen in the equation for hydrostatic pressure for fluids at rest (Equation 4). It describes the pressure caused by the weight of static, non-moving fluid above a specific point [38]. Participants mentioned pressure being affected by depth and gravity more than all three of the variables of hydrostatic pressure in Equation 4.

$$P = \rho g h \qquad \text{(Equation 4)}$$

Where,
P: pressure (lb/ft^2)
ρ: density of the fluid (lb/ft^3)
g: gravity (ft/s^2)
h: height of water above a point (ft)

Participants who explained their logic for pressure changes more in depth stated that pressure is a function of water density, gravity, and depth, or the weight of the water, which are all variables in Equation 4. It is likely that participants who did not provide as detailed of an explanation also relied on this equation as the fluid density and gravity are constant in most situations [38] and depth is the only changing variable.

The percentage of participants who made comments about vertical pipes from a hydrostatic pressure point of view is shown in Table 9. It was more common for participants who had not taken fluid mechanics to make comments relating to hydrostatic pressure than it was for participants who had graduated with a civil engineering degree. However, there was significant amount of participants who had completed fluid mechanics, but not graduated, who also made these types of comments. This indicates that even after completing fluid mechanics students still struggle to accurately apply their knowledge to fluid mechanics problems.

Table 9: Percentage of participants who made comments related to hydrostatic pressure

	Fluid Mechanics Experience		
Interview	**Pre-Instruction**	**Post-Instruction**	**Degree Conferred**
All Interviews	63%	43%	33%
Pressurized Pipe System	63%	22%	-
FMCI Question 3 & 4*	-	50%	33%

**Only asked to cohort 1*

5. Discussion

The ontological shift and framework theory approaches to conceptual change, as mentioned in the literature review, represent the views of two prominent and highly cited conceptual change researchers in recent literature: Chi and Vosniadou. To review, Chi believes that to correct robust misconceptions a concept must shift from the incorrect ontological category to the correct one. Vosniadou's modified cognitive perspective approach to conceptual change, the framework theory, incorporates the effects of culture and context on an individual's knowledge.

The following sections will outline the approaches to conceptual change that have been proposed by Chi and Vosniadou along with an example of applying each of their approaches, as well as discussing how the data fits the theories.

5.1 Chi's Ontological Category Shift Approach

Ontological categories are the "basic categories of realities or the kinds existent in the world, such as concrete objects, events, and abstractions" [13, p. 163]. Essentially, they are the categories an individual uses to organize and make sense of the world around them. Chi has developed three primary ontological categories (*matter*, *processes*, and *abstractions*), but recognizes that other ontological categories may exist [21, 23]. In Chi's ontological category approach to conceptual change, misconceptions exist because concepts "have been laterally or ontologically miscategorized," or that the correct and incorrect ontological categories "conflict by definition of a kind and/or ontology" [15, p. 72]. Using this theory, conceptual change requires that students become aware of their miscategorization of a particular concept [16].

The ontological category approach to conceptual change has been applied to the concept of electric current. Students often classify "electric current as a material substance" that would flow from one point to another in a wire [12, p. 377]. The more ontologically correct way of approaching electric current is as a "process of interaction, constrained by the potential difference between two points in a circuit" [12, p. 377]. In this case, the constraint is a type of process in which a system must adhere to the interactions of two or more variables that are governed by specific principles (e.g. Newton's second law) [12]. Students who operate in the ontological category of *material substance* rather than the category of *processes* will find it difficult to learn future concepts relating to electricity because the way in which they think is "incompatible with subsequent information about the concept" [12, p. 377].

Utilizing this conceptual change theory, participants who had issues accurately determining the pressure in pipeline flow used phrases that implied they were thinking about the problems from the ontological category of matter, or *physical substance*. Participants who provided a detailed explanation frequently used phrases such as 'water condenses,' 'water compresses,' 'water squeezes,' and 'more water in the small pipe' (see Table 10).

Table 10: Quotes indicating participants operate in the ontological category of physical substances in horizontal pipes

Student 1: … with the pressures, because of the sides getting decreased, it's ***going to squeeze it more that's why the pressure might increase.***
Student 5: So, that's pressure-- it makes sense that it would increase too, but I don't think that's right ***just because you're condensing it****, but I thought they stayed the same, but that's not a choice. So, I'll just go that it will increase.*
Interviewer: Okay. And how come you said that P2 is greater than P1? *Student 6: …because the contraction, I'm not 100 percent positive about this, but* ***since there's less diameter, or the diameter is smaller, then there's more water flowing through a smaller area, so there's more pressure.***
Student 204: … I feel like that you could ***increase the pressure by decreasing the size of it so you can fit more water through a smaller area****. So I guess technically you have the same amount of water coming out, but it's coming out faster because it's being constricted, so it's coming out of a smaller area. So I guess that's what they'd be asking, I think.*
Interviewer: Okay. Where would you expect the highest pressure in the system? *Student 107:* ***The highest pressure, probably from right here, these two-inch pipes or this two-inch pipe because it's thinner and there's more water going through it****…So all the pressure is being--* ***all the water's being compressed when it gets to these changes in diameter, so it has to-- so it experiences more pressure as it goes through the pipe.*** *That's my reasoning, I guess.*

Changes in velocity and pressure in pressurized pipeline flow should fall into the ontological category of *processes*. Attributes of this category include being abstract, invisible, non-tactile, and continuous. They may further be classified as emergent, non-linear, or *multi-variable problems*. An emergent process can be briefly described as a process in which the observed pattern is not directly caused by a single agent, but rather by the interaction of many agents [13]. In looking at the energy equation an observed pattern is the change in pressure in a pipeline, and the agents are the pressure, velocity, and elevation heads. Pressure simply doesn't change due to one specific variable, such as a change in pipe diameter; instead it changes due to the interaction of the changes in velocity and elevation, which occur simultaneously.

The act of *solving* problems with pressurized pipeline flow, however, is a semi-emergent process as there is a rough outline of steps to follow to accurately solve the problems. To easily and accurately solve the pressurized pipeline problems presented in the interviews one would first need to utilize the continuity equation (Equation 1), which is based on the conservation of mass, to determine how velocity will change between two points in the system. Next the energy equation (Equation 2), based on the conservation of energy, which primarily consists of elevation, velocity, and pressure head components, must be balanced (elevation head can be easily inferred from the diagrams included with the interview questions and can be seen as equal in the horizontal pipe problems, or approximately equal in the vertical pipe problems if the change in diameter is sudden).

Many participants discussed changes in pressure in terms of a *single variable problem*. The phrases "because the pipe area increase/decreases, the velocity will decrease/increase" and "because the pipe area increases/decreases, the pressure in the pipe will decrease/increase" were common ways in which participants initially explained the reasoning for their answers (see Table 11). Even when probed for further explanation some students did not provide a more in-depth response, and often times those that did had misconceptions. Since the participants provided limited explanations, they likely did not understand what was happening in the system.

In the vertical pipe problems, the *single variable problem* attribute can be seen in the participants' simple explanations that pressure increases with depth. This idea is related to the concept of hydrostatic pressure, which is the notion that for, fluids at rest, pressure "increase[s]

Table 11: Quotes exemplifying single variable explanations

Pressure & Pipe Area Relations
Student 4: …and the pressure is because the flow rate's the same. ***It's a small area so the pressure has to go up.***
Student 8: A constant flow. Yeah. So since it has a constriction on it, or a contraction on it, I would say that the pressure would have to increase from here, or decrease. No. ***The pressure would increase as the constriction got smaller****. So the velocity would have to decrease. So P2 is greater than P1. And V2 is less than V1, I would say C.* *Interviewer: Okay. So P2 is greater than P1. So why is the pressure getting larger?* *Student 8:* ***Because it's got a smaller area.***
Interviewer: …So where would you expect the highest pressure in the system? *Student 106: I should know this. I'm trying to remember that equation that we learned in physics. I think the* ***highest pressure would be the smallest diameter.***
Pressure & Velocity Relationship
Student 4: Going off what I said for the first one, it would be the opposite. P2 is less than P1 and V2 is less than V1. *Interviewer: How did you arrive at that?* *Student 4: They have the same flow rate and so the area's going to be small for the first and moderate for the second and so because the area increases, velocity has to decrease for the same flow to go through.* ***Then because there's a lower flow rate there's gonna be less pressure.***
Student 106: …And then for pressure, basically since it's a smaller-- let's see. The way I thought about it is that it's a smaller section but water's still flowing. ***So pressure's going to have to be greater. Because you have more-- because velocity's greater****. And so it's going to be pushing on the cross section of the pipe more.*
Student 227: Yeah. And then the pressure, I just-- I don't know. ***I guess that's a concept that's stuck in my head, as velocity goes up, the pressure goes down.***

with depth to 'hold up' the fluid above it" [38, p. 33]. The elevation component of the energy equation (Equation 2) also expresses this idea of hydrostatic pressure, but in terms of energy. The simple relation of pressure and depth was the most frequent way in which participants solved for pressure changes in vertical pipelines (see Table 12). It is inappropriate for participants to rely only on hydrostatic pressure to determine pressure changes and ignore any effects of velocity changes. Hydrostatic pressure effects in vertical pipelines would be significant only in large sections of vertical pipes. However, it has less of an effect when the change in elevation is minimal, as with the sudden expansions or contractions in the FMCI interview questions. To properly understand horizontal and vertical pipeline flow participants must shift their way of thinking from the *physical substance* with single variable problems category to the *process* category with multi variable problems.

Table 12: Quotes indicating a hydrostatic pressure frame of mind when solving vertical pipe problems

Pressure & Depth Relationship
Student 11: … I'm going to say that the pressure at 1 is less than the pressure at 2. Because if it's standing up like this, ***I'm thinking of a pool, so the pressure at the top will be less than the pressure at the bottom.***
Interviewer: Okay. All right. So how could you increase the pressure in your house one? *Student 108:* ***Lowering the elevation of it*** *or getting some sort of pump* ***to increase the water pressure*** *going up that hill, to get it there better.*
Student 208: ***The highest pressure is going to be down at these houses as opposed to up here because pressure increases as you go down in elevation****. So, since these are at 50 feet and that's at 150 feet, you could set up- there's the- what's that thing called? Bernoulli's equation, is that what I'm thinking of? No. The one that has, like, it's, like, P over delta plus you have, like, your velocity head and you have your elevation head equals that and* ***you could actually solve the two pressures but it's going to be the highest at the lower elevation down here.***
Hydrostatic Pressure
Student 19: Okay, don't neglect gravity, okay. <Pause> Boy. <Pause> ***I don't think I've ever done something like this*** *but my guess would be,* ***pressure would be increasing as it goes down, just due to depth****, possibly and velocity would be increasing due to the added force of gravity.* *Interviewer: Okay.* *Student 19: So that would be, if that's even an answer, P2 is greater and V2 is greater so I guess B. B2 I guess.* *Interviewer: Okay and how are you relating pressure and depth?* *Student 19:* ***Pressure and depth would be, that would be gamma HG I believe****. No, wait. Oh boy.* *Interviewer: Okay so that makes sense. You're using that equation on pressure equals.* *…* *Student 19: Yeah, this is a closed or it's a closed channel flow. So hmm <Pause> This one's kind of tough.* ***I don't know if I've really studied this situation before or remember studying it I guess.***
Student 20: Okay. So, again, Q=VA. Area increased, velocity decreased so V2 is less than V1, process of elimination, cross out A, B and D. Then I'm going to go with C as my answer ***because of the buildup hydrostatic pressure****, however I don't know if that's correct because of the-- it's already a pressurized pipe so...*
Student 101: Oh, okay. ***Pressure will increase because there's more mass and water weighs a lot so there's more mass coming out this pipe so there's a lot of mass coming down, and so there's more pressure****, yeah. Pressure will increase <inaudible> obviously on this system.*
Student 212: Mostly, but also, it-- … But even if the gravity were to be taken into account-- because, yeah, I'm saying ***P2 is less than P1-- if we were to look at it as just a column of water that was sitting there like that, and look at the water pressure at point two and point one, point one has more-- has a higher column water, a taller column of water, resting on it, so it has a greater pressure in a static condition****--*

The ontological category of *physical substance* holds concepts that have attributes such as being concrete, tactile, tangible, and visible. Conceptions that fall into this ontological category are more likely to be intuitive to individuals as they can typically receive some sort of physical feedback through touch or sight. One can see or feel water flow faster after a constriction in a channel. Fluid pressure can be experienced with balloons; however, one cannot experience the pressure changes in pipelines. This helps explain why students operate in a *physical substance* ontological category. To achieve conceptual change a shift from the ontological category of *physical substance* to *process* is necessary (see Figure 5).

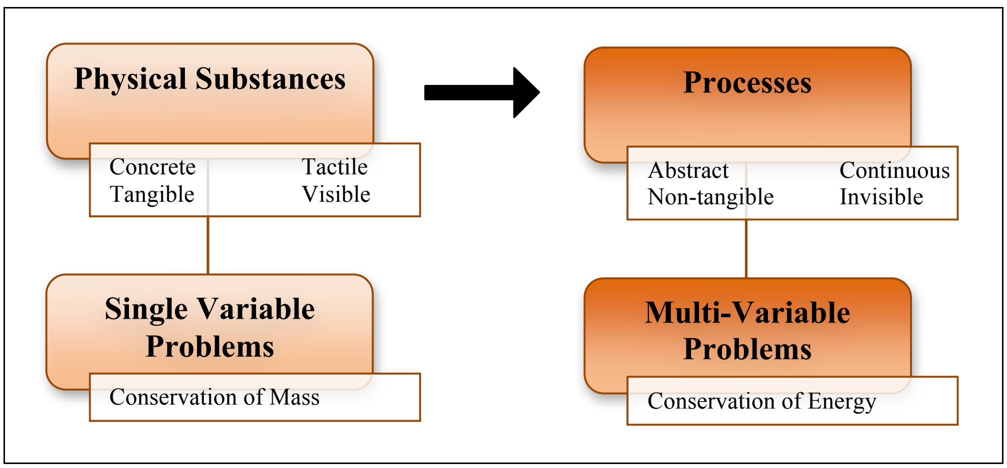


Figure 5: The shift in ontological categories necessary for conceptual change

Even though the participants' thinking about horizontal and vertical pipes are both from a *physical substance* category, one big issue in using Chi's approach is that her theory cannot fully account for the differences in the participants understanding of horizontal and vertical pipelines. To reiterate, the cognitive perspective approach to conceptual change focuses on the transferability of concepts to different concepts [19]. Since horizontal and vertical pipelines are conceptually similar in that they both require the concepts of conservation of mass and energy participants should approach both problems in a similar manner. Another downside is that the ontological categories Chi has chosen, such as *processes*, seem random [10]. The actual hierarchy of concepts within an ontological category as well as the categories themselves may be different than what was suggested in this paper. The hierarchy of concepts and categories utilized may impact how misconceptions must be addressed in order for students to form the correct conceptions. It is possible that instead of shifting from one broad ontological category to another, a shift from a more specific category is necessary.

While Chi would argue that the participants are operating from a *physical substance* category Vosniadou, on the other hand, would say that the context, or the images from the problems and what they represent, may be more important.

5.2 Applying Vosniadou's Framework Theory Approach

In Vosniadou's framework theory, concepts are constrained within a framework that includes the epistemological and ontological presuppositions of individuals [10]. Epistemology refers to the beliefs that people have about knowledge and knowing [7]. Within the framework theory there exist various 'specific theories' that are created based on the everyday observations individuals make about the world around them, and contribute to the "beliefs that describe the properties and behavior of physical objects" [10, p. 47]. Misconceptions form when individuals attempt "to reconcile the inconsistent pieces of information and produce a synthetic mental model" that is scientifically incorrect, but helps them rationalize their beliefs [10, p. 50]. Mental models are a combination of the framework and specific theory that individuals use to "provide causal explanations of the physical phenomena and make predictions about the" world [10, p. 48]. An example would be children believing the earth is a semi-hollow sphere [10, 25]. In this synthetic mental model children rationalize the experience of a flat earth that they witness everyday with the notion of the earth being a sphere and create a semi-hollow sphere with flat ground inside a sphere.

Conceptual change is achieved by correcting the presuppositions and beliefs that exist in a framework theory [18]. The learning of science conceptions is often more difficult to achieve as it is frequently requires shifts in ontological categories [24]. According to Vosniadou, conceptual change can occur through the enrichment of existing knowledge or through the revision of previously acquired information [10]. The former is "the simplest form of conceptual change" while the latter is more complex [10, p. 48].

Research on framework and specific theories has been applied to heat transfer. An example of everyday observations people would make are that "some objects feel hot, others feel warm…when you touch them" and that "you become cold when you touch a cold object" [10, p. 62]. These observations lead to the beliefs that students held, such as "hotness and coldness are two distinct properties of objects" and "hotness and coldness can transfer to other objects by direct contact" [10, p. 62]. These observations and beliefs contribute to a specific theory about heat transfer. The framework theory includes an ontological presupposition that "hotness and coldness are properties of objects" and an epistemological presupposition that "things are as they appear to be" [10, p. 62]. Figure 6 shows an example based on Vosniadou's work on heat [10]. In this example students have utilized their observations of heat transfer to form beliefs and presuppositions that will negatively impact how they learn future concepts relating to heat.

Vosniadou's framework theory can better explain the shift in participants' conceptual understanding of pressure between horizontal and vertical pipelines. A few participants expressed that they had never seen or do no remember working with vertical pressurized pipelines, despite working with horizontal pipes within the same interview. Others mentioned that gravity not being negligible in the problem statement also made it difficult for them solve the FMCI problems. Examples of these issues that participants had with vertical problems are

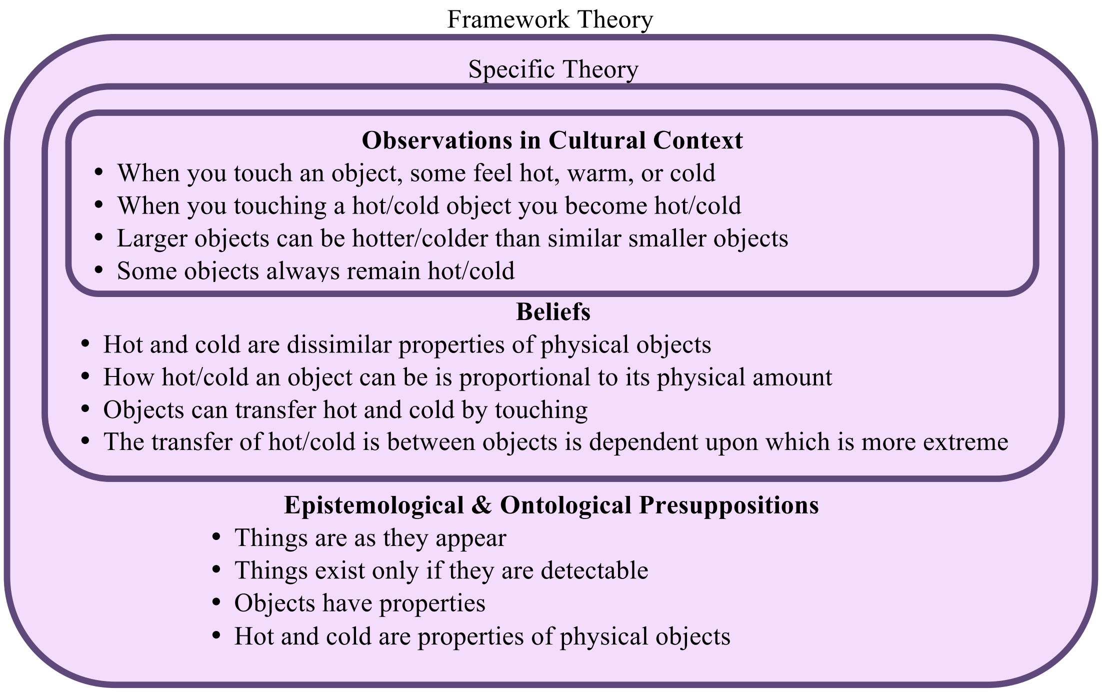


Figure 6: Observations, beliefs, and epistemological and ontological presuppositions for heat transfer

shown in Table 13. In addition to how students approach pressure changes, a portion of participants also changed how they approached solving for velocity. To include the gravitation affects in vertical pipe problems on the FMCI some students began to express a belief that water flowing upward would slow down or go faster if flowing downward (see Table 14). These indicate that the context in which a problem is presented can heavily influence students' conceptual understanding of pipelines. Even though the problems are conceptually the same and are solved using the same process students changed how they thought about the problems.

The suggested observations, beliefs, and epistemological and ontological presuppositions of the participants are shown in Figure 7. A number of participants referenced balloons and pools (or ponds/lakes) when asked about pressure (see Table 15), which indicates that balloons and pools are activated concepts when students think about pressure. Both of these are situations where pressure is easily observable. A third situation, not thought of by the participants due to the nature of the interview question, is a free jet. As the orifice on a free jet gets smaller one will

Table 13: Quotes emphasizing the importance of context in pipeline problems

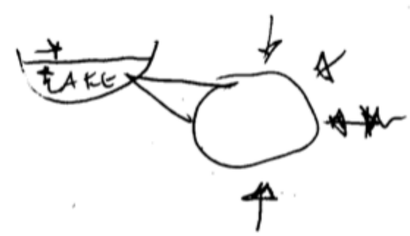
Student 6: I don't really-- **I don't think I've ever like had a problem with this before, or like I've never been introduced to this before as far as the pipe being vertical**, and the flow going downward
Student 19: Yeah, this is a closed or it's a closed channel flow. So hmm <Pause> This one's kind of tough. **I don't know if I've really studied this situation before or remember studying it I guess.**
Student 103: I just got to thinking, maybe I should have asked on the other ones too, but I don't know what's happening out here. **So I'm thinking if this is a free surface or something like that--** Interviewer: You can assume that the pipes continue. Student 103: Continue? Okay. That's kind of different then. I don't know. Just forever?
Student 206: Viscosity and friction are negligible. **The whole gravitational part is throwing me off now.** Interviewer: If the gravitational effects were negligible, how do you think you would answer? Student 206: I don't even know; my brain's all over the place I'm trying to pull back in my head how this even operates.

Table 14: Quotes exemplifying a change in the participants' conceptual understanding of velocity in vertical pipelines

Student 7: Okay… So **velocity would increase due to the gravity**, so I think that p1 would still be greater than p2, so p2 is less than p1 and then velocity 2 is greater than velocity 1. … Interviewer: Okay. And so then did the gravity come into effect in that question? Student 7: Yeah. I would think that the change in velocity over the change in time would be acceleration which is gravity, so it would increase.
Student 11: I'm going to assume that because it's going down...**because if it's accelerating with the rate of gravity then...I'm going to say V2 is greater.**
Student 108: Yeah, I'm not sure. Mostly on the velocity one is the one that's throwing me off, … But **the velocity since it's fighting against gravity-- I'm not sure because I feel like gravity would have an effect**, but I don't like.. I'm not sure if this one's big enough that gravity would slow it down, slower than this or like what the difference is. There's no numbers so I'm not sure how gravity would effect it. I mean if this is huge gravity would have enough effect to like slow it down, but if it was really small then gravity might not be as big a deal. So on the velocity it would still be greater. So I'm not really sure on that one, but I think that V2 would be less than-- hmm. I don't know. I'm really split. Interviewer: Okay. So why would the effects of gravity vary, depending on how high the velocity was? Student 108: Well if it was.. if it was like-- I guess-- I feel-- I don't know. I was more just thinking like about like if this was like a huge opening, there would be-- gravity would have a lot more effect on it rather than if this is like an inch or something in diameter, really small.

notice that the water will come out quicker, like with a garden hose. With a free jet the fluid pressure at the orifice is negligible; however, one might place their hand in the pathway of the water and feel the force of the water stream. Free jets do not expose individuals to pressure in the way they need to understand pipeline flow, but it is one of the few situations where an individual can receive direct physical feedback about water properties.

Table 15: Ideas activated when participants were questioned about pressure*

Balloons
Interviewer: Why did you say that pressure acts normal to the surface? *Student 6: Well, I read pressure acts parallel to the surface, and that just doesn't really make sense to me. Because when I think about pressure I think about like say a balloon, the pressure's going to act on perpendicular to the walls rather than parallel to the walls. So those two answers, whether it's parallel or normal, stuck out more to me than answers A or C did. So since they're contracting I figured maybe it has to be one of those, and the fact that pressure acts normal made more sense to me conceptually.* *Interviewer: Can you draw a little picture of the balloon you were talking about?* 
Free-Surface Water (Pools)
Student 15: So pressure is a body force, which I kind of, I'm going to guess what that means later. Pressure acts normal to the surface, so normal to the surface, just kind of like pointing up, like let's say I'm thinking of like a lake right now, so that's kind of... *Interviewer: You can draw a picture if it would help.* *Student 15: Lake. And so pressure acting normal to the surface so it would just kind of like be up and then acting parallel to the surface, which is like that, but if you take like a little particle inside the lake, you have pressure acting parallel and pressure acting normal, because it's acting from all sides.* 

**Responses are only from cohort 1*

The participants' responses indicate a belief that water is squeezable or compressible, based on the frequent comments about water squeezing, condensing, and pressure being inversely related to pipe area (see Table 11). They also hold a belief for vertical pipes that pressure is directly related to depth, or that it is a hydrostatic pressure (see Tables 12). Based on the observations and these expressed beliefs of the participants in the specific theory a framework theory can be proposed. An epistemological presupposition would be that things are as they appear to be in comparable situations. And an ontological presupposition might be that balloons, free jets, pressurized pipeline flow and pools are all comparable situations. The fact that gases and liquids are both fluids might also lead to an ontological presupposition that liquids have the same properties as gases. Or in other words, that water would be squeezable or compressible, like air in balloons.

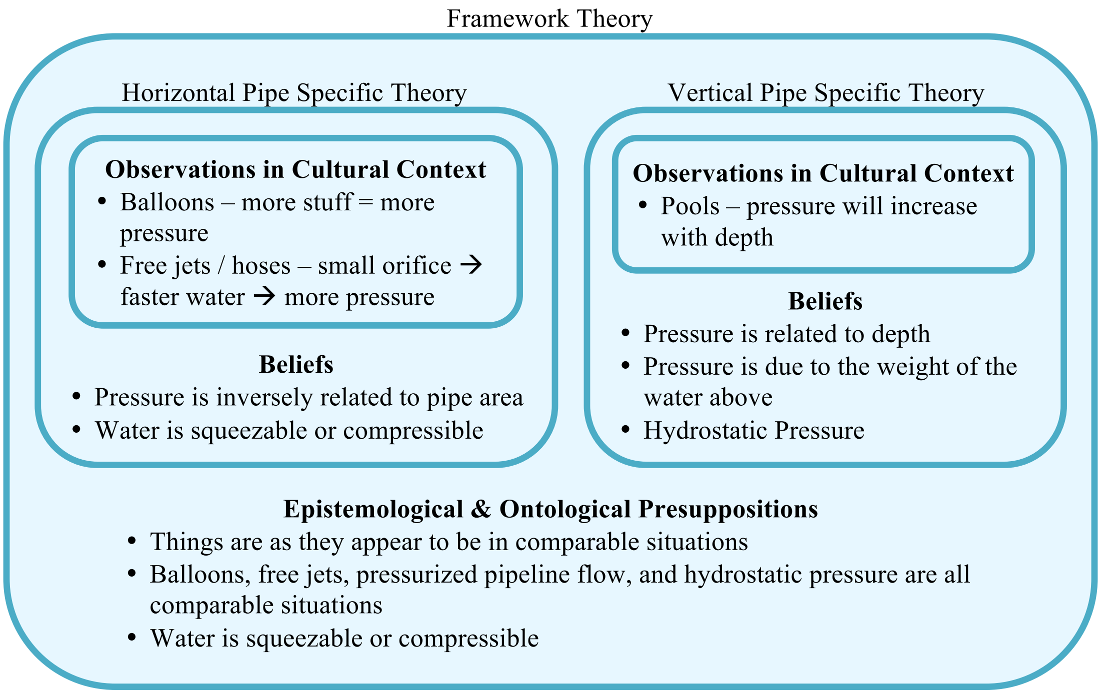


Figure 7: Observations, beliefs, and epistemological and ontological presuppositions in fluid mechanics

An issue with using Vosniadou's framework theory is that the examples she uses greatly contrasts the difference between framework and specific theories [10], making it difficult to apply to subject areas with less contrast The misconception that water is squeezable or compressible seems to be able to fit as both a belief and an epistemological and ontological presupposition. This makes it a little more difficult to appropriately apply Vosniadou's framework theory, but the interview results strongly suggest that context in which fluid mechanics problems are presented in will influence student's conceptual understanding.

6. Conclusions

Using Chi's ontological category shift theory, the participants are operating in a *physical substance* category when they should be in a *process* category. Utilizing Vosniadou's framework theory, the context in which the problems are presented greatly affects student's conceptual understanding of pressurized pipeline flow. Chi suggests using schema training, which exposes students to the correct ontological category to encourage students to form the correct conceptions. Vosniadou suggests an active learning approach, which requires students to engage with others and to form, explain, and test hypotheses about certain scenarios in a subject area. Since a combination of both approaches can fully explain the misconceptions identified in this paper, suggestions on how to implement both are presented. Also, suggestions are made for future research to verify the identified misconceptions as well as explore further into why the misconceptions exist.

6.1 Invoking Conceptual Change using Chi's Theory

Slotta and Chi have demonstrated that 'schema training' has been beneficial in repairing students' misconceptions of electricity [39]. Their study consisted of assessing the impact of an emergent process training module on shifting students' understanding of electricity from a *material substance* ontological category to a *process* category [39]. The computer training modules focused on presenting students with four attributes of emergent processes: (1) the process is system wide with "no clear cause-and-effect explanation," (2) the system seeks equilibrium, (3) the observable pattern is caused by "smaller processes occurring simultaneously and independently," (4) there is no definitive end or beginning, even after equilibrium is achieved [39, p. 271]. It should be noted that Slotta and Chi believe that more attributes of emergent processes exist, but these were easiest for students to recognize in their study [39].

The computer training module presented students with text referring to different simulations that could be run in the program [39].When a training module with a piston of air was displayed, the air molecules continued to move even when a simulation was not running to enforce the idea that emergent processes are continuous [39].

No portions of the computer training modules mentioned or referenced electricity [39] due to the ontological shift approach to conceptual change being a "domain-general explanation for misconceptions" that can be applied across all subject areas [13, p. 187]. A domain-general approach "assumes that there are underlying commonalities that exist across a diverse set of formal…and everyday phenomena" and that "these commonalities can be construed as attributes of an ontological kind or category" [13, p. 163]. Therefore, "teaching students the causal structure underlying…processes may enable them to recognize and understand a variety of" other processes that are misunderstood [13, p. 161].

Slotta and Chi recommend that professors "should not try to 'bridge the gap' between students' misconceptions and the" scientifically correct conception "as there is no tenable pathway between distinct ontological conceptions" [39, p. 286]. They also recommend that professors focus on "explicitly draw[ing] attention to fundamental (ontological) aspects of the concepts in order to help students formulate new conceptions that adhere…to the scientifically normative view" [39, p. 287]. In other words, to achieve conceptual change students must be confronted with the idea that there is another, ontologically different, way to think about concepts and, if shown how, this new way of thinking can accurately and appropriately explain scientific phenomena.

Schema training has also been shown to be effective at increasing students' conceptual understanding of heat transfer [40]. It was discovered that students who had taken two or less courses on heat transfer displayed a significant improvement between their pre- and post-test scores, while those who take taken three or more classes show no significant improvement [40]. Therefore, the earlier students were exposed to schema training in their education the more likely they were to undergo conceptual change. The implementation of schema training is beneficial "to help students develop correct mental schema for understanding robust misconceptions involving emergent processes" [40, p. 209].

6.2 Invoking Conceptual Change using Vosniadou's Theory

Vosniadou's theory offers some general suggestions to implement conceptual change in the classroom [10, 25, 38]. Vosniadou suggests that "effective instruction should pay attention to both the process of knowledge building and its products" [18, p. 64]. Oftentimes science educators do not comprehend the amount of prior, naïve knowledge students bring to a new topic or how much it can impact students' learning [18, 25]. In order to achieve conceptual change in the classroom, educators must "pay attention to the prior knowledge that students bring" with them and determine how to enrich and change it [25, p. 26]. Since conceptual change requires that students be made aware of "the difference between their naïve beliefs and the scientific concepts," also known as metaconceptual awareness, the ideas and concepts that students form in the classroom should be as important as the act of teaching students [18, p. 64].

Since conceptual change is naturally a long and gradual process, simply instructing students that a single naïve concept is in conflict with the correct scientific concept will not be effective in most classrooms [25]. This was exemplified by students' misconceptions of pressurized pipeline flow after formal education in fluid mechanics. A better way to foster conceptual change is with a long-term curriculum that includes "carefully planning the sequence of concepts to be taught by identifying the points at which conceptual change is necessary" [25,

p. 26]. Students will frequently revisit portions of fluid mechanics throughout their academic career; a civil engineering student will typically first encounter fluid mechanics concepts in school in their physics class, then revisit it more in-depth in fluid mechanics, and again revisit some aspects in water resources. Due to this and the variations in educators' teaching style, a carefully planned, long-term curriculum may be difficult to design.

The framework theory an individual creates to understand an aspect of the world around them is a set of "unquestionable truths about the way the physical world operates" instead of hypotheses that can be subjected to experimentation and falsification" [10, p. 67]. This prevents learners from acknowledging that their presuppositions and beliefs are naïve and incorrect. Vosniadou has noted that instructional programs that fail to make students aware of their naïve presuppositions and beliefs do not "create the necessary metaconceptual awareness" that is important for conceptual change [10, p. 67]. In order to make students aware of their naïve presuppositions and beliefs Vosniadou suggests that (1) students are put into a situation where they can actively engage in science experiments, (2) students are encouraged to "provide verbal explanations of phenomena" with other students so that they can defend and compare different beliefs, and (3) that students express their mental models so that they can manipulate, test, and revise their beliefs and presuppositions [10, p. 67]. Encouraging students to converse with, listen to, and challenge one another helps to create the sociocultural environment necessary for metaconceptual awareness [25]. This sociocultural environment, or 'active learning,' encourages instruction induced conceptual change in the classroom [25, 41].

Research shows that students who are exposed to a learning environment that encourages them "to take active control of their learning, express and support their ideas, and make predictions and hypotheses and test[ing]" their validity in experiments has resulted in increasing the students conceptual understanding of physics [42, p. 381]. This type of environment is similar to the learning environment presented to students to encourage the understanding of open channel flow. The implementation of an interactive flume along with an environment that encouraged the formation and testing of hypotheses resulted in an increase of conceptual understanding of open channel flow concepts [43]. The interactive flume and the sociocultural environment was able to significantly improve students post-test scores on open channel flow concepts [43].

6.3 Suggestions for Classroom Instruction

The use of computer simulations, similar to those used in schema training by Slotta and Chi seem adequate for exposing students to emergent processes that can be applied to other situations in which an emergent processes ontological category is necessary. Since the models used in schema training were not related to electricity, but were successful at improving students' scores on problems related to electricity it is possible that undergoing schema training for emergent processes will only be necessary once [39]. After that students should be able to recognize the similarity between horizontal and vertical pressurized pipelines.

However, due to the drastic shift in students thought process between horizontal and vertical pipelines the active learning approach recommended by Vosniadou may be more successful for fluid mechanics. A physical model may not be practical for pressurized pipelines as students will not be able to receive direct physical feedback, but would have to read pressure and flow gauges. Also, the lab space for pipelines, even on a small scale, may not be feasible for large class sizes. Therefore a series of computer simulations for which students must create and test a hypothesis in a small group may expose students to the sociocultural environment necessary for metaconceptual awareness.

The following is a suggestion for how these methods to achieving conceptual change can be implemented in the classroom. Using schema training to expose students to processes specifically emergent processes. A computer simulation similar to the one used by Slotta and Chi should be successful [12]. Active learning can be implemented with small group work either in class or in a lab outside of regular lectures. This group work should focus on inter-group discussions about concepts in fluid mechanics that students struggle with, including pressurized pipeline flow. During these discussions individuals, or small groups, should form and a hypothesis. These hypothesis should then be tested utilizing either actual lab set-ups or with computer simulations. Afterwards students should determine if their hypothesis was valid, as well as if the logic behind their hypothesis was correct. This final part may help students learn what happens in fluid mechanics systems beyond memorizing rules of thumb.

6.4 Future Research

Future research on students' conceptual understanding of pressurized pipeline flow should continue to focus on applying a conceptual change theory to robust misconceptions. This will ensure that the most appropriate teaching methods can be applied to fluid mechanics curricula. Specifically, future research should question students directly if liquids are a compressible or incompressible fluid. Knowing this will help determine if students are simply able to remember facts (since participants in this study indicated that they view water as squeezable or compressible), or if students are not picking up on fundamental concepts of fluid mechanics.

If the FMCI is used in future research, the multiple choice options should be altered. As briefly mentioned in the literature review, a few students wanted to choose a non-existing option of pressure being constant, or not changing. Replacing the multiple choice options with the two part answers shown in Table 16 will make every possible response available. For example, one particular participant didn't believe any of the available multiple-choice options was correct, but felt forced to choose one. It may also be beneficial to ask participants if their prediction for pressure change remains the same for dynamic conditions as well.

Table 16: New two-part multiple-choice options for the FMCI questions

Velocity Answers	**Pressure Answers**
A) V_2 is less than V_1	D) P_2 is less than P_1
B) V_2 is equal to V_1	E) P_2 is equal to P_1
C) V_2 is greater than V_1	F) P_2 is greater than P_1

To further explore the change in students' thought process of solving for pressure in vertical pipes, future research should focus on determining why it occurs. A possible reason may be due to the isolation of the pipeline from the system. Similar to how a free body diagram of a beam can be a simplified, isolated component of an entire building, the vertical pipes in the FMCI interview would be a small section of a larger system. Another reason may be due to a misinterpretation of the boundary conditions. A few participants struggled with understanding that the vertical pipeline segment was part of a larger pressurized pipeline system (see Student 103's quote in Table 13). This would emphasize importance of the context of a problem on altering students' conceptions.

To explore both of these ideas, future research should be structured to question students about how a pipeline segment might fit into a larger system, or to have students explain what happens after the pipeline segment. Another possibility may to be to alter the drawings of the pipe segments to be explicitly obvious that the pipe segment is "broken off" of a larger pipe system. These should help determine what aspects of a problem in a new concept leads students to hold different misconceptions about pressurized pipeline flow.

6.5 Summary

Students frequently hold misconceptions about pressurized pipeline flow. In horizontal pipes participants frequently expressed a belief that water was a compressible fluid that had to squeeze or compress into small pipe sections. Participants also expressed that they thought of hydrostatic pressure when predicting pressure changes in vertical pipes.

Using Chi's ontological shift approach to conceptual change, participants appear to be operating in a *physical substance* category when they should be in a *process* category. This approach, however, is unable to explain why participants shifted their thought process about pressure changes between horizontal and vertical pipelines, which are conceptually similar problems. Vosniadou's framework theory approach is able to explain this shift in the participants' conceptual understanding. Using this approach, the context in which these problems are presented (horizontal versus vertical orientation) affects how participants think about and approach the problem.

To help students form the correct conceptions about pressurized pipeline flow, schema training, as recommended by Slotta and Chi, can be implemented to help shift students from a *physical substance* category to a *process* category. Vosniadou suggests an active learning approach to encourage conceptual change. In this approach, students are encouraged to create, defend, and test hypothesis with classmates to evaluate their beliefs and understanding of fluid mechanics, or other subject areas.

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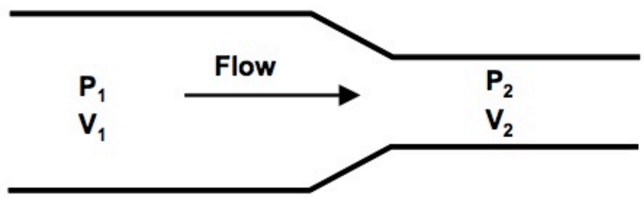
Appendix A: FMCI Interview Handouts

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. Circle the letter of the correct statement about the change in pressure p and average velocity V.

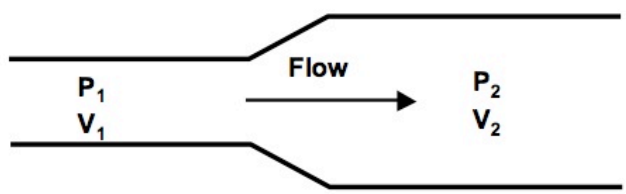
A P_2 is less than P_1 and V_2 is less than V_1
B P_2 is less than P_1 and V_2 is greater than V_1
C P_2 is greater than P_1 and V_2 is less than V_1
D P_2 is greater than P_1 and V_2 is greater than V_1



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. Circle the letter of the correct statement about the change in pressure p and average velocity V.

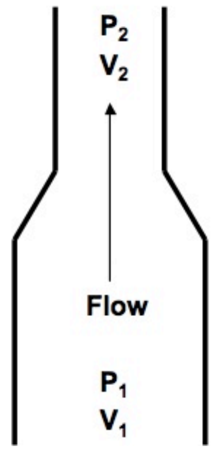
A P_2 is less than P_1 and V_2 is less than V_1
B P_2 is less than P_1 and V_2 is greater than V_1
C P_2 is greater than P_1 and V_2 is less than V_1
D P_2 is greater than P_1 and V_2 is greater than V_1



Question # 3

Water flows vertically up through a pipe and enters a section where the cross sectional area is smaller. Viscosity and pipe friction effects are negligible but gravitational effects are not negligible. Circle the letter of the correct statement about the pressure P_2 and velocity V_2.

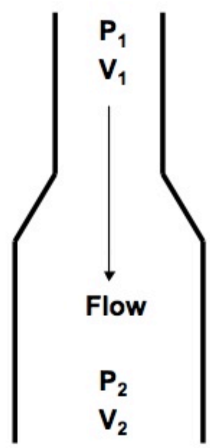
A. P_2 equals P_1 and V_2 equals V_1
B. P_2 is greater than P_1 and the V_2 is greater than V_1
C. P_2 is greater than P_1 and the V_2 is less than V_1
D. P_2 is less than P_1 and the V_2 is greater than V_1
E. P_2 is less than P_1 and the V_2 is less than V_1



Question # 4

Water flows vertically down through a pipe and enters a section where the cross sectional area is larger. Viscosity and pipe friction effects are negligible but gravitational effects are not negligible. Circle the letter of the correct statement about the pressure P_2 and velocity V_2.

A. P_2 equals P_1 and V_2 equals V_1
B. P_2 is greater than P_1 and the V_2 is greater than V_1
C. P_2 is greater than P_1 and the V_2 is less than V_1
D. P_2 is less than P_1 and the V_2 is greater than V_1
E. P_2 is less than P_1 and the V_2 is less than V_1



Question # 5

7. Circle the letter of the correct statement about pressure in a fluid.

A. Pressure is a body force
B. Pressure acts normal to a surface
C. Pressure is a frictional force
D. Pressure acts parallel to a surface

Appendix B: Solutions to Selected Interview Questions

Table B-1: Solution to the the first FMCI qeustion, with a horizontal pipeline

In question 1 of theFMCI interview water flows through a contraction in a horizontal pipe.

Utilizing the notion of conservation of mass, the continuity equation (Equation 1) can be used to determine the change in velocity.

$$A_1 > A_2$$
$$V_1 < V_2$$

Since friction effects, or headloss, is assumed to be neglegible using the energy equation (Equation 2) yields the following.

$$Z_1 = Z_2$$

$$\frac{V_1^2}{2g} < \frac{V_2^2}{2g}$$

$$\frac{P_1}{\gamma} > \frac{P_2}{\gamma}$$

Energy in the system can be displayed visually using the energy grade line (EGL) and hydraulic grade line (HGL). The velocity, or dynamic head, represents the kinetic energy in the pipeline. The pressure and elevation heads, or static head, represent the potential energy.

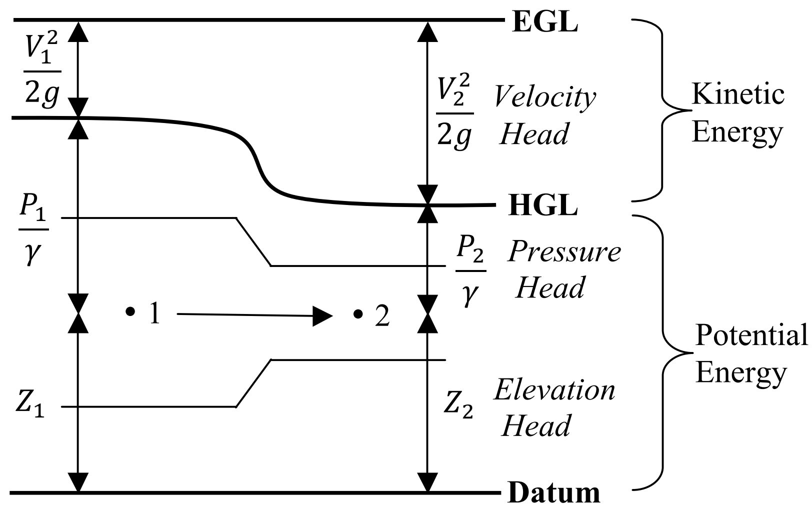


Table B-2: Solution to the the third FMCI qeustion, with a vertical pipeline

In question 3 of the FMCI interview water flows upwards througha contraction in a vertical pipe.

Using the notion of the conservation of mass the following, as with the previous solution for the first FMCI question, the following is determined.

The change in velocity is found using the continuity equation (Equation 1) .

$$A_1 > A_2$$
$$V_1 < V_2$$

The assumption of negligible friction loss and yields the following using the energy equation (Equation 2).

$$Z_1 < Z_2$$

$$\frac{V_1^2}{2g} < \frac{V_2^2}{2g}$$

$$\frac{P_1}{\gamma} > \frac{P_2}{\gamma}$$

Energy in the system can be displayed visually using the energy grade line (EGL) and hydraulic grade line (HGL). The dynamic head represents the kinetic energy in the pipeline and the static head represents the potential energy.

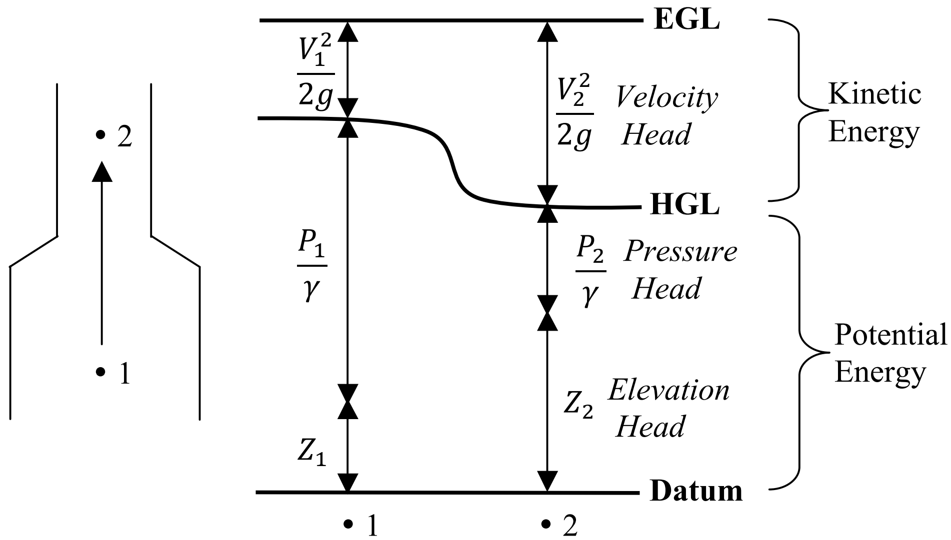
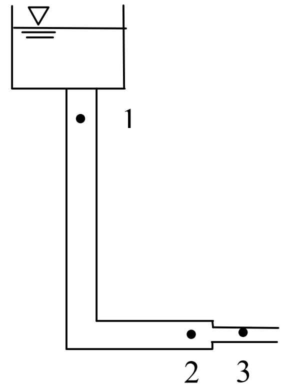
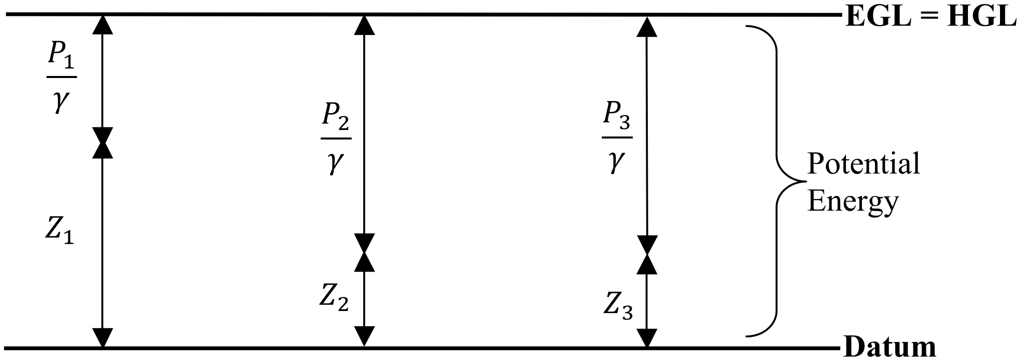
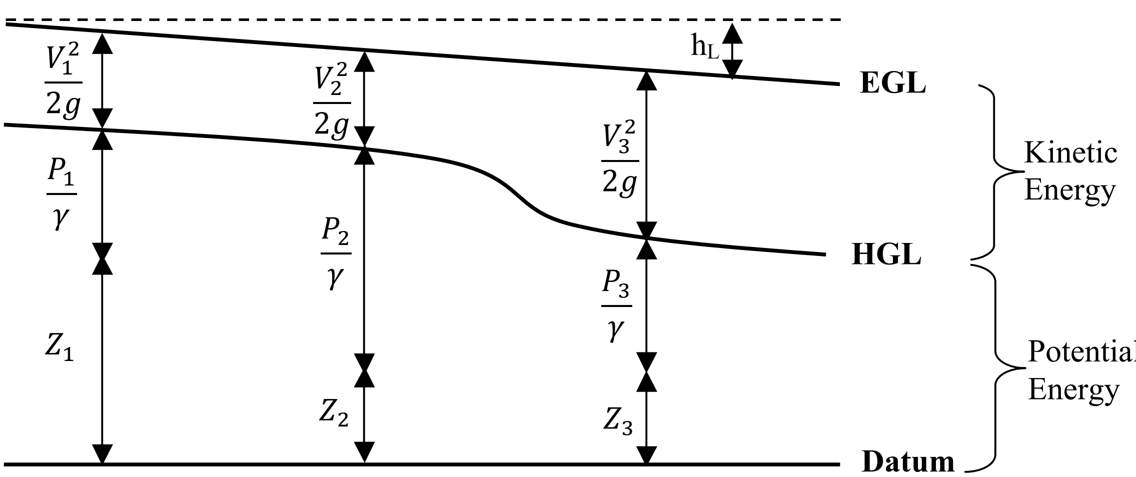


Table B-3: Partial solution to finding the highest pressure in the pressurized pipe system

<table>
<tr>
<td>Looking at the beginning portion of the pipelines until shortly after the first contraction three points can be set up. Pressure will vary between these three points during both static and dynamic conditions.

During dynamic conditions velocity can be predicted with the continuity equation (Equation 1). During both static and dynamic conditions changes in pressure can be determiend using the energy equation (Equation 2).</td>
<td>
</td>
</tr>
<tr>
<td colspan="2">The total energy in the system during static conditions, when no water is moving in the pipelines, is displayed below.


During dynamic conditions, when water is moving in the system due to a home using water, the total energy in the system can be drawn. The highest pressure is still at the point of lowest elevation, however, the contraction in the pipeline will affect where at the lowest elevation pressure is greatest. As seen below, the highest pressure is in the portion of the pipeline before the contraction.

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