ASEE 2022 ANNUAL CONFERENCE
Excellence Through Diversity
MINNEAPOLIS, MINNESOTA, JUNE 26TH-29TH, 2022 ASEE

Paper ID #37161

Using Post-Assessment Reflection to Enhance Student Learning Outcomes in a Fluid Mechanics Course

Boni Frances Yraguen (PhD Student)

Boni Yraguen is a PhD student at Georgia Tech. Her dissertation work is in the field of combustion/thermo./fluids. She studies a novel diesel injection strategy: Ducted Fuel Injection (DFI), which is used to drastically decrease soot emissions during diesel combustion. In addition to her thesis work, Boni is passionate about engineering education. She has led and participated in various educational studies on the impact of student reflections, authentic learning assignments, ad the use of technology in the classroom. Boni hopes to pursue a career in academia with a focus on teaching and engineering education.

Anna K Lummus

Hannia Elisa Koolman

Roxanne Moore (Research Engineer II)

Roxanne Moore is a Senior Research Engineer in the G.W. Woodruff School of Mechanical Engineering and the Center for Education Integrating Science, Mathematics, and Computing (CEISMC) at the Georgia Institute of Technology. Her research focuses on design and engineering education with a focus on promoting diversity and inclusion. She has served as PI and co-PI for grants from multiple sponsors including NSF and Amazon totaling more than $9M. In addition, her STEM outreach programs and curricula have impacted hundreds of thousands of K-12 students nationwide. She is the co-founder and director of Georgia Tech's K-12 InVenture Prize, a statewide invention competition, open to all students and teachers in Georgia. She earned her BS in Mechanical Engineering from the University of Illinois at Urbana Champaign in 2007, and her Masters and PhD in Mechanical Engineering from Georgia Tech in 2009 and 2012. Dr. Moore received the Georgia Tech Teaching Effectiveness Award in 2018.

Katherine Fu (Assistant Professor)

Using Post-Assessment Reflection to Enhance Student Learning Outcomes in a Fluid Mechanics Course

Abstract

This evidence-based practice paper will assess the impact of reflecting on student learning levels as compared to typical assessments of understanding (quizzes) in a fluid mechanics course.

Problem solving skills are critical to becoming an effective engineer. With minimal application opportunities for upper-level course material in the typical engineering curriculum, students are often not sufficiently prepared to accomplish rigorous design projects in industry immediately following graduation. Having the requisite knowledge is only one part of the task; being able to effectively utilize and apply prior knowledge requires more advanced learning outcomes. Fluid mechanics is a lecture-based course in which deep understanding of the material is required to comfortably approach new problems. It is also generally considered to be one of the harder and less intuitive engineering courses in the mechanical engineering (ME) curriculum.

Reflections encourage students to understand the problem, analyze their problem-solving strategies, identify areas of improvement, and correct themselves, thus encouraging a higher level of learning. Introducing post-assessment reflection in the classroom could improve student understanding of the course material and encourage higher levels of learning. Bloom's Taxonomy categorizes levels of problem-solving and learning in a tiered system, the bottom of which is the most basic level of learning and the highest is the most complex and critical level of learning. Using Bloom's Taxonomy to code student quiz reflections, the level of understanding the students employed while completing different tasks in the assessment and during the reflection process can be identified. To conduct this study, post-assessment reflections written by 54 students in a fluid mechanics class have been coded sentence-by-sentence for each tier of Bloom's Taxonomy to characterize levels of learning. Using keywords, sentences coded under each category were then sorted depending on whether they indicated a student reflecting versus the student's assessment performance alone. Based on preliminary analyses, we hypothesize that students achieved higher levels on Bloom's Taxonomy during the reflection assignment than during the quiz assessment. In this paper, we will describe the assessment, reflection assignment, and coding scheme, and use coded student data to test this hypothesis.

Keywords: Reflection, Bloom's Taxonomy, Critical-thinking, Fluid Mechanics

Authors: B.F. Yraguen, A. K. Lummus, H.E. Koolman, R.A. Moore, K.K. Fu

Introduction

The gap between engineering curriculum and practice has widened in recent years [1]. According to employers, students graduating in recent years struggle to navigate less-defined problem spaces, including navigating constraints and open-ended problem-solving as compared to engineers who graduated ten years ago [2]. Graduates now need additional training in the workplace to "acquire missing competencies" [3]. Further, students undervalue skills required to effectively communicate results and ideas, and they do not understand how these types of communication skills apply to the "real world" [3]. Ideally, recent graduates should be equipped to apply knowledge from their degree programs without the need for further training. To address the gap between knowledge and application, some schools have started implementing co-op programs [4, 5], but co-op programs are not practical for schools with limited access to partner companies and may not be practical for students based on location and timing. This disproportionately affects rural communities, as well as disadvantaged students, who have less opportunity to bridge this knowledge gap. Efforts have also been made to implement project-based learning into engineering curricula, but these efforts are mainly in the design area [6-8]. Some schools have also added lab courses, like Georgia Tech's ME2110 course [9, 10]. Even so, student-focused course delivery, such as projects or labs, accounts for less than 20% of the time in an engineering classroom [11]. Over 60% of engineering classes are didactic, lecture-based or teacher-focused [11]. However, lecture courses can employ instructional methods and assessments that improve student outcomes and better prepare students for real-world applications. This gap shows a need for increased depth of learning.

Reflections are a simple intervention that might easily begin to address this gap for lecture-based courses. They are a tool commonly used to increase learning and understanding yet are rarely employed in engineering classrooms. The goal of this study is to assess the effectiveness of reflections as measured by levels of learning as characterized using Bloom's Taxonomy [12], a taxonomy for identifying depth of learning. We will quantify the levels of learning that students employ while taking typical assessments (quizzes) as compared to reflecting on said quiz. Using the method outlined by Evans et al. [13], we first coded quiz reflections for levels of learning based on Bloom's Taxonomy. Then reflections were coded again to classify whether students were summarizing steps and thoughts they had during the quiz, versus commenting on their answers and analysis. We hypothesize that the process of reflection increases a student's engagement with the subject matter material by means of Bloom's Taxonomy than could be achieved solely with the quiz assessment.

Background

Reflections

Teaching and learning tools have been evolving in mechanical engineering (ME) to include problem-based learning and other best practices from teaching and learning sciences. One tool with a long history of positive impact on student learning is reflection [14]. Reflection has been used as an educational tool since the 1930s [15]. Typically, studies on reflections have shown that reflection increases understanding, continuous learning, and meaning making. Even so, reflective assignments are rarely employed in technical engineering courses. When reflections have been employed in higher education engineering courses, the focus has been on less technical artifacts including peer interactions [16], portfolios [17], or using course grades to measure the efficacy of reflections [18]. That is, reflection is mostly used for behavior-based reflection (i.e., working well in a group, learning a tool, or effective study habits) rather than more typical engineering content.

Reflection assignments can be categorized to quantify levels of learning. Multiple studies have offered categorical ways in which reflections can be coded [19-22]. Typically, these coding schemes focus on the student's ability to reflect, or on their level of reflection. For example, Kember at al. categorized reflection data with a four-category coding scheme to assess the student's level of reflection. These categories were: non-reflective, understanding, reflective, and critical reflection [21]. The first two categories are representative of thoughts that are not the result of reflection, while the second two categories are. While these categories are may correlate to different levels of learning (i.e., non-reflective and understanding), they do not precisely evaluate the level of learning a student is engaging in with respect to the subject matter material.

Alternatively, Evans et al. coded reflections from an engineering design course using a Bloom's Taxonomy coding scheme [13]. In Evans et al., they requested students write a reflection based on their course work (in this case design activities) and respond to some prompts. For data analysis, they created a coding scheme by writing a detailed rubric, or thematic codebook, of types of sentences that fit within each level of Bloom's Taxonomy. Bloom's Taxonomy's hierarchical structure categorizes types of learning into remember, understand, apply, analyze, evaluate, and create. Girgis related Bloom's Taxonomy to the ABET criteria and expected outcomes for an engineering course, linking the higher levels of Bloom's to the ability to apply engineering knowledge after graduation and to participate in life-long learning [23], which would in turn aid in closing the curriculum-practice gap. So, students that engage in higher levels of learning will readily be able to apply engineering principles in their careers. The levels of learning that typical assessments (homework, quizzes, exams) usually require are remember, understand, and apply, while design and project-based courses naturally are aimed to include analyze, evaluate, and create [23]. With Bloom's Taxonomy [24], students' reflections will not be measured by "depth" of reflection but by their cognitive process.

Upper-Level Interventions

Engineering education research is often focused on first-year or lower-level courses in the engineering track [23, 25, 26]. Upper-level engineering courses, like fluid mechanics, typically require students to apply knowledge from previous foundational courses and expand upon that knowledge to more abstract concepts that can be applied to a wider variety of physical applications. Fluid mechanics is typically one of the first courses mechanical engineering students encounter that requires this skill at such a high level. Thus, it is an ideal candidate for a lecture-based course in which alternative educational tools and interventions can be used to improve student engagement and learning.

There have been prior efforts to study learning interventions in fluid mechanics [27-29]. These studies largely focus on problem-based learning, multi-disciplinary labs, and the use of computation as a teaching tool [27]. However, none of these studies incorporated reflection as a learning tool. Prior interventions modify the course delivery style. For project-based learning, the classroom is student-focused rather than teacher-focused [28], and with activity-based learning, the activities replace lecture time [29]. Incorporating reflection assignments into the course does not change course delivery or the topics that can be covered in a given course period.

Methods

The current study explores the extent to which students engage with subject matter material according to Bloom's Taxonomy in a typical assessment compared to that of a reflection. The following questions guided our research:

1) How can reflections be used to analyze the level of student engagement/learning during a quiz as measured using Bloom's Taxonomy?

2) How does the student's engagement with the material differ during the assessment versus reflection?
3) How does the act of reflection impact the level of critical thinking a student employs compared to that of a typical assessment, such as a quiz?

This study was conducted in a fluid mechanics course in the spring semester of 2021 at the Georgia Institute of Technology. Due to the Covid-19 pandemic, the course was offered in a virtual format. The course was delivered using a mixture of synchronous and asynchronous lectures. Similar to a flipped classroom, the bulk of the lecture material was delivered in short 5-15 asynchronous video content. These are complimented by synchronous lectures in which the instructor completes example problems. Course assessments included six quizzes and two projects. Each of the eight assessments required students to write a reflection on their work. All elements of this study were mandatory components of the course and students completed them whether or not they consented to study participation. Agreement to voluntarily participate in the study allowed the researchers to use the students course deliverables in the analysis. Of the 55 students enrolled in the course, 54 students were eligible and elected to participate in the study. Of the 54 participants, 37 identified as male, 16 as female, and 1 as non-binary. The average age of the students was 20 ± 0.48 years, and almost all of them were majoring in mechanical engineering. These and other demographics data can be found in Table 1.

Table 1. Demographics Information

Individual-Level Variables	N	Percent [%]
Gender		
Female	16	29.6
Male	37	68.5
Non-binary	1	1.9
Age in Years		
17-19	11	20.4
20-22	43	79.6
Ethnicity/Race*		
Black or African American	4	7.4
Asian, Native Hawaiian, or Other Pacific Islander	15	27.8
White	31	57.4
Hispanic or Latino	5	9.3
More than one race	3	5.6
Other	1	1.9
Major		
Mechanical Engineering	49	90.7
Nuclear and Radiological Engineering	4	7.4
Computer Engineering	1	1.9
Year of Undergraduate Study		
2	18	33.3
3	27	50.0
4	9	16.7
Internship/Co-op Experience Prior to Taking Class		
Yes	23	42.6
No	31	57.4

***Students were given the option to select all that apply. Totals do not equal 100%**

Each of the six quizzes corresponded to a concept or group of concepts in fluid mechanics: (1) hydrostatics, (2) Bernoulli's principle, (3) fluid kinematics, Reynolds transport theorem, and control volume analysis, (4) differential analysis of fluid flow, potential flow, and Navier Stokes, (5) dimensional analysis and pipe flow, and (6) boundary layers and external flows. The quizzes consisted of two or three multiple-choice questions taken from a fluid mechanics concept inventory [30, 31] and one or two free-response analysis questions. The scope of this paper focuses on documenting the methods of analysis used, and we present results from Quiz 1, as an example. After completing a quiz, students were given one day to write a one-page response to the reflection prompt shown below. The reflection prompt was designed to encourage students to describe their problem-solving process and identify the areas that challenged them while getting students to engage with the material for a second time in a low-pressure environment. This reflection prompt was developed over the course of three months in a collaborative faculty development seminar on reflections [32] with the goal of guiding students in the direction of reflecting on their solution strategies rather than on their preparation for the assessment – which is often typical for reflections. The prompt was structured this way since the main goal of the reflection is for students to enhance their learning of the material. Students were asked to reflect on their submissions prior to receiving the solutions to the quiz. The grades of the students were not compared to their level of engagement in the reflections as grades are not the only metric with which to measure a student's level of mastery or understanding; in other words, it is possible a student with a high level of engagement with the reflection did not perform well on the quiz, and vice-versa.

Please reflect on/describe your process for solving problem 3. You may use the following questions as prompts for what type of information to include in this reflection:

- *How did you decide on a solution strategy for this problem?*
- *What assumptions did you make while solving the problem? How? (i.e., Were assumptions stated in the problem, similar to a practice problem, did you guess, question too difficult/un-solvable without making the assumption, etc.)*
- *Were there any parts of the question you found confusing?*
- *Which parts, if any, of the problem did you get stuck on?*
- *If you could approach the problem again, what would you do differently to improve your confidence in your answer or answer the question more efficiently?*

Coding for Bloom's Taxonomy

The reflections were first coded using a rubric developed by the authors based on Bloom's Taxonomy. Bloom's Taxonomy was chosen because of its proven theory of learning and link to the levels of critical thinking used by students [13]. Coding was conducted sentence-by-sentence for one or more levels of Bloom's Taxonomy. The code book definitions can be seen in Table 2 below. Example statements for each sub-item can be found in the appendix.

Table 2. Coding Guide for All Levels of Bloom's Taxonomy

Code	Indicators
Remember	• Student cites/states facts/definitions, memorized equations not in the context of the way they are solving the problem • Student references equations • Student notices a mistake (either during the test or during reflection) but does not correct the mistake

Understand	• Student demonstrates understanding of how an equation/fact is to be used • Assumption: student makes assumption that comes directly from the problem statement • Student demonstrates ability to understand important characteristics of the problem / Student restates or summarizes problem in their own words • Student can demonstrate incorrect understanding, but still be applying understanding as it makes sense to them • Student understands what certain equations mean and the context of the current problem they are solving
Apply	• Free Body Diagram: Student completes FBD as part of a process they are repeating • Assumption: student assumes from practice/applies a correct assumption but does not demonstrate reasoning behind it • Student applies skill they have practiced before • Student uses an equation to define a system • Student solves equations even when stating they are unsure • Student solves or implies that they solved equation • Student states or re-states answer: emphasis on the action of solving the problem • Student catches mistake and re-calculates equation/describes correct answer
Analyze	• Student checks/defends answer using different assumption or solution method, but does not provide an assessment of the impact of their decision or different solution • Free Body Diagram: Student provides reasoning/logic behind why FBD is used • Assumption: student makes assumption that is not directly given in the problem statement AND provides a defense based in physical understanding of why assumption applies • Student identifies multiple ways to arrive at an answer, chooses one, and defends it • Student responds to new information – must indicate not having seen before, no similar examples, etc. – by analyzing an approach to solve problem • Student explains link between an equation and its application/impact • Catching mistakes: When a student has a reason to go back and check their answer or do the problem again another way
Evaluate	• Student provides reasoning for certainty/uncertainty of applicability or accuracy of their solution in the context of an engineering problem • Student evaluates the efficacy of their solution (ex: checking answers)
Create	• Student provides insight into problem design/mentions combining different principles of fluid mechanics or engineering to design a problem • Student explains reasoning behind new method to solve problem that was not taught in class • Student discusses process of modelling a real-world engineering problem within the scope of a typical course example problem • Student recognizes an initial solution/model was flawed and makes adjustments to better represent the engineering problem. (Revision of original concept/problem) • Student develops the model of the problem • Student ideates or brainstorms • Student independently develops or demonstrates a skill that is novel to them while doing this assignment
N/A	• General comments on the problem • Statements of confidence with no technical reasoning/support • Generic statements of certainty/uncertainty • Comments on testing strategy

To reduce inter-rater error, entire sentences were coded, rather than breaking sentences into individual thoughts or clauses. Therefore, sentences could be coded for more than one level of Bloom's Taxonomy, as they often conveyed more than one thought per sentence relating to a student's problem-solving process; an example of a sentence coded for both *Understand* and *Remember* can be found below:

"For the second part of the question, I saw that it was a find the force acting on the hinged door type of problem, so I decided that following the method in our notes (outlined in Module 2) was the best way to go about doing it."

This sentence demonstrates a clear understanding of the important characteristics of the problem; this is highlighted in blue, and indicative of the *Understand* code. The student then decides to use a method demonstrated in class (a set of equations and definitions) by referring to his/her notes; this is highlighted in yellow and indicative of remember. Therefore, the entire sentence was coded as both remember and understand. In addition to coding for levels of Bloom's, sentences that were not relevant to the quiz material were coded as *N/A*. This included the text that was from the prompt as well as any irrelevant statements.

Interrater agreement was evaluated on a random sample of 25% of the data collected; specifically, 14 student reflections from each quiz were coded by two raters. Cohen's Kappa was used to evaluate the strength of interrater agreement. A kappa value for each code (one for each level of Bloom's) was calculated and can be seen in Table 3, below, for Quiz 1. It can be seen that the agreement for all codes is within the range of moderate (0.41 - 0.60) to near perfect (0.81 - 1) agreement. The total agreement for Quiz 1 was substantial (0.61 - 0.80). Substantial agreement was met for all categories except for *Understand*. This may be due to it commonly being coded along with one or more codes for a sentence (e.g. one coder used only *Apply*, the second coder used both *Apply* and *Understand*). This makes sense as *Understand* has the broadest definition. *Create* has a perfect agreement because there were no instances of it being used in the reflections for Quiz 1, meaning the students did not engage with the material at this level in either the assessment or while reflecting.

Table 3.Cohen's Kappa Agreement for Bloom's Taxonomy Codes

Cohen's Kappa							
Remember	Understand	Apply	Analyze	Evaluate	Create	N/A	Total Agreement
0.69	0.49	0.61	0.61	0.71	1	0.81	0.71

Coding for *Summary* vs. *Commentary*

Once each sentence was coded for one or more levels of Bloom's Taxonomy, each sentence was then coded for *Summary* versus *Commentary*. A rubric for these codes provided in Table 4. Examples of sentences coded under each sub-category can be found in the appendix. This was done to differentiate between sentences that describe a student's thought process while taking the quiz versus sentences that suggest a student actively engaging in reflection. Specifically, items codded as *Summary* are meant to be representative of engagement the student had with the material while they were taking the quiz. When the student is summarizing, they are simply restating thoughts they previously had. Alternatively, items coded as *Commentary* are meant to be representative of new engagement with the material that takes place only during the reflection process. Thus, these codes are mutually exclusive, and clauses could not be coded for both *Summary* and *Commentary*.

Table 4. Coding guide for Summary and Commentary

Code	Indicators
Summary	• Student discusses method for which they solved problem • Student notes previous thoughts while solving problem • Student restates important aspects of problem in own words
Commentary	• Student makes new observations while reflecting • Student outlines what they should have done / would do now if they had to solve problem again • Student comments on their performance

While *Summary* and *Commentary* are mutually exclusive at the clause level, students do write sentences that include both *Summary* and *Commentary*. In this case, sentences are broken into clauses for coding. An example of how one sentence can be coded for *Summary* and *Commentary* is shown below:

"I definitely think that my signs were wrong at some point, but I didn't have enough time to track through and find my errors."

The first clause of the sentence, highlighted in green, contains a comment the student has on his or her performance; thus, this is coded as *Commentary*. The second clause, highlighted in magenta, explains a circumstance he or she dealt with when taking the quiz; this is subsequently coded as *Summary*.

While coding, it was observed that students commonly used past tense of the active verb when summarizing and present and/or future tense of the active verb when commenting; this makes sense as a past-tense sentence is indicative of previous thought, not current thought. As such, we propose an alternative methodology:

Summary – the active verb of a clause is past tense.

Commentary – the active verb of a clause is present or future tense.

When using tense as an indicator for either *Summary* or *Commentary*, it is important to use the active verb while deciding. Examples of the active verbs of sentences can be seen in Table 5. In these examples, the active verb tends to be present or future tense if coded as *Commentary* and past tense if coding for *Summary*. However, the method of coding using tense as an indicator was not an infallible factor in choosing *Summary* or *Commentary*. For example a student might usie the phrase "Looking back" which indicates present tense and therefore would be coded as Commentary, but then simply restate the steps they took during their quiz. In cases like these, the tense in "Looking back" would be ignored and the context of the sentence would be the determining factor for how the sentence was coded. . This was commonly the method deferred to in situations where some students used exclusively present tense to describe their problem-solving process. Thus, coding by tense was used as a guide but was ultimately not the single deciding factor in coding. Lastly, there were some cases of students simply using improper tense. In these cases, the coder deferred to the indicators listed in Table 4 and did not use tense as an indicator.

Table 5. Coding Process Examples for Summary and Commentary

Code	Indicators
Summary	• "For part b of question three, to find the resultant force from having static pressure on the gauge I decided to find the horizontal force component (Fpx) and the vertical force component (Fpz)." • "For the third part of the question, I was mainly confused on the trigonometry of the problem rather than the concept of the forces itself." • "For part B, I needed to find the resultant force vector, so I solved for the components first Fx, Fz."
Commentary	• "Also, upon reviewing the quiz, I noticed I screwed up the trig for the moment equation, in that I used sin(θ) to equate the moment arm for the weight force when I should have used cos(θ)." • "To approach this part differently, I would indicate the P_{atm} at the surface to distinguish the difference between gage pressure and absolute pressure." • "I think the methods I used for all parts of this problem were valid from a conceptual standpoint, so if I lose points, it's likely due to something algebraic or clerical."

To compare the methods for coding *Summary* and *Commentary*, 20 reflections from Quiz 1 were coded by two raters, with 10 using strictly the coding scheme outlined in Table 4 and 10 coded with tense as an additional indicator. Again, Cohen's Kappa was used to evaluate inter-rater agreement. The agreement values for both methods can be found in Table 6 below. A higher agreement was observed when including tense as a differentiator for coding. Ultimately the inclusion of tense differentiation was the method used to code *Summary* vs. *Commentary* for the results discussed in this paper. The authors are not aware of any studies that have been conducted to distinguish specifically between writing *Summary* and *Commentary*. However, tense provides a simple and clear indication of this that is less subjective and leads to more consistent coding among raters and could potentially be easily automated. It is not within the scope of this paper to fully evaluate the difference in using tense as an indicator; this is an avenue for future work.

Table 6. Cohen's Kappa Agreement for Summary and Commentary

Cohen's Kappa			
Rubric Method		**Tense Method**	
Summary	Commentary	Summary	Commentary
0.63	0.64	0.69	0.81
Total Agreement = 0.63		Total Agreement = 0.75	

Results

Fifty-four students elected to participate in the study; of those, only 48 participants completed Quiz 1 reflections. Reflections were coded first for levels of Bloom's Taxonomy. Then, reflections were coded once more for *Summary* vs. *Commentary*. The portion of the reflections coded as *Summary* are the portion of the reflection where the students were simply reporting what they did on the quiz. This type of activity is not considered reflective. The portion of the reflection response that is considered reflective was coded as *Commentary*. Nvivo, a coding and data analysis software, was used to code the data and to calculate the portion of each student response corresponding to each level of Bloom's. That is, each code from Table 2 is applied across the entire student sample, and percentages are used to quantify the relative presence of critical thinking skills throughout the activity. Because students submitted reflections in both Word and PDF formats, Nvivo calculates the percent coverage slightly differently. Percent coverage was based on the percentage of characters coded at each node (or level of code) for Word document submissions. For PDFs, the percent coverage was calculated by taking the average of the percentage of characters coded at the node and the percentage of the page area coded at the node. There were no images in any of the files coded so these differences should be insignificant.

Figure 1 shows the distribution of codes across Bloom's taxonomy for the entire participant pool. The *N/A* category holds a large majority of the percent coverage of the reflections. This is partly due to the fact that the students submitted their reflections alongside the approximately one-page reflection prompt. This portion of the page was also coded as *N/A*. It can be approximated that 50% of the coverage was due to the reflection prompt. Thus, of the 62.63% coverage that was coded as *N/A*, only 12.63% was due to student responses. It was expected that the lower three levels of Bloom's (*Remember, Understand, Apply*) would comprise large portions of the student reflections, as these levels of Bloom's are what is most commonly exercised during typical assessments. These categories composed 9.22%, 18.08%, and 13.30% of the coverage, respectively. A smaller portion of the reflection responses were coded as *Analyze* and *Evaluate*. Only 20 of the 48 students engaged in *Analyze* during their quiz reflection, while even fewer, six, students engaged in the *Evaluate* level. No students engaged in the *Create* level for Quiz 1. Note, coding for Bloom's levels is not mutually exclusive. Thus, the percent coverage for each category can sum to more than 100%.

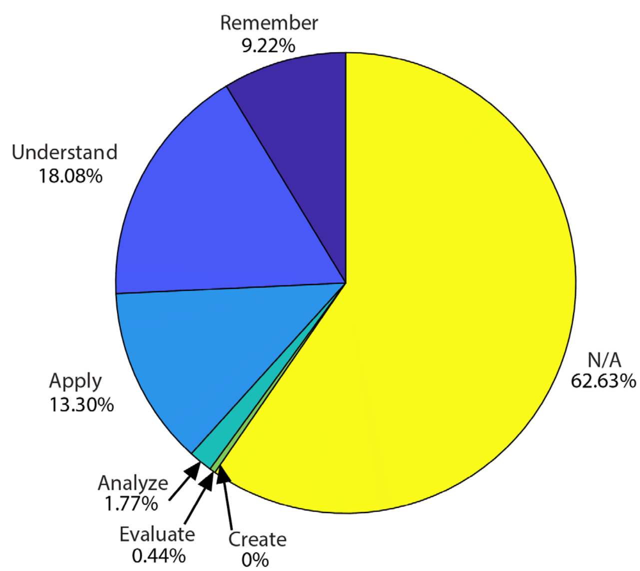

Figure 1. Percent coverage for each level of Bloom's Taxonomy and category "N/A" code across all reflections completed for Quiz 1.

The intersection of *Summary* and *Commentary* was calculated for each level of Bloom's. This way, it can be seen how much of each level was the student *Summarizing* their quiz performance vs. *Commenting* on it (i.e., actively reflecting). Figure 2 shows the percent of each node in Bloom's that was *Summary* vs. *Commentary*. Note that the percentages shown in Figure 2 are no longer showing percent coverage of the total reflection, but rather the percent of code at each node that was *Summary* vs. *Commentary*. Thus, the sum of the two adds up to 100% for each level. For example, the *Remember* code covers 9.22% of total reflection content. Of that 9.22% coverage, 7.08% coverage was also coded as *Summary* and the remaining 2.14% coverage was coded as *Commentary*. Thus, 76.81% of *Remember* code was coded as *Summary* and 23.19% was coded as *Commentary.* This follows for all the other levels of Bloom's.

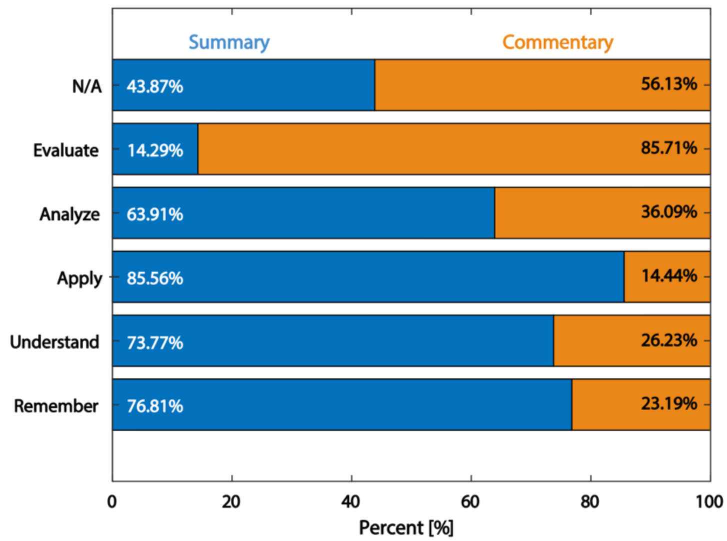

*Figure 2. Distribution between Summary and Commentary categories for each level of Bloom's Taxonomy and N/A codes. *Create has been excluded since no students indicated this level in any reflections.*

To analyze the effect that reflection had on the student's engagement with the subject matter material at each level of Bloom's, non-parametric paired samples testing was conducted. These tests were chosen due to the non-normal distribution in the data. The data is continuous (i.e., 0-100%) and the coded groups, *Summary* and *Commentary*, are dependent. Therefore, either a Sign Test or Wilcoxon Signed Rank Test was needed. Both test for whether or not there is a difference between the median for each group, but the Wilcoxon Signed Rank Test assumes symmetric data while the Sign Test does not. The symmetry of the data for each group was determined by testing the skewness of the data. These results are reported in Table 7. Thus, for the *Analyze* and *N/A* categories, the distribution of the data was symmetric ($-0.5 < S < 0.5$), and thus a Wilcoxon Signed Rank Test was used. For all other levels of Bloom's, a Sign Test was conducted. The results of these tests, as well as the skewness of the data, and the test used for each paired samples test, can be seen in Table 7.

Based on the aforementioned tests, a statistically significant difference was found in the amount that students engaged in the lower four levels of Bloom's between *Summary* and *Commentary* ($p < 0.05$ for *Remember, Understand,* and *Apply* categories while $p = .031$ for the *Analyze* category). *Summary*, which is indicative of thoughts students had while taking the quiz, held a larger portion of the *Remember, Understand*, *Apply,* and *Analyze* categories. Alternatively, there was no significant difference between the student's engagement in the *Evaluate* and *N/A* categories between *Summary* and *Commentary* ($p = 0.219$ and $p = 0.054$ respectively). There were no students who engaged in the *Create* category, so this category was not considered in analysis.

Table 7. Paired Samples Testing

Bloom's Category	p value	Paired Samples Test	Skewness (S)
Remember	<0.05	Sign Test	-0.824
Understand	<0.05	Sign Test	-1.222
Apply	<0.05	Sign Test	-1.910
Analyze	0.031	Wilcoxon Test	0.228
Evaluate	0.219	Sign Test	-1.355
Create	-	-	-
N/A	.054	Wilcoxon Test	-0.252

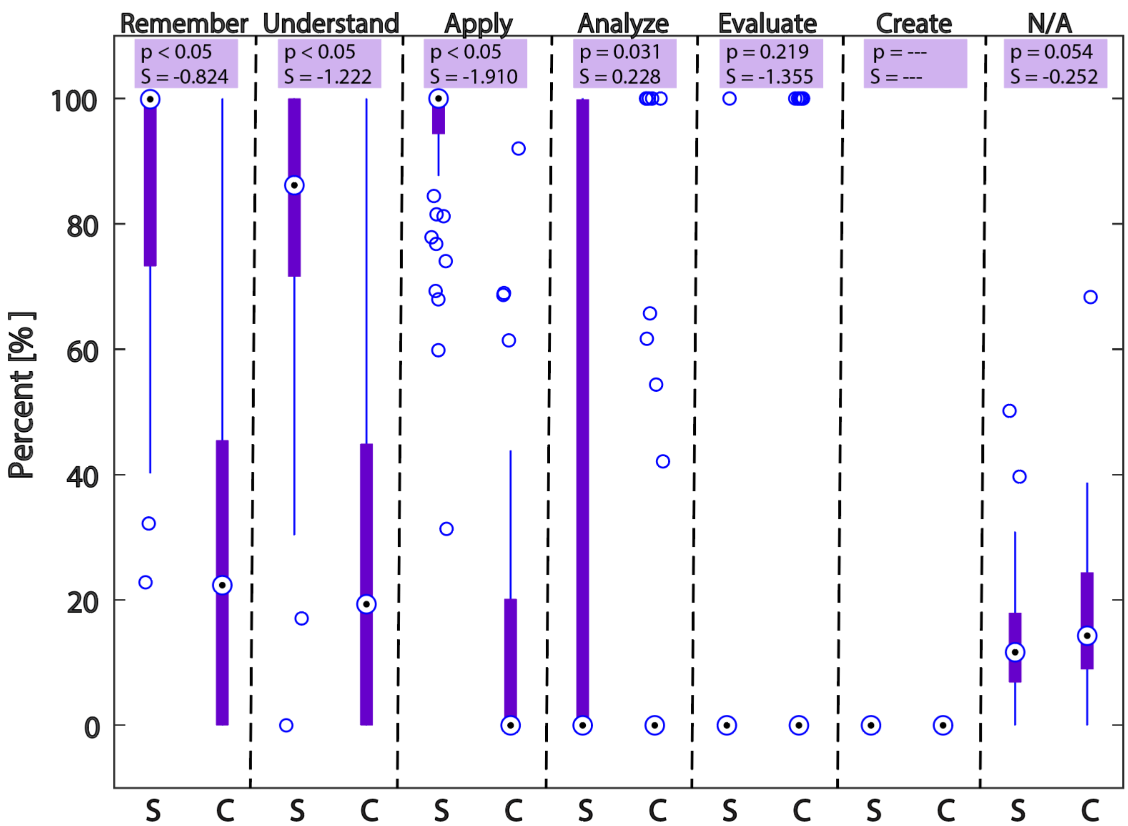

Figure 3. Distribution of the categorical make-up of Summary and Commentary code for each level of Bloom's as well as N/A.

Discussion

Results show that students engage in the lower four levels of Bloom's taxonomy more while *Summarizing* their quiz responses compared to *Commenting* on them. This is the expected result for the first three levels of Bloom's. It is well known that typical course assessments, such as quizzes, tend to engage students on these levels. The fourth category of Bloom's, *Analyze*, results show that students engaged in this level more while *Summarizing* their quiz activity rather than *Commenting* on it. Of the 20 students who did indicate engaging with the material on the *Analyze* level, 18 of them did so while *Summarizing* their quiz responses. Only 9 of them showed further engagement at the *Analyze* level while *Commenting* on their quiz responses during their reflections. Figure 3 shows the distribution of the results for each level of Bloom's. For the *Analyze* level, 12 students indicated engagement exclusively while *Summarizing*, while only 4 student reflections indicated that they exclusively engaged in this level while *Commenting*. The majority of students engaged with the material at this level either while *Summarizing* or *Commenting*, while only 4 students engaged at this level for both. While these results do not conclude that reflection activities increased the student's engagement with the material at this level, it is encouraging that the quiz was prompting almost half of the students to think critically about the problems. This could potentially be due to the complexity of the concepts covered for this quiz (hydrostatics). Learning the concepts of hydrostatic pressure distributions and forces on submerged surfaces typically requires students to frame problems in a way that is novel to their education at that point in the curriculum. In future work, it will be interesting to look at the distribution of students who engage with the material at higher levels across the six concept categories tested on quizzes over the course of the semester.

Further analysis suggests one of the reasons for no significant difference in student engagement at the *Evaluate* level between *Summarizing* and *Commenting* on their quiz performance is due to an overwhelming majority of students not engaging at this level at all. In fact, only six students indicated engagement at the *Evaluate* level in their reflections. Therefore, it is not surprising to have found no significant difference during the pairwise analysis. If we further analyze the responses from the students who did engage at this level, we can see that most students (5 out of 6) did so while *Commenting* on their quiz responses. Table 8 shows the student sentences that were coded as *Evaluate*. It can be seen that the majority of these

Table 8. Student reflection statements coded under: Evaluate

Student	***Evaluate* statements**	Summary vs. Commentary
1	"It's very possible to mess up calculating the moment of inertia, so calculating the moment of inertia for two x-z coordinates orientations might minimize the possibility of getting it wrong."	Commentary
6	"When a final value was attained for part b and c, I used the FLT system of units to make sure my answers came out to both be forces as a method of checking that my answer was consistent unit-wise."	Summary
9	"A couple things that make me confident in this solution are that the weight is proportional to gamma and b, which makes sense conceptually." "Had I been less lazy, a good option for part b would've been to double check this method with the provided equations to see if they'd give the same thing."	Commentary
36	"Looking back at this problem I realized that I am changing where on the z direction I am solving from so the pressure would change. I don't think I'm able to sub those values directly into the equation I solved for in part (b)."	Commentary
44	"I should have either adjusted the formula for the horizontal force component or defined my axes at the surface of the fluid rather than at the bottom of the tank. This is to reflect that the pressure at the surface is zero gage pressure and is increasing with depth until it is maximum at the bottom, my initial formula used did not reflect that."	Commentary
46	"It might be more difficult to separate them into the x and z components, but in order to check that the solution works, it would be better to use the Pythagorean theorem with the calculated x and z components and see if it matches the total force calculated with the pressure prism method."	Commentary

comments focus on i) what they would do to check their answer and improve their certainty in their solution, or ii) adjusting their solution strategy to prevent a mistake they noticed.

Schön argues that expert practitioners in a profession are distinguished from novices by their ability to reflect on their practice when dealing with unusual or particularly complex cases [33]. While the results for Quiz 1 reflections alone show no significant changes in upper-level engagement with the course material, it is possible that the act of reflecting consistently over the course of the semester could show improvements in upper-level engagement with practice. Kember et al. showed that higher levels of reflection, involving perspective transformation, is likely to take a significant period of time [21, 22]. Future work will aim to look at the impact of reflecting over the span of all 6 quizzes, which took place during the course.

A potential limitation to student understanding could be due to the virtual format of the course. Although the course content and deliverables did not change, unknown variables could have impacted the baseline level of student engagement. Thus, replicating this study in an in-person classroom environment would provide helpful insight. Additionally, the results of this work once completed across all six quizzes could be used to inform improvements to the reflection prompt so as to engage more students at a higher level of Bloom's. An item for future work would be to compare the assessment grades of students with high levels of engagement with the reflection to identify any possible correlations between student performance and engagement; this was not performed in this study as the number of students with high levels of engagement did not meet the desired sample size with which to perform such an analysis.

Conclusions

This work presents a method for measuring student engagement and learning using reflections coded for levels of Bloom's Taxonomy. The method is applied to a reflection assignment in a fluid dynamics course where students are prompted to reflect on their quiz performance prior to knowing the solutions. Student responses were first coded for Bloom's Taxonomy critical thinking level. Then, responses were coded as *Summary*, summarizing what was done on the quiz, and *Commentary*, active reflection and opportunities for improvement. A significant difference was found in several Bloom's Taxonomy categories for students engaging in *Summary* or *Commentary* reflection. Students were more likely to be engaging the lower four levels of Bloom's while *Summarizing* their quiz results, rather than *Commenting* on them. The final Bloom's level for this study, *Evaluate*, did not have a significant difference between *Summary* and *Commentary*, but it was also applied infrequently in the reflections compared to the other levels. This work serves as a basis for understanding how students reflect on complex topics, such as hydrostatics. In future work, this method will be applied to all six quizzes in the course.

References

[1] J. J. A. Selter, "Infusing Professional Skills Development into Co-op Student," in *2012 ASEE Annual Conference & Exposition*, 2012, pp. 25.777. 1-25.777. 3.

[2] L. R. Lattuca, P. T. Terenzini, J. F. Volkwein, and G. D. Peterson, "The changing face of engineering education," *BRIDGE-WASHINGTON-NATIONAL ACADEMY OF ENGINEERING-,* vol. 36, no. 2, p. 5, 2006.

[3] S. R. Brunhaver, R. F. Korte, S. R. Barley, and S. D. Sheppard, "4. Bridging the Gaps between Engineering Education and Practice," in *US engineering in a global economy*: University of Chicago Press, 2018, pp. 129-164.
[4] B. E. Barry, M. W. Ohland, K. J. Mumford, and R. A. Long, "Influence of job market conditions on engineering cooperative education participation," *Journal of Professional Issues in Engineering Education and Practice,* vol. 142, no. 3, p. 04015017, 2016.
[5] R. Ammerman and P. Sen, "An Undergraduate Power Engineering Curriculum: A Unique and Practical Approach to Bridging the Gap Between Academia and Industry," in *2006 Annual Conference & Exposition*, 2006, pp. 11.211. 1-11.211. 12.
[6] Y. V. Shuhailo and T. M. Derkach, "Project-based learning for undergraduate engineering students minoring in textile technology and design," in *Journal of Physics: Conference Series*, 2021, vol. 1840, no. 1: IOP Publishing, p. 012042.
[7] K. Gavin, "Case study of a project-based learning course in civil engineering design," *European Journal of Engineering Education,* vol. 36, no. 6, pp. 547-558, 2011.
[8] A. Shekar, "Project-based learning in engineering design education: sharing best practices," in *2014 ASEE Annual Conference & Exposition*, 2014, pp. 24.1016. 1-24.1016. 18.
[9] M. T. Neal, "Development, evaluation, and impact of a hands-on introductory course in mechanical engineering," The Ohio State University, 2013.
[10] "https://2110.me.gatech.edu/home." (accessed 2.10.2022, 2022).
[11] M. Stains *et al.*, "Anatomy of STEM teaching in North American universities," *Science,* vol. 359, no. 6383, pp. 1468-1470, 2018.
[12] B. Bloom, "Bloom's taxonomy," ed, 1956.
[13] E. Evans, J. Menold, and C. McComb, "Critical Thinking in the Design Classroom: An Analysis of Student Design Reflections," in *International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, 2019, vol. 59216: American Society of Mechanical Engineers, p. V003T04A012.
[14] C. Rodgers, "Defining reflection: Another look at John Dewey and reflective thinking," *Teachers college record,* vol. 104, no. 4, pp. 842-866, 2002.
[15] J. Dewey, "How We Think. A Restatement of the Relation of Reflective Thinking to the Educative Process, Boston etc.(DC Heath and Company) 1933," 1933.
[16] B. Baruah, T. Ward, and N. Jackson, "Is reflective writing an effective peer assessment tool for students in higher education?," in *2017 16th International Conference on Information Technology Based Higher Education and Training (ITHET)*, 2017: IEEE, pp. 1-6.
[17] J. M. Williams, "The engineering portfolio: Communication, reflection, and student learning outcomes assessment," *International Journal of Engineering Education,* vol. 18, no. 2, pp. 199-207, 2002.
[18] I. El Bojairami *et al.*, "UTILITY AND IMPLEMENTATION OF REFLECTION IN DISTINCT TYPES OF ENGINEERING COURSES," *Proceedings of the Canadian Engineering Education Association (CEEA),* 2019.
[19] G. M. Sparks-Langer, J. M. Simmons, M. Pasch, A. Colton, and A. Starko, "Reflective pedagogical thinking: How can we promote it and measure it?," *Journal of teacher education,* vol. 41, no. 5, pp. 23-32, 1990.
[20] J. H. Powell, "The reflective practitioner in nursing," *Journal of Advanced Nursing,* vol. 14, no. 10, pp. 824-832, 1989.
[21] D. Kember, J. McKay, K. Sinclair, and F. K. Y. Wong, "A four-category scheme for coding and assessing the level of reflection in written work," *Assessment & evaluation in higher education,* vol. 33, no. 4, pp. 369-379, 2008.

[22] D. Kember, *Reflective teaching and learning in the health professions: Action research in professional education*. John Wiley & Sons, 2008.

[23] M. Girgis, "A New Engineering Taxonomy For Assessing Conceptual And Problem Solving Competencies," in *2010 Annual Conference & Exposition*, 2010, pp. 15.64. 1-15.64. 15.

[24] D. R. Krathwohl, "A revision of Bloom's taxonomy: An overview," *Theory into practice,* vol. 41, no. 4, pp. 212-218, 2002.

[25] R. M. Marra, B. Palmer, and T. A. Litzinger, "The effects of a first-year engineering design course on student intellectual development as measured by the Perry scheme," *Journal of Engineering Education,* vol. 89, no. 1, pp. 39-45, 2000.

[26] M. M. Lombardi and D. Oblinger, "Approaches that work: How authentic learning is transforming higher education," *EDUCAUSE Learning Initiative (ELI) Paper,* vol. 5, 2007.

[27] A. Vaidya, "Contributions to the Teaching and Learning of Fluid Mechanics," vol. 6, ed: Multidisciplinary Digital Publishing Institute, 2021, p. 269.

[28] D. L. Bondehagen, "Inspiring Students to Learn Fluid Mechanics through Engagement with," in *2011 ASEE Annual Conference & Exposition*, 2011, pp. 22.887. 1-22.887. 10.

[29] L. Albers and L. Bottomley, "The impact of activity based learning, a new instructional method, in an existing mechanical engineering curriculum for fluid mechanics," in *2011 ASEE Annual Conference & Exposition*, 2011, pp. 22.1467. 1-22.1467. 12.

[30] J. K. Martin, J. Mitchell, and T. Newell, "Work in progress: Analysis of reliability of the Fluid Mechanics Concept Inventory," in *34th Annual Frontiers in Education, 2004. FIE 2004.*, 2004: IEEE, pp. F1F-3.

[31] J. Martin, J. Mitchell, and T. Newell, "Development of a concept inventory for fluid mechanics," in *33rd Annual Frontiers in Education, 2003. FIE 2003.*, 2003, vol. 1: IEEE, pp. T3D-T3D.

[32] K. Z. Mejia *et al.*, "Benefits of Codesigning with Educators as Faculty Development," in *2021 ASEE Virtual Annual Conference Content Access*, 2021.

[33] D. A. Schon, *The reflective practitioner: How professionals think in action*. Basic books, 1984.

Appendix

Table 1. Coding Guide and Examples for Remember

Indicator	Examples
Student cites/states facts/definitions, memorized equations not in the context of the way they are solving the problem	• "I know that pressure increases with depth, and that pressure acts normal to the surface." • "Gravity act downwards and that should not change regardless of whether the surface is slanted or not." • "I understood that gage pressure uses atmospheric pressure as its starting point, whereas absolute pressure uses zero as its starting point."
Student references equations	• "For 6.1.a and 6.1.b, I started out by asserting that Pabs = Pg + Patm." • "For solving problem 3, seeing that it was a "gate at the bottom of the tank" problem, I knew that I would need to find equations for P(z), Fpx, Fpz, and their corresponding moments (Mv and Mh) because we have needed those key equations in this type of problem every time." • "This approach being defined as Fr = (Gamma)*(hc)*(A), with hc being the depth from the liquid surface to the geometric center of the gate, and A being the area of the gate."
Student notices a mistake (either during the test or during reflection) but does not correct the mistake	• "When I tried to solve the horizontal force component, the most difficult part of that process was finding what values to integrate on and I ended up using something that I now think is wrong." • "Oh, I just realized I didn't calculate volume correctly." • "Quickly looking back over my quiz solutions to fill out this reflection, I noticed my integral for FPX were relative to the origin only and did not account for the depth h."

Table 2. Coding Guide and Examples for Understand

Indicator	Examples
Student demonstrates understanding of how an equation/fact is to be used	• "To solve part a, I drew the pressure distributions based on the fact that pressures will act normally to the surfaces and increase with fluid depth." • "Since atmospheric pressure is constant, I only had to lengthen the lines by a set amount to adjust for the atmospheric pressure." • "I also kept in mind that the fluid is static and so the sum of all my forces should be equal to zero since it is in equilibrium."
Assumption: student makes assumption that comes directly from the problem statement	• "The problem statement told me that the fluid had a uniform and constant density which allowed me to adequately gage the way the pressure vectors were supposed to be arranged." • "I assumed that the shape of the gate's base is square, which in turn makes the cross-sectional area for the gate to be (b2)." "This approach being defined as Fr = (Gamma)*(hc)*(A), with hc being the depth from the liquid surface to the geometric center of the gate, and A being the area of the gate." • "I used assumptions given in the problem – like a constant density – and other that just make common sense – such as a constant acceleration due to gravity g, so that I could pull gamma out of integrals as a constant."
Student demonstrates ability to understand important	• "Problem 3 was a complex problem that focused on exploring how pressure acts in a fluid, especially along another surface (i.e. a wall, gate, hinged door, etc.)."

characteristics of the problem / Student restates or summarizes problem in their own words	• "The third part of the question combines the concept of where the pressure acts as well as the previous answer of the resultant force to derive an expression for the minimum weight by summing the moments." • "I knew the components of this problem involved summing the moment about the hinge, and finding the vertical and horizontal components of the resultant force."
Student can demonstrate incorrect understanding, but still be applying understanding as it makes sense to them	• "Maybe I should have made the absolute vectors all slightly longer than their gage counterparts and included atmospheric vectors on the outside of the tank, but I was thinking more along the lines of, 'No matter how you read the pressures, the perceived pressure is the same magnitude strictly because of the depth (all things else equal)'." • "This is because the container was drawn closed, and there was no triangle on top of the water, so I assumed that there was no atmospheric pressure acting on the system." • "I was not given enough information on the dimensions of the container of the tank to solve for the area of the rectangle plus the area of the triangle and sum those together to find the volume so I was unable to find the vertical force components of the hydrostatic pressure on the gate."
Student understands what certain equations mean and the context of the current problem they are solving	• "Knowing that Pabs = Pgage + Patm it makes sense that there would be in offset for absolute pressure in the diagram to account for atmospheric pressure." • "And then we can use the fact that pressure = rho * g * h and add any other pressures accordingly to find PA and PB separately, then we can use the fact that the atmospheric pressure is the same for both separate manometers and use that to relate PA to PB, which would then give us the final equation for the closed manometer with the combined bulbs." • "I know that gauge pressure increases linearly with [depth] as in the formula it equals -gz(rho)."

Table 3. Coding Guide and Examples for Apply

Indicator	**Examples**
Free Body Diagram: Student completes FBD as part of a process they are repeating	• "I attempted to draw a free body diagram and do the moments about the hinge-like point at the bottom of the gate but I am not sure if that was the correct approach or not." • "To set it up, I first familiarized myself with the problem by drawing pictures, labeling axis and understanding what it was asking for • "For part (b), finding the resultant force, I drew a free body diagram to start with the forces of pressure that were acting on the gate."
Assumption: student assumes from practice/applies the ability to make correct assumption but does not demonstrate reasoning behind it	• "I assumed the centroid was equidistant from both ends of the gate, which also implies I assumed the density and weight of the door was evenly distributed." • "Another assumption I made was that the origin lied at the hinge of the slanted hatch." • "I assumed that for this problem we were using gage pressure and that the liquid was not compressible, so nothing was deforming."
Student applies skill they have practiced before	• "This equation had worked for me for past problems, and I thought that this problem was a good chance to use that method." • "For Fpz, I also used the formula, but I am not very good with double integrals so I decided to make the assumption that the force acts halfway down the gate (after being stuck on this portion for the longest time compared to other problems), which is an assumption we have made several times in homework questions."

	• "I had used that method for the homework as well, and I felt pretty confident that I knew how to do it."
Student uses an equation to define a system	• "For part (a), drawing the diagrams, I used the formula of Pabs = Pg + Patm to help guide me on my diagrams." • "I decided to use the given force equations for hydrostatic pressure, and simply plugged in variables I knew for Fpx (which was the horizontal component)." • "This can easily be solved by the product of the specific weight, gamma, and the volume that it occupies, which is h*b*L*cos(theta) minus the volume of the triangular prismatic space under the gate."
Student solves equations even when stating they are unsure	• "For the last question, I didn't know with 100% certainty of which formula to use, but since I saw that it gave us the distance of the forces acting on the gate, I decided to use the moment at the hinge of the gate to solve this problem" • "I attempted by writing my moment equations and drawing my free body diagrams but I still felt like I did not have any enough information to solve the problem in addition to the fact that I actually did not know how to continue." • "I also wasn't fully confident in how I solved the multivariable integral in part 3 but from what I remember of multi I believe my solution was at least on the right track."
Student solves or implies that they solved equation	• "The fluid directly above the hatch most closely resembled a 3D trapezoid, and by multiplying this volume times the specific weight γ, I was able to find FPZ and, as a result, RPZ." • "I took the sum of the moments and used that to find the force of the weight." • "I used the length L and the angle theta of the gate that was given to find the z component and the x component."
Student states or re-states answer: emphasis on the action of solving the problem	• "I solved an expression for the minimum weight from the sum of the moments equation." • "After solving the cross products and rearranging the equation for the variable W, I was able to find the expression for the minimum weight of the gate that will prevent itself from opening." • "Dividing the monstrous expression for Mw by L/2, a final expression for Wmin was thus obtained."
Student catches mistake and re-calculates equation/describes correct answer	• "What I should have done was use those centroids to find the horizontal and the vertical moments summed them and set that equal the weight of the gate taking into account the angle in which it was at." • "Finally, I initially defined right to be +x direction, but eventually reversed it because I saw that +x is defined to be pointing left in part (c) so I went back and changed the signs." • "Thinking back on it I should've said W*d – F*the distance to the pivot = 0 for the moment balance, where F is the force calculated previously."

Table 4. Coding Guide and Examples for Analyze

Indicator	Examples
Student checks/defends answer using different assumption or solution method, but does not provide some kind of assessment of the impact of their decision or different solution	• "A couple things that make me confident in this solution are that the weight is proportional to gamma and b, which makes sense conceptually; the wider the y dimension, the heavier the gate, and the denser the fluid, the heavier the gate." • "“To double check myself, I wrote out the sentence 'As z increases, P(z) decreases' and compared my sentence, my P(z) equation, and my understanding of pressure in the real world." • "For part (b), finding the resultant force, I drew a free body diagram to start with the forces of pressure that were acting on the gate."

Free Body Diagram: Student provides reasoning/logic behind why FBD is used	• "I assumed the centroid was equidistant from both ends of the gate, which also implies I assumed the density and weight of the door was evenly distributed." • "Another assumption I made was that the origin lied at the hinge of the slanted hatch." • "I assumed that for this problem we were using gage pressure and that the liquid was not compressible, so nothing was deforming."
Assumption: student makes assumption that is not directly given in the problem statement AND provides a base defense based in physical understanding of why assumption applies	• "This equation had worked for me for past problems, and I thought that this problem was a good chance to use that method." • "For Fpz, I also used the formula, but I am not very good with double integrals so I decided to make the assumption that the force acts halfway down the gate (after being stuck on this portion for the longest time compared to other problems), which is an assumption we have made several times in homework questions." • "I had used that method for the homework as well, and I felt pretty confident that I knew how to do it."
Student identifies multiple ways to arrive at an answer, chooses one, and defends it	• "For part (a), drawing the diagrams, I used the formula of Pabs = Pg + Patm to help guide me on my diagrams." • "I decided to use the given force equations for hydrostatic pressure, and simply plugged in variables I knew for Fpx (which was the horizontal component)." • "This can easily be solved by the product of the specific weight, gamma, and the volume that it occupies, which is h*b*L*cos(theta) minus the volume of the triangular prismatic space under the gate."
Student responds to new information – must indicate not having seen before, no similar examples, etc. – by analyzing an approach to solve problem	• "For the last question, I didn't know with 100% certainty of which formula to use, but since I saw that it gave us the distance of the forces acting on the gate, I decided to use the moment at the hinge of the gate to solve this problem" • "I attempted by writing my moment equations and drawing my free body diagrams but I still felt like I did not have any enough information to solve the problem in addition to the fact that I actually did not know how to continue." • "I also wasn't fully confident in how I solved the multivariable integral in part 3 but from what I remember of multi I believe my solution was at least on the right track."
Student explains link between an equation and its application/impact	• "The fluid directly above the hatch most closely resembled a 3D trapezoid, and by multiplying this volume times the specific weight γ, I was able to find FPZ and, as a result, RPZ." • "I took the sum of the moments and used that to find the force of the weight." • "I used the length L and the angle theta of the gate that was given to find the z component and the x component."
Catching mistakes: When a student has a reason to go back and check their answer or do the problem again another way	• "I solved an expression for the minimum weight from the sum of the moments equation." • "After solving the cross products and rearranging the equation for the variable W, I was able to find the expression for the minimum weight of the gate that will prevent itself from opening." • "Dividing the monstrous expression for Mw by L/2, a final expression for Wmin was thus obtained."

Table 5. Coding Guide and Examples for Evaluate

Indicator	**Examples**
Student provides reasoning for certainty/uncertainty of applicability or	• "A couple things that make me confident in this solution are that the weight is proportional to gamma and b, which makes sense conceptually; the wider the y dimension, the heavier the gate, and the denser the fluid, the heavier the gate."

accuracy of their solution in the context of an engineering problem	• "My Reynolds number (Re = 2.45 * 10^7) seems way to high and may negate some of my laminar assumptions made when using the equation (f = Re / 64 [for laminar fluids only])." • "I tried to use the relationships of continuity I knew to solve the problem but the answer I came up with seemed too big and I knew that I wasn't working the problem the correct way."
Student evaluates the efficacy of their solution (ex: checking answers)	• "When a final value was attained for part b and c, I used the FLT system of units to make sure my answers came out to both be forces as a method of checking that my answer was consistent unit-wise." • "It might be more difficult to separate them into the x and z components, but in order to check that the solution works, it would be better to use the Pythagorean theorem with the calculated x and z components and see if it matches the total force calculated with the pressure prism method." • "It is interesting to note that the major losses are actually lower than the minor losses, and this is perfectly acceptable for pipe systems that aren't super long and have a lot of bendsz."

Table 6. Coding Guide and Examples for Summary

Indicator	Examples
Student discusses method for which they solved problem	• "For part b of question three, to find the resultant force from having static pressure on the gauge I decided to find the horizontal force component (Fpx) and the vertical force component (Fpz)." • "I used the equations given to me in lecture and applied them to the variables that were presented to me in the problem statement." • "When trying to come up with a solution for part a and b, I knew the forces had to be normal to the surface, so I started drawing perpendicular lines."
Student notes previous thoughts while solving problem	• "First, I was unsure of how to draw the difference between gauge pressure and absolute pressure, but then I remembered that in this situation the gauge pressure would be less than absolute pressure so I drew the absolute pressure arrows with grater magnitude." • "When I was taking the quiz, I got confused about how the pressure with respect to z should be written for this problem." • "For the third part of the question, I was mainly confused on the trigonometry of the problem rather than the concept of the forces itself."
Student restates important aspects of problem in own words	• "Part c was really just a moment balance." • "For part B, I needed to find the resultant force vector, so I solved for the components first Fx, Fz." • "When seeing part B, I knew I would need to use the Vertical and Horizontal Force components due to hydrostatic pressure."

Table 7. Coding Guide and Examples for Commentary

Indicator	Examples
Student makes new observations while reflecting	• "While this made some calculations easier, such as the computation of the moment about the hatch in order to achieve its static equilibrium, I believe this assumption also tripped me up during part b."

	• "Quickly looking back over my quiz solutions to fill out this reflection, I noticed my integral for FPX were relative to the origin only and did not account for the depth h." • "Also, upon reviewing the quiz, I noticed I screwed up the Trig for the moment equation, in that I used sin theta to equate the moment arm for the weight force when I should have used cos theta."
Student outlines what they should have done / would do now if they had to solve problem again	• "To approach this part differently, I would indicate the Patm at the surface to distinguish the difference between gage pressure and absolute pressure." • "If I were to attempt this problem again, I would change the z bounds for my Fpx integral, because I just realized that I did not account for the depth of the gate." • "Had I been less lazy, a good option for part b would've been to double check this method with the provided equations to see if they'd give the same thing."
Student comments on their performance	• "I think I spent too much time worrying about whether my geometry and integral bounds were correct." • "Again, I may have been wrong in my constant of integration and therefore all my answers would technically be incorrect, but I think in terms of process I did everything right here." • "I will admit I had been challenged by submerged surfaces problems in homework and in-class worksheets, however I believe I successfully completed the problem on the quiz."