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Promoting Equity and Cognitive Growth: The Influence of an Authentic Learning Assignment on Engineering Problem-Solving Skills

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ABSTRACT

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

Fluid Mechanics and other upper-level engineering courses rely upon a student's prior knowledge of basic engineering principles and abstract understanding of mathematical concepts to comfortably approach new problems in this field. It is one of the first courses in which more abstract concepts are given physical and applicable meaning. As such, this course is a critical opportunity to teach higher order engineering skills, such as problem definition, problem simplification, modeling, and solution analysis. These skills are required to solve ill-structured or open-ended engineering problems, which are the majority of problems an engineer will face during their career. Yet, the vast majority of problems students are assigned are well-structured or closed-ended problems. There is a need to scaffold student learning from simple, well-posed textbook problems to more open-ended problems requiring higher levels of critical thinking. One possible strategy is to use authentic learning assignments in upper-level lecture-based engineering courses.

Employing Bloom's taxonomy as a framework for evaluating cognitive engagement levels, our analysis of student reflections sheds light on a significant increase in higher-order cognitive skills manifested during the completion of the Design Your Own Problem (DYOP) as opposed to the conventional quiz assignments. This heightened cognitive engagement is marked by an increased emphasis on analysis, evaluation, and creativity, signifying a significant shift towards more sophisticated problem-solving strategies among students. Notably, this trend remains consistent across diverse student cohorts, irrespective of gender, racial or ethnic background, or prior experience in internship or Co-Op programs. These findings underscore the inclusive nature of the DYOP framework, demonstrating its capacity to facilitate equitable learning experiences for all engineering students, regardless of their individual backgrounds or prior academic achievements.

Furthermore, the study elucidates the adaptable nature of the DYOP approach, as it accommodates students with varying levels of proficiency, ranging from those who demonstrate exemplary performance in traditional quizzes to those who require additional revisions and support. Notably, the analysis reveals that students with prior Co-Op experiences, although able to draw from their real-world exposure, did not necessarily exhibit a substantial advantage in terms of the heightened cognitive engagement observed during the DYOP. Similarly, the study highlights the potential of the DYOP to serve as a valuable revisiting tool, enabling students to consolidate their understanding of the course material and bridge any existing gaps in their comprehension, regardless of their initial performance levels. These findings highlight the transformative potential of the DYOP framework in nurturing comprehensive and inclusive learning experiences, all while introducing minimal disruptions to the conventional pace of lecture-style engineering courses.

Keywords: Authentic learning assignment, Bloom's Taxonomy, Critical-thinking, Fluid Mechanics, problem solving

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INTRODUCTION

The widening gap between engineering curriculum and practice[1] has led to recent graduates facing challenges in navigating less-defined problem spaces, as noted by employers[2]. These graduates often require additional workplace training to acquire missing competencies[3]. While co-op programs have been introduced to bridge this gap[4,5], they may not be feasible for schools with limited industry partnerships or for students due to location and timing constraints. This disproportionately affects rural and disadvantaged communities. Although project-based learning initiatives have been implemented, particularly in design areas[6-8], and some institutions have introduced lab courses like Georgia Tech's ME2110[9,10], such student-focused activities account for less than 20% of class time in engineering education[11]. The predominance of didactic, lecture-based teaching methods[11] underscores the need for instructional approaches and assessments that can be deployed in traditional lecture-based courses that enhance student outcomes and prepare them for real-world scenarios, highlighting a need for deeper learning experiences.

Authentic Learning Assignments[12,13] might easily begin to address this gap for lecture-based courses. The goal of this study is to assess the effectiveness of an authentic learning assignment, Design Your Own Problem (DYOP), as measured by levels of learning as characterized using Bloom's Taxonomy[14], 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 their DYOP. Using the method outlined by Evans et al.[15] and Yraguen et al.[16], we coded reflections written by students about their quiz and DYOP assignments for levels of learning based on Bloom's Taxonomy. We hypothesize that the DYOP increases a student's engagement with the subject matter material by means of Bloom's Taxonomy compared to that of a traditional quiz assessment.

BACKGROUND

Upper-Level Interventions

Engineering education research is often focused on first-year or lower-level courses in the engineering track[12,17,18]. 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[19-25]. These studies largely focus on problem-based learning, multi-disciplinary labs, and the use of computation as a teaching tool. Prior interventions modify the course delivery style by flipping classrooms, incorporating many activities into lecture, designing complex projects for students to complete, and more[20,21]. While these evidence-based practices typically have positive outcomes for student learning, the time and effort required by faculty to effectively implement them often presents a significant barrier to adoption. Incorporating an authentic learning assignment[12,13] such as the one presented here does not change course delivery or the topics that can be covered in a given course period.

Reflections

Engineering education has evolved to incorporate problem-based learning and insights from the learning sciences, with reflection emerging as a longstanding tool for enhancing student learning[26,27]. Even so, its application in technical engineering courses remains limited. Instead, reflections in engineering education often focus on behavior-based aspects rather than traditional engineering content assessment[28-30].

Reflection assignments can be categorized to quantify levels of learning. Multiple studies have offered categorical ways in which reflections can be coded[15,16,31-34]. Typically, these coding schemes focus on the student's ability to reflect. While these categories may correlate to different levels of learning, they do not precisely evaluate the level or type of learning a student is engaging in with respect to the subject matter material. Other authors[15,16] have designed coding schemes that focus on the level of learning, as defined by Bloom's Taxonomy[14], to measure a student's cognitive process rather than their "depth" of reflection. Bloom's Taxonomy's hierarchical structure categorizes types of learning into 'remember', 'understand', 'apply', 'analyze', 'evaluate', and 'create'.

Framework

The Taxonomy of Educational Objectives, better known as Bloom's Taxonomy, was created to be a tool for measuring educational goals and standards [35]. The revised version of the taxonomy we reference in this paper has the levels Remember, Understand, Apply, Analyze, Evaluate, and Create, from lowest level to highest level. This taxonomy is referenced in numerous educational studies as a common method for evaluating educational material and the level of cognitive engagement it enables [36] [37] [38]. Girgis[18] correlated Bloom's Taxonomy with ABET criteria, emphasizing higher Bloom's levels' importance in applying engineering knowledge post-graduation and fostering lifelong learning. This correlation suggests that students engaging in higher levels of learning can more effectively apply engineering principles in their careers, with design and project-based courses naturally encompassing analyze, evaluate, and create levels.

METHODS

The current IRB-approved 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 an authentic learning assignment. The following question guided our research: How does the novel authentic learning assignment, Design Your Own Problem (DYOP), affect engagement at various levels of learning (as defined by Bloom's Taxonomy) when compared to traditional assessments?

Course Structure

This study was conducted in a fluid mechanics course in the mechanical engineering department at the Georgia Institute of Technology in the Spring of 2021. The course was offered in a virtual format due to the COVID-19 pandemic. The format of delivery used a mixture of synchronous and asynchronous lectures. Theory and technical information were delivered using the asynchronous lectures in 5–15-minute videos, and the synchronous course time was used primarily to complete example problems and facilitate discussion. The course included 8 assessments: six quizzes and two projects. The projects were submitted as a midterm and a final.

After each assessment, the students submitted a one-page reflection of their work within 24 hours of completing the assignment. The reflection component of the assessment was graded for completion. The assessments and reflections were a mandatory component of the course regardless of a student's choice to participate in the current study. The format of the quizzes, the DYOP projects, and reflection assignments will be described in detail in the following sub-section.

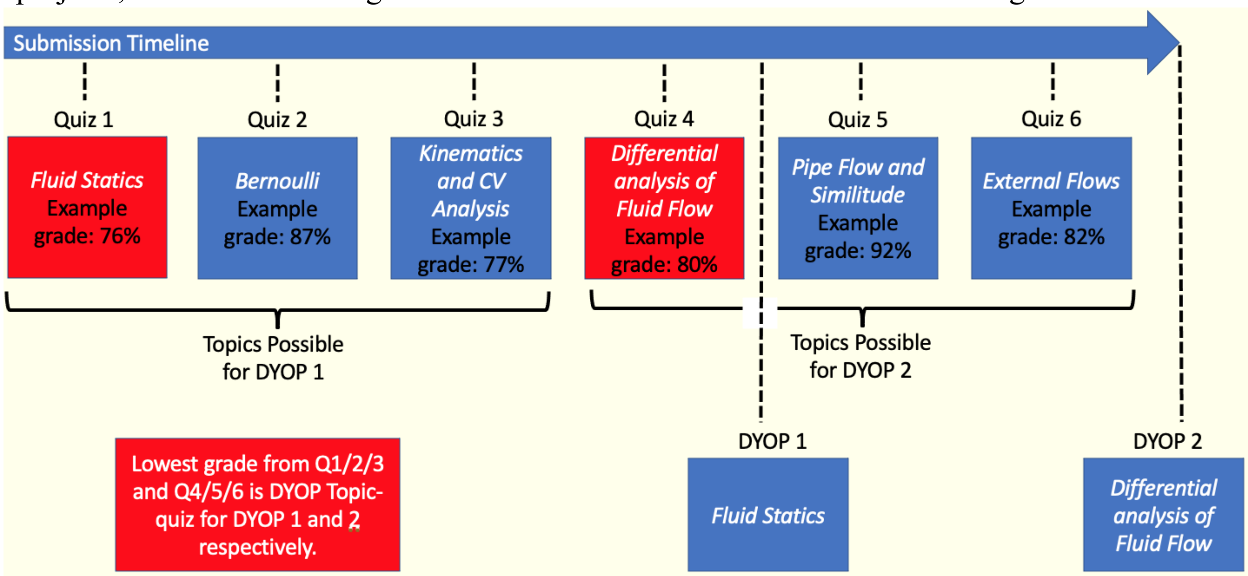

Figure 1. Diagram of assessment work-flow throughout semester. An illustration of how a student would select their topic for their DYOP assignment is given. Numbers indicating grades are provided as an illustration only and do not come from a student who participated in this study.

The assessments were broken up into two sections. The first section included quiz 1, quiz 2, quiz 3, and the midterm project. The second section included quiz 4, quiz 5, quiz 6, and the final project. 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. Students completed DYOP projects on the quiz topic the student received their lowest grade on for that section. For example, if a student received a 76% on quiz one (Q1), an 87% on Q2, and a 77% on Q3, the student would complete their midterm project on quiz-topic one: hydrostatics. We then define Q1 (in this example) this as the student's *topic quiz*. If a student received equally low grades on more than one quiz in the same section (e.g. a 76% on Q1 and Q3), they were able to choose between the topics. An illustration of submission timeline for the course assessments and example grades can be seen in Figure 1. The students began working on their midterm projects after they received all their quiz grades for the first half of the semester but did not turn in the midterm project until after they completed quiz four.

Participants

One of the students in the 55-person class was ineligible to participate in the study, leaving 54 eligible students that elected to participate in the study. As seen in Table 1, of the eligible students, 37 identify as a man, 16 identify as a woman, and one identifies as non-binary. The majority of the class, 31 students, are white, and 28 students identify as students of color and more than one race. Additionally, nearly half of the students participated in an internship or Co-Op in previous semesters. Specific details of the demographic data that was collected can be seen in Table 1.

Table 1. Demographics Information

Individual-Level Variables	N	Percent [%]
Gender		
Woman	16	29.6
Man	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%**

Quiz Assessment

Students took 6 quizzes throughout the semester. Each quiz followed the same general format: two-to-three multiple-choice questions and one-to-two free-response questions. The multiple-choice questions were sourced from the Fluid Mechanics Concept Inventory[39,40]. These questions were chosen because they had been designed specifically to assess a student's conceptual understanding of key topics in Fluid Mechanics. The free-response questions focused more heavily on a student's ability to interpret a problem statement and appropriately apply a calculation-based solution strategy. An example quiz is included in the appendix A1 for reference.

Reflection Assignment

While reflections often focus on guiding students to reflect on their preparation for an assessment and more behavior-based outcomes, this reflection prompt was developed with the goal of having students reflect specifically on their solution strategies. The prompt was developed over the course of three months in a collaborative faculty development seminar on reflections[41]. The prompt asks students to describe their problem-solving process and identify the areas that challenged them. In this way, students are encouraged to engage with the material for a second time in a low-pressure environment. One key component of this reflection assignment is that students were asked to reflect on their submissions prior to receiving the solutions to the quiz. Therefore, students had to use their best judgement and conceptual understanding of the material to analyze and reflect on their work. The reflection prompt was as follows:

Please reflect on/describe your process for solving problem during the quiz. 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?*

The reflection prompt was graded for completion only. To promote honest reflections, students were told that the instructor would not read the reflections until after the semester had ended.

DYOP Assignment

The DYOP assignment is an authentic learning assignment in that it is designed to begin transitioning students towards engaging with subject matter material in a manner authentic to practicing engineers. In particular, this assignment asks students to research a real-life topic that can be modelled leveraging one or more of the strategies used in class. Students are tasked with researching the application, modelling the problem (which requires them to research fluid properties, equipment specifications, and system requirements), and then solving the problem. This type of assignment is also commonly referred to as *Student Generated Questions*[42]. An example of the assignment prompt used for the DYOP can be found in appendix A2.

Coding Bloom's Taxonomy

Student reflections were coded using the codebook developed by the researchers to map student responses to the various levels of Bloom's taxonomy. Bloom's taxonomy was leveraged due to its link to levels of critical thinking used by students[15,16]. The complete codebook can be found in Yraguen et al.[16] and has been reproduced in appendix A3 for ease of reference. Examples of statements coded at each level for each sub-item can be found in Yraguen et al. as well. The reflections were coded at each level of Bloom's taxonomy in complete sentences such that each sentence could be coded as one or more of the Bloom's taxonomy levels. For example, a sentence can be coded as both the *Remember* and *Understand* levels of Bloom's taxonomy. The only code that is considered mutually exclusive with the various Bloom's levels is the *Not Applicable (N/A)* code. The decision to code reflections as complete sentences was made to reduce interrater error. For example, some sentences might have clauses that encompass themes from multiple levels of Bloom's simultaneously, while others may have two clauses that represent different Bloom's taxonomy levels. An example of a sentence coded as both *Understand* and *Remember* is shown 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."*

In the example above, the student understood the prompt of the question and the important characteristics, so the first independent clause is highlighted blue to indicate this student is at the *Understand* level of Bloom's taxonomy. The second independent clause is the student describing their decision to refer to their notes from class which includes a set of equations and definitions, so this section is highlighted yellow indicating this student is in the *Remember* level of Bloom's Taxonomy. Therefore, the whole sentence is coded as *Understand* and *Remember*. Sentences coded as N/A included statements that were often focused on the student's emotional state or material related more to the experience of taking the quiz rather than the quiz content itself.

After the first researcher coded the reflections, a second researcher coded a random sample of 25% of the students for each assessment. Cohen's Kappa was used to evaluate the strength of interrater agreement. The kappa values for each assessment are shown in Table 2 categorized by Bloom's taxonomy level in each column. The values in the table range from moderate (0.41-0.6) to near perfect (0.81-1) agreement, with half showing substantial agreement (0.61-0.8). For this study, a minimum acceptable Kappa value of 0.41 was set. Given sufficient training, interrators were able to meet this minimum requirement consistently for all data coded.

Table 2. Cohen's Kappa agreement for Bloom's Taxonomy codes

	Cohen's Kappa							
	Remember	Understand	Apply	Analyze	Evaluate	Create	N/A	Total Agreement
Quiz 1	0.69	0.49	0.61	0.61	0.71	1	0.81	0.71
Quiz 2	0.62	0.55	0.7	0.67	0.92	1	0.75	0.74
Quiz 3	0.79	0.73	0.8	0.46	0.97	1	0.92	0.81
Quiz 4	0.54	0.5	0.68	0.5	1	1	0.88	0.72
Quiz 5	0.46	0.51	0.66	0.44	1	1	0.85	0.70
Quiz 6	0.81	0.75	0.83	1	1	1	0.93	0.90
DYO P 1	0.81	0.63	0.86	0.92	0.94	0.74	0.67	0.79
DYO P 2	0.91	0.97	0.97	0.97	0.99	0.97	0.94	0.96

Coding Coverage Organization

Once reflections had been coded for each level of Bloom's, the relative level of student-engagement at each level is quantified by calculating the percent coverage of each code. For example, out of a student's entire reflection, 30% of the reflection might be coded as *Remember* while only 5% is coded as *Analyze*. This quantification allowed us to better analyze larger trends in engagement level across different assessments and student groupings. This method is known as "quantizing" qualitative data which was first described in 2003 by Sandelowski[43,44]. This process allows the use of statistical tests without generalizing the population and to utilize a categorization framework[45]. The percent coverage is calculated using the word count (as opposed to character count). A comparison between word count and character count was conducted and it was found that the difference in percent coverage calculated between the two methods was less than 1%. This is approximately equivalent to 10 words which is well within the uncertainty levels at each code based upon the interrater agreement. Therefore, the word count metric was used for this calculation as it was less cumbersome to extract from the coding software. The reader should note that the percent coverage for each reflection can sum to greater than 100%. This is due to the fact that codes at each Bloom's level are not mutually exclusive. This analysis allows us to calculate the percent coverage at each level of Bloom's Taxonomy for each student.

To answer the aforementioned research questions, this study conducted statistical analyses to determine the percent-coverage difference between the students' topic-quiz reflections and DYOP reflections. Additional analyses were conducted to evaluate the effect of topic-quiz grade, demographics, and work experience.

Topic-Quiz to DYOP Comparison

While there were 54 students that participated in this study, each student submitted two topic quiz and DYOP assignment reflections that can be included for analysis (e.g. 108 total submissions). Only students who completed reflections for both their topic-quiz and corresponding DYOP were included in the analysis resulting in an N = 97. The percent coverage comparison between the topic quiz and DYOP was made for each level of Bloom's Taxonomy.

The coverage data spread for each taxonomy level is different; some code coverages have a normal, non-skewed spread with no outliers, while others have a very skewed, non-normal spread with outliers. Fortunately, the sample size for this data is sufficiently large and therefore the central limit theorem can be imposed such that the t-test is used for analysis. To verify the efficacy of this assumption, the t-test, Wilcoxon-signed rank test, and sign tests were run. These resulted in consistent conclusions throughout, and therefore only the t-test results are presented here.

Student Groupings by Topic-Quiz Grade

This analysis aims to assess the change in a student's engagement level based on their initial topic quiz grade. We seek to answer questions such as whether a student who received an F on their topic quiz showed more improvement in Bloom's level engagement during DYOP compared to a student who received a B. The dataset is divided into groups based on topic quiz grades, which averaged 67%. Due to the skewed distribution towards low grades, a K-means clustering analysis[46] was employed to create evenly distributed grade groups (n=29, 35, 33) with grade divisions at 65.5% and 79.1%. DYOP grades were not considered due to minimal variation (mostly A grades). Comparisons between groups were made by running ANOVAs on: 1. the percent coverage difference between the DYOP reflection and Topic-quiz reflection, 2. the percent coverage for the DYOP reflections, and 3. the percent coverage for the topic quiz reflections. For any between group comparison that indicated significant differences, Tukey's Honestly Significant Difference was conducted.

Student Grouping by Demographics

To test whether this DYOP assignment impacted certain groups of students more than others, demographic comparisons were conducted. To conduct comparisons, students were grouped by work experience status, gender-minority status, and race/ethnicity-minority status. First students were grouped by relevant work-experience (e.g. having participated in an engineering internship or co-op previously). Students were grouped by those who had experience (N=45) and those without (N=52). Gender differences were examined by dividing students into two groups: women/non-binary (N=30) and men (N=67). This distribution aligns with the gender-minority status in the engineering program. Race/ethnicity-based groups comprised non-white (N=48) and white (N=49) students. The non-white group includes all students that selected "Black or African American", "Asian or Pacific Islander", "Hispanic/Latinx", or "other" due to low numbers in each individual minority group. The Mann U Whitney test, suitable for non-parametric data with independent groups and no assumption of homogeneity of variance, was employed for these analyses. The independent t-test was not used due to the lack of homogeneity of variance and insufficient group sizes to impose the central limit theorem.

RESULTS AND DISCUSSION

Topic Quiz to DYOP Comparison

Table 3 shows the descriptive statistics, skewness, kurtosis and results of the t-test for the percent-coverage comparison between the topic-quiz and DYOP reflections for each Bloom's taxonomy level. For all levels of Bloom's, the mean value of the DYOP reflection coverage was significantly different from the DYOP topic-quiz reflection coverage. *Understand*, *Analyze*, *Evaluate*, *Create*, and *NA* have $p<0.001$; *Remember* has $p=0.005$; and *Apply* has $p=0.05$. Figure 2 shows a histogram of the difference in coverage percentage between the DYOP reflection and the DYOP topic-quiz reflection for each Bloom's taxonomy level. Positive values indicate higher DYOP percent-coverage compared to the Topic-quiz percent-coverage for the respective Bloom's taxonomy level, while negative values indicate the opposite.

Table 3. Descriptive statistics, skewness, kurtosis, and t-test results for comparison between DYOP and Topic-quiz coverage at all levels of Bloom's

	Difference			σ	Skewness	Kurtosis	t	p-value
	Minimum	Mean	Maximum					
Remember	-31.92	4.0	45.21	2.9	0.41	0.68	2.9	p = 0.005
Understand	-50.25	-16.7	41.20	-9.1	0.73	1.10	-9.1	p < 0.001
Apply	-56.75	-3.5	33.24	-1.9	-0.11	0.16	-1.9	p = 0.05
Analyze	-33.50	5.7	30.25	6.4	-0.14	3.81	6.4	p < 0.001
Evaluate	-7.10	13	37.56	12.3	0.38	-0.79	12.3	p < 0.001
Create	0.00	26.6	75.23	17.3	0.65	0.32	17.3	p < 0.001
NA	-61.46	-20.6	29.50	-5.0	-0.16	-0.70	-5.0	p < 0.001

It can be seen in Figure 2 that *Remember*, *Analyze*, *Evaluate*, and *Create* Bloom's levels show higher percent-coverage in the DYOP reflection compared to that of the topic quiz reflection. It can also be seen that *Understand, Apply,* and *NA* Bloom's levels show lower percent-coverage in the DYOP reflection compared to that of the topic-quiz reflection. These results might be explained by the fact that students were requested to write a 1-page reflection for both the topic quiz and DYOP. It is reasonable that for some levels to increase, others must decrease. Since problems designed by students on the DYOP were of similar complexity as those they completed on quizzes, a decrease in percent coverage at the *Understand* and *Apply* levels indicates less emphasis placed on engagement at these levels during reflection rather than less engagement at them. Indeed, it would be difficult for students to engage at the *Analyze* level without first having engaged fully in the *Understand* and *Apply* levels. The decrease in *N/A* (-20.6%), however, can be attributed to a decrease in anxiety felt by students while completing the DYOP assessment compared to a traditional quiz.

This highlights the unintended yet positive result of the DYOP intervention that students are provided an opportunity to demonstrate mastery of a course topic in a format that de-emphasizes the testing anxiety felt by most students, allowing them to focus more on course content and their own learning. In general, the higher levels of Bloom’s taxonomy showed an increase in percent coverage in the DYOP assignment, with a mean percent coverage increase of 12.86% for *Evaluate* and 26.97% for *Create.* These results underscore the effectiveness of DYOP assignments in promoting deeper engagement, especially at the higher cognitive levels of Bloom's taxonomy.

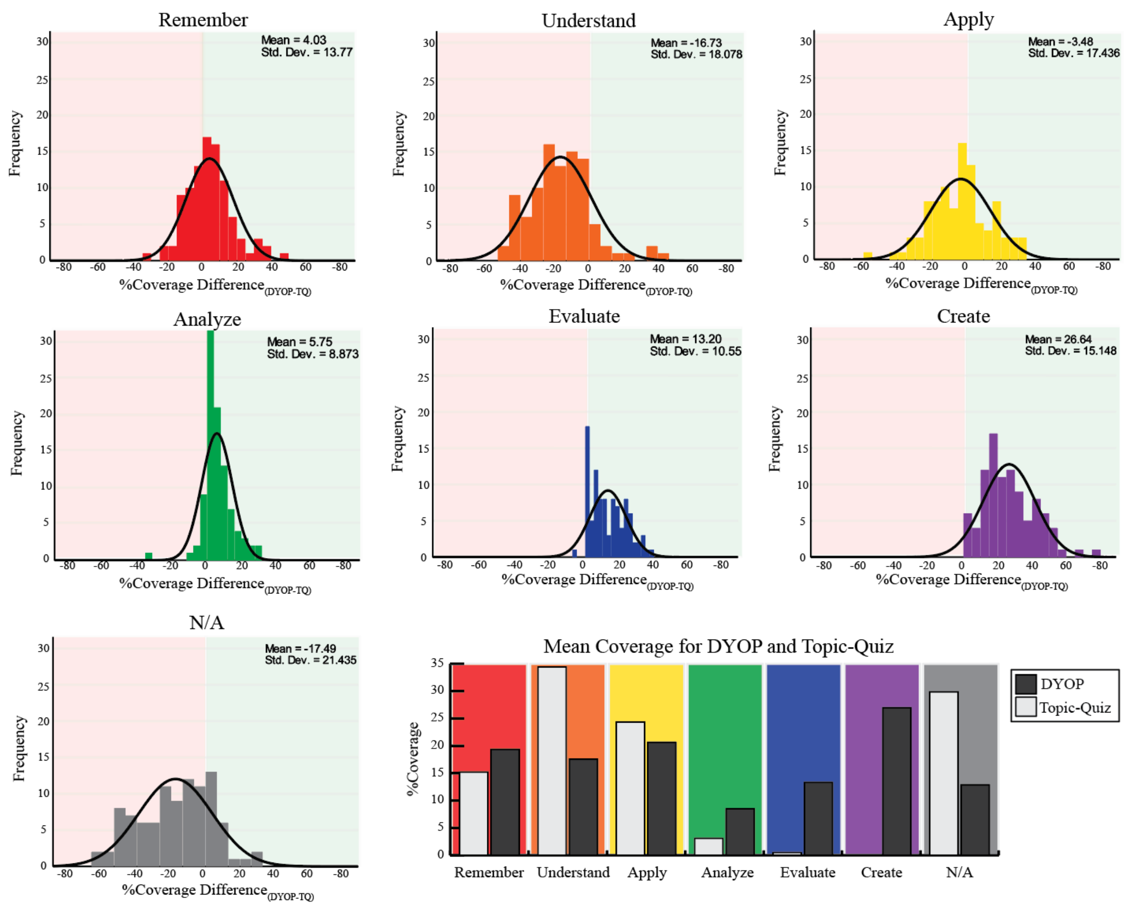

Figure 2. Histograms: %Coverage Difference between the DYOP and Topic-quiz reflections for each level of Bloom's. Bar chart: Mean %Coverage for each level of Bloom's for both the DYOP and Topic-quiz reflections

Student Groupings Comparison of Grades

Table 4 shows the results of the ANOVA that tested differences between grade-groups. The grade-groups broadly represent students who made A/B grades (group 1), C/D grades (group 2), and D/F grades (group 3). Three separate ANOVAs were run: 1. On the percent coverage difference between the DYOP reflection and Topic quiz reflection (%Coverage Difference$_{(DYOP\text{-}TQ)}$), 2. On the percent coverage for the DYOP reflections (%Coverage DYOP), and 3. On the percent coverage for topic quiz reflections (%Coverage Topic Quiz). Table 4 includes the F-statistic, with higher F-values indicating that the variance between grade groups is larger than the variance within

Table 4. ANOVA results for comparisons between grade groups.

	%Coverage Difference$_{DYOP-TQ}$		**%Coverage DYOP**		**%Coverage Topic Quiz**	
	F	p-value	F	p-value	F	p-value
Remember	1.54	p = 0.22	1.12	p = 0.33	0.36	p = 0.70
Understand	0.10	p = 0.90	0.42	p = 0.67	0.91	p = 0.41
Apply	0.44	p = 0.64	0.71	p = 0.49	0.41	p = 0.67
Analyze	9.23	*p < 0.001	9.73	*p < 0.001	4.28	*p = 0.02
Evaluate	2.35	p = 0.10	1.71	p = 0.19	1.30	p = 0.28
Create	0.09	p = 0.92	0.09	p = 0.92	-	-
NA	0.59	p = 0.59	4.11	*p = 0.02	1.17	p = 0.31

***Three ANOVAs were run to tests for between grade group differences for (1) the percent coverage difference between the DYOP reflection and Topic quiz reflection, (2) the percent coverage for the DYOP reflections, and (3). the percent coverage for the topic quiz reflections.**

grade groups, and p-value, with p < 0.05 indicating there are significant differences found between grade groups. On the percent-coverage for the Topic quiz reflections. For the most part there were no significant differences found in between grade groups. This indicates that students are engaging at the various levels of Bloom's similarly for both assessments regardless of the accuracy of their topic quiz answers. The main exception to this is at the *Analyze* level, where a significant difference was found between grade groups for each ANOVA run. To better understand the nature of this difference, the results of Tukey's HSD can be seen in Tables 5 and 6. First, for the percent coverage difference between the DYOP reflection and Topic-quiz reflection, group 1 is significantly different than groups 2 and 3 with p<0.001 and p=0.039 respectively.

Table 5. Tukey's HSD results for differences found between grade groups at the Analyze level

	%Coverage Difference$_{(DYOP-TQ)}$			**%Coverage DYOP**			**%Coverage Topic-Quiz**		
Mean Diff. / Sig.	**G1**	**G2**	**G3**	**G1**	**G2**	**G3**	**G1**	**G2**	**G3**
G1	-	8.7 / *p < 0.001	5.3 / *p = 0.039	-	7.42 / *p < 0.001	8.04 / *p < 0.001	-	-1.34 / p = 0.60	2.57 / p = 0.17
G2	-	-	-3.4 / p = 0.223	-	-	0.62 / p = 0.94	-	-	3.91 / *p = 0.01
G3	-	-	-	-	-	-	-	-	-

***Group 1: (A/B) 79.2% - 100%; Group 2: (C/D) 65.6% - 79.1%; Group 3: (D/F) 0% - 65.5%. Mean difference indicated is calculated by: row-column. Relative mean values for each category (%Coverage Difference$_{(DYOP-TQ)}$, %Coverage DYOP, and %Coverage Topic-Quiz) are indicated by their highlighted color, with blue indicating the highest value, green the middle value, and yellow the least value.**
****Note that with a high number of comparisons conducted in this analysis, the chances of a false positive increases.**

A similar result was found for ANOVA run on the percent-coverage for the DYOP reflections only. Group 1 is significantly different than groups 2 and 3 with p<0.001 for both. Last, for the ANOVA run on the percent-coverage for the topic-quiz reflections only a significant difference was found between Group 2 and 3 with p = 0.01. When looking at the DYOP reflections alone, these results indicate that the A/B group engaged at the *Analyze* level more than the C/D and D/F groups. This could indicate a possible higher-level of complexity of the problems designed by the A/B students for their DYOP assignment. Further analysis of the DYOP submissions would be required to determine if this is the case. Alternatively, when looking at the topic-quiz reflections alone, these results indicate that the C/D group engaged at the *Analyze* level more than both the A/B and D/F group while taking their quiz. This result indicates that there might exist an optimum amount of uncertainty regarding the accuracy of an answer or solution strategy that will prompt students to engage more deeply at the *Analyze* level. It follows that this optimum value would exist in the middle grade-group.

Last a significant difference was found between groups for the ANOVA run on the percent-coverage for the DYOP reflections only at the *N/A* level. A significant difference was found between Groups 1 and 3. In this case Group 3 (the D/F group) engaged at the *N/A* level more than Group 1 (the A/B group). While a majority of the *N/A* comments were representative of generalized comments on the assessment and statements representing student confidence, anxiety, and uncertainty. Further qualitative analysis is needed to infer the cause of this difference seen between groups for the *N/A* level.

Table 6. Tukey's HSD results for differences found between grade groups at the N/A level

	%Coverage DYOP		
Mean Diff. / Sig.	**G1**	**G2**	**G3**
G1	-	-6.10 / p = 0.07	-7.54 / *p = 0.02
G2	-	-	-1.44 / p = 0.02
G3	-	-	-

*** Group 1: (A/B) 79.2% - 100%; Group 2: (C/D) 65.6% - 79.1%; Group 3: (D/F) 0% - 65.5%. Mean difference indicated is calculated by: row-column.**
****Note that with a high number of comparisons conducted in this analysis, the chances of a false positive increases.**

Student Grouping Comparison of Demographics

Table 7 shows the results of the Mann-U Whitney tests run for comparison between demographic groups on (1) the percent coverage difference between the DYOP and Topic-quiz reflections and (2) the percent coverage on just the Topic-quiz reflections for each Bloom's taxonomy level for each category. No demographic category tested resulted in significant differences for any Bloom's taxonomy level. All comparisons at all levels of Bloom's had $p > 0.05$. This indicates that the student's work-experience, gender, and racial minority status did not impact their test performance, nor did it impact their potential growth at any level of Bloom's during the DYOP assignment. Participating in a Co-op is commonly perceived as a chance for students to acquire practical, real-world skills. Both students with Co-op experience and those without can leverage the DYOP to enhance their understanding of course material using real-life experiences regardless of having had the opportunity to engage in an experiential learning opportunity such as a co-op or internship. While some Co-op students incorporated their work experience into their projects, it didn't always translate into greater learning outcomes compared to their peers who did not have such an experience to draw on.

Table 7. Mann-U Whitney results for differences between demographic groups by work-experience, gender minority status, and racial minority status

	Work-Experience Status ***Co-Op vs. No Co-Op***		**Gender Minority Status** ***Male vs. Not Male***		**Racial Minority Status** ***White vs. Not White***	
	%Cov. Difference(DYOP-TQ)	%Cov. Topic-Quiz	%Cov. Difference(DYOP-TQ)	%Cov. Topic-Quiz	%Cov. Difference(DYOP-TQ)	%Cov. Topic-Quiz
Remember	p = 0.25	p = 0.22	p = 0.307	p = 0.764	p = 0.655	p = 0.303
Understand	p = 0.52	p = 0.633	p = 0.743	p = 0.357	p = 0.432	p = 0.462
Apply	p = 0.723	p = 0.806	p = 0.512	p = 0.743	p = 0.851	p = 0.104
Analyze	p = 0.827	p = 0.672	*p = 0.04	p = 0.886	p = 0.552	p = 0.472
Evaluate	p = 0.331	p = 0.603	p = 0.76	p = 0.735	p = 0.263	p = 0.976
Create	p = 1	p = 1	p = 0.696	p = 1	p = 0.977	p = 1
NA	p = 0.734	p = 0.715	p = 0.056	p = 0.115	p = 0.215	p = 0.458

*Note that with a high number of comparisons conducted in this analysis, the chances of a false positive increases.

CONCLUSION

In conclusion, this study reveals that an authentic learning assignment like the DYOP can increase student engagement with subject matter material at the higher levels of cognitive learning. Furthermore, this tool promoted cognitive growth equally across student groups based on gender, ethnicity, experiential learning experiences, and traditional assessment performance (quiz grades) highlighting its potential to be an equitable learning tool.

The analysis of percent-coverage comparison between Topic-quiz and DYOP reflections across Bloom's taxonomy levels reveals significant differences. While *Understand*, *Apply*, and *N/A* levels show lower percent-coverage in DYOP reflection compared to topic-quiz reflection, *Remember*, *Analyze*, *Evaluate*, and *Create* levels demonstrate higher coverage in DYOP reflection. These findings suggest a trade-off between different cognitive levels during reflection writing, possibly influenced by the nature of the DYOP assignment and decreased testing anxiety. Notably, higher Bloom's taxonomy levels exhibit substantial percent-coverage increases in DYOP reflection, emphasizing the effectiveness of DYOP assignments in fostering deeper engagement, particularly at advanced cognitive levels.

The ANOVA analysis revealed insights into the engagement levels of students across different grade-groups, focusing on their engagement-levels in DYOP reflections, Topic-quiz reflections, and the difference between the two. Overall, there were no significant differences found between grade-groups, suggesting similar levels of engagement on both assessments across all levels of Bloom's taxonomy irrespective of quiz accuracy. Students achieving near-perfect grades and those struggling with mastery benefitted similarly from the DYOP. However, notable exceptions were observed at the *Analyze* level, where Group 1 (A/B grades) displayed significantly higher engagement compared to Groups 2 and 3 on their DYOP reflections. This disparity indicates potential differences in problem complexity designed by students. Conversely, in Topic quiz reflections, Group 2 (C/D grades) showed greater *Analyze*-level engagement than Group 1 and 3

(A/B and D/F grades), suggesting an optimal level of uncertainty during assessment might prompt deeper analysis. Additionally, a significant difference was noted at the *N/A* level for the DYOP reflections, where Group 3 (D/F grades) exhibited higher engagement, possibly influenced by student feelings of anxiety and lack-of confidence. Further qualitative analysis is warranted to understand these discrepancies fully.

The progression of engagement at each Bloom's level between quizzes and the DYOP assignment remained unaffected by factors such as student gender, racial or ethnic minority status, or Co-op experience. Notably, both historically excluded groups in engineering, namely gender minorities and racial/ethnic minorities, equally benefited from this assignment. This underscores the importance of integrating more equitable assignments into engineering education. While experiential learning experiences offer real-world learning opportunities, both Co-op and non-Co-op students benefit from the DYOP. Both groups have the opportunity to draw on real-life experiences to grasp course concepts regardless of work-experience.

Additional work is being done to determine the effects of the reflection itself on the student's engagement at each Bloom's level as it is possible that the act of reflecting could prompt increased engagement, particularly, at the Analyze level from that conducted during the quiz itself.

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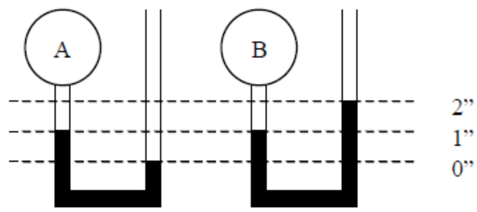
APPENDIX
A1. Example Quiz (Quiz 1: Hydrostatics)

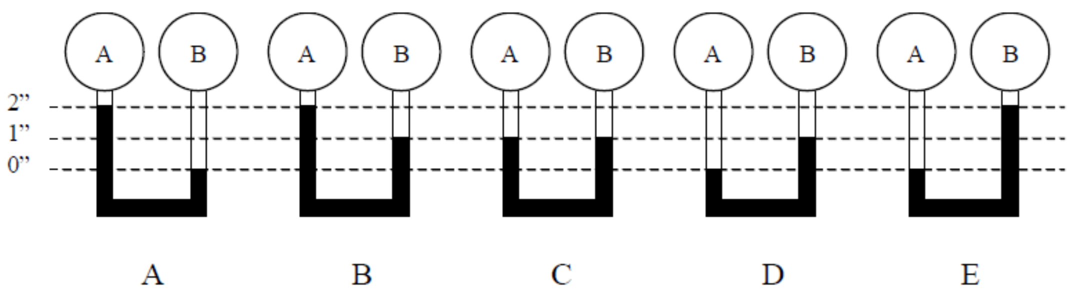
1. Circle the letter of the correct statement about pressure in a fluid. (2.5 pt)

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.

Explain your thought process and/or the reasoning for your answer below. (This is how partial credit will be awarded in case of incorrect answers.)

2. Two tanks filled with air are shown below. Water filled manometers that are open to the atmosphere are connected to each, and the water levels are as shown. Circle the letter of the correct answer for the water levels when a single manometer joins the two tanks. (2.5 pt)

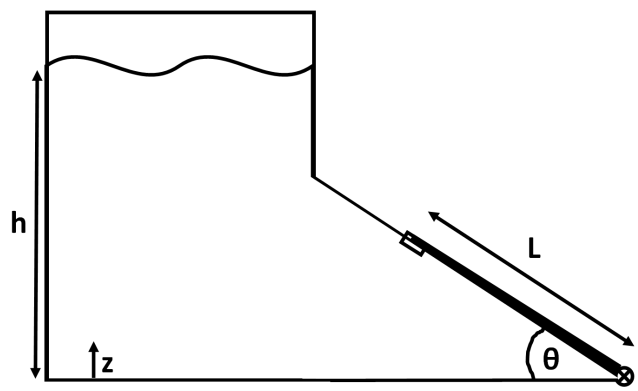




a. Figure A
b. Figure B
c. Figure C
d. Figure D
e. Figure E

Explain your thought process and/or the reasoning for your answer below. (This is how partial credit will be awarded in case of incorrect answers)

3. A Static fluid of constant density with depth h is contained in the tank as shown below. A uniform rectangular gate is hinged at the bottom and rests against a stop. The gate has an inclination angle of **θ** with respect to the horizontal, a width **b** (into the page), a length **L**, and weighs **W**. The fluid has a density **ρ** and specific weight **γ**.

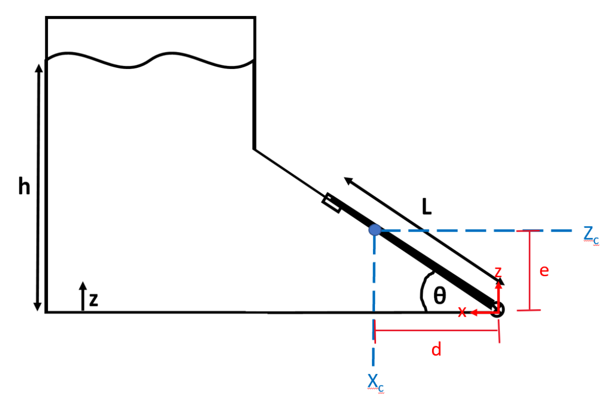


3.a) Sketch the pressure distribution along the internal gate surface first in gage pressure then again in absolute pressure. **(3pts)**

3.b) Find the resultant force (**F**) from hydrostatic pressure on the gate. **(6 pts)**

3.c) Determine the expression for the minimum weight of the gate $\mathbf{W_{min}}$ that will prevent the gate from opening. **(4pts)**

The coordinates for Xc and Zc are as follows:



A2. Design Your Own Problem Assignment Prompt

<u>Objective:</u>

In this assignment, you will apply the knowledge of fluid mechanics you have obtained in this course to real-world problems. After completing this project, you should be able to fully describe at least one example of how fluid mechanics can be used to solve an engineering problem.

<u>Deliverable:</u>

You will design a homework question based off of an engineering problem where fluid mechanics has/can be applied to solve it. In this assignment, you will:

- Write a **problem summary** that identifies an engineering problem that involves at least one of the topics in the relevant area (see topic areas below for details).
  - This can either be a problem that has already been solved or is in use, or you can design your own problem and propose fluid mechanics solutions to it.
  - Write 1-2 paragraphs (~300 words) explaining the historical and/or engineering significance of the problem.
- Write a **problem statement** that sets up the problem.
  - State all known values.
  - Clearly state the properties to be solved for.
  - Include at least one figure.
- Write a **problem solution** that solves the problem.
  - State simplifying assumptions, write out the relevant equations, and solve.
  - You must include a short, written explanation for your reasoning. This could be referencing an equation in the textbook (must cite properly), explaining why you made an assumption, etc.
- Write a **problem reflection.**
  - Write a ~1 page reflection which outlines your process coming up with a problem topic, designing the problem statement, and working through the solution strategy.

A3. Bloom's Taxonomy Codebook Used to Code Student Reflection

Table 8. 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