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Facilitate Improved Student Learning through Bloom's Taxonomy-Based Assignments in an Undergraduate Fluid Mechanics Course

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Work In Progress: Facilitate Improved Student Learning through Bloom's Taxonomy-based Assignments in an undergraduate Fluid Mechanics Course

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Abstract
This work-in-progress paper examines the effect of modified assignments with Bloom's Taxonomy-based questions on students' learning and metacognition. In undergraduate engineering courses, most textbook problems and assignments are designed to evaluate the ability of students to recall facts and basic concepts, and apply these concepts to solve numerical problems. Based on the authors' instructional experiences, these assignments are typically insufficient to facilitate and gauge students' learning. Through these assignments, students might develop problem-solving skills, partially through pattern-based recognition, but are often unable to gain a strong grasp over concepts or apply them to contexts beyond the class. A lack of complete understanding of fundamental undergraduate concepts can adversely affect students' learning in the long term, their knowledge retention, and ability to succeed in their engineering careers. In this study, assignments on several topics in a large undergraduate fluid mechanics course, including homework, in-class activities, and quizzes, were revised to inclusively cover problems at five different Bloom's Taxonomy cognitive levels: *remember, understand, apply, analyze*, and *evaluate*. Preliminary results indicate that regardless of the teaching approach (instructor-centered or student-centered), students generally performed well on problems in the *remember* and *apply* cognitive domains in the formative assessments. However, students from the instructor-centered group underperformed on questions at the *understanding* and the *evaluating* levels. When students in a different class section participated in the in-class activities and completed homework that included Bloom's Taxonomy questions in an active learning environment, they showed significant improvement in their *understanding* and performance in a summative assessment (midterm exams). Overall, our present findings suggest that a minimal revision of assignments with attentive design to include problems addressing various Bloom's Taxonomy levels in an active learning class could promote students' learning. Although these teaching innovations do not significantly impact students' metacognition, most students found that the modified class structure and the revised class assignments were beneficial to their learning process.

Introduction
Assessments are an integral part of any undergraduate engineering course since they allow instructors to evaluate student proficiency of concepts important in engineering disciplines and provide feedback about the effectiveness of their own classroom instruction. Studies have found that a majority of undergraduate engineering students spend a significant portion of their study time solving textbook problems [1, 2]. In undergraduate engineering courses, most of these textbook problems (and course assessments designed by instructors to include these textbook problems either verbatim or a variation of these problems) are designed to evaluate the ability of students to recall facts and basic concepts, and apply these concepts in various contexts to solve numerical problems (Please refer to Tables A.1 and A.2 for sample questions). Students might develop problem-solving skills, partially through pattern-based recognition, by completing these assignments and also be able to achieve good grades in the course. However, these grades (and

overall GPAs) are often not an accurate reflection of their understanding of fundamental concepts, ability to retain knowledge gained, or their ability to apply these concepts to solve real world problems in their future engineering careers [3]. Additionally, in recent years, 90% of students have been found to use solutions manuals available online or on 'homework help' platforms to complete homework assignments [4]. While the effective use of solutions manuals could potentially help students be more motivated, learn at a deeper level, and level the playing field for all students, it can also pose a risk for some students who might not spend adequate time solving the problem and merely copy from the solutions manuals.

Engineering educators have used various techniques like active learning, gamification and game-based learning, hands-on in class experiments, and flipped (or inverted) classrooms to improve student learning outcomes [5-18]. Gamification in education makes learning more engaging and enjoyable by incorporating game-like interactive activities into the learning process. In-class demonstrations are an effective teaching method where instructors explain abstract concepts, theories, or processes through hands-on experiments conducted by the instructor or students in class. In a flipped classroom, students take control of their own learning by engaging in active learning activities during class time. Although these techniques have all been successfully shown to be effective, they also have associated drawbacks that may impact students, teaching assistants, graders, or faculty. Literature shows that both the gamification and in-class demonstrations should be implemented with careful consideration because their effectiveness may vary depending on the individual characteristics of the students [19, 20]. Additionally, the flipped-classroom requires considerable faculty time investment: an additional 127% of time to redesign and implement the first iteration with recorded lectures, in-class active learning exercises, and grading of projects/exams and additional time (although less) for preparation and grading in subsequent iterations [21, 22]. Further, flipped classrooms can increase the digital divide for minority students from low-income communities in addition to pre-recorded videos not allowing instructors to provide instant feedback on conceptual questions.

In this paper, a methodology is developed to improve student learning in a large undergraduate mechanical engineering course (number of students ≥ 100) at a four-year degree granting public university by modifying the in-class activities (e.g., polling questions), quizzes, and homework in two 'traditionally difficult' chapters (based on the author's own experiences teaching the class for multiple semesters as well as previous student evaluations) to include questions at the Bloom's Taxonomy levels of 'understanding', 'analyzing' and 'evaluating'. The multi-tiered Bloom's Taxonomy model, first developed in 1956 by Benjamin Bloom and collaborators, and later revised in 2001, hierarchically categorizes learning goals to cover remembering, understanding, applying, analyzing, evaluating, and creating [23]. These learning goals help both instructors and students understand the purpose of the learning exchange process, plan appropriate instructional materials, design assessment strategies, and ensure that the instructional process aligns with learning outcomes. The assessment methods (i.e., homework, quizzes, and exams) traditionally used in this class evaluate the ability of students to *remember* facts and basic concepts as well as *apply* these concepts in various contexts. However, to the best of the authors' knowledge, there remains additional scope to test the student's *understanding* of ideas/ concepts covered in class, *analyzing* ideas by comparing different solution approaches, and supporting decisions (i.e., *evaluating*) using knowledge gained in class. The study hypothesizes the interventions to lead to: 1) Improved class performance on quizzes and exams covering topics where interventions have been applied; 2) Improved student experience in the class as gauged by first-hand student feedback from end-of-semester surveys; 3) Reduced reliance on solution manuals as measured by improvement in class performance on quizzes and exams with varied applications of concepts covered in class; 4) Develop evaluation skills that help students apply their knowledge from the classroom in the real world. In the long run, the authors hope that the modifications will lead to shortened graduation timeframes, increased retention of minority students, better hiring rates, and promotion trajectories of mechanical engineering students in their future careers.

While the authors do not claim this method to be better or worse than other techniques like flipped classrooms, in-class hands-on learning used by engineering educators, it has some advantages and novel features as described below:

1. This technique to modify assignments requires minimal time investment for faculty (about 10 hours for each chapter). This time commitment is expected to decrease further once a well-endowed question bank is developed for each course topic after multiple semesters of instruction. Instructors would then need to simply replace questions in the modified assignments from the previous semester with another appropriate question from the repository.
2. This methodology causes minimal interruptions to the course since the polling questions/activities are blended within class time while the questions from the 'understand', 'analyze', and 'evaluate' Bloom's Taxonomy categories are added as bonus questions to the regular quizzes and homework. Thus, instructors are able to stay on schedule with other sections of the same course that share common exams. Further, students are not overburdened by additional assignments during the semester.
3. It is easy to scale up the intervention to apply to classes with even larger undergraduate enrollment or multiple sections in the future.
4. Other engineering educators can easily adapt this methodology, provided in detail in this paper, to implement in any engineering course by modifying the questions (example questions provided in Appendix A).

Methods

Pre-design Process

In April 2022, faculty within the Texas A&M University (TAMU) mechanical engineering department formed teams and responded to an internal departmental solicitation requesting project proposals implementing teaching innovations in undergraduate classes, preferably with multiple sections, under the National Science Foundation (NSF) Revolutionizing Engineering Departments (RED) grant. The authors' proposal aiming to improve student learning by incorporating Bloom's Taxonomy-based questions within assignments in Fluid Mechanics, was accepted. During Summer 2022, the authors attended multiple interactive workshops organized by experienced engineering education faculty at TAMU and participated in discussions about leading indicators (a measurable project factor that helps predict future target achievement), lag indicators (identifiable and measurable metrics for project goals), ultimate goals of the intervention, metrics for measuring success, and minimum viable product for the project [24]. The authors chose two traditionally difficult chapters (based on student feedback from previous semesters and the authors' experience) from the course to implement interventions in the first semester, with the intention of including more chapters in future semesters. Extensive literature review was conducted to understand question types that would fall under each of the five categories of Bloom's Taxonomy [11, 13, 25]. Weekly faculty team meetings were held throughout the Fall 2022 semester to brainstorm possible questions for in-class activities, homework, and quizzes in the 'understand', 'analyze', and 'evaluate' categories.

Course Intervention Design

This study was conducted in an undergraduate-level Fluid Mechanics course in Mechanical Engineering (MEEN) at TAMU. Fluid Mechanics is a required course for junior mechanical engineering students and a prerequisite for various upper-division classes like 'Heat Transfer', 'Internal Combustion Engines', 'Principles of Heating, Ventilating, and Air-conditioning', 'Gas Dynamics', etc. In Fall 2022, three sections taught by two instructors were included in the study (Table 1). Both instructors have more than 8 years of experience in teaching Fluid Mechanics and related mechanical engineering courses.

Table 1. Description of the three student groups participating in the study: the number of students, type of assignments/assessments, and instructors assigned to each group.

Groups	**No. of Students**	**Assignments**	**Instructor**
Traditional **(TRAD)**	100	• No in-class activities • Regular homework	A
Active Learning **(AL)**	100	• In-class activities • Regular homework	B
Active Learning and Bloom's Taxonomy Questions **(AL+BT)**	100	• In-class activities contain questions at Bloom's Taxonomy levels of 'understanding', 'analyzing' and 'evaluating • Homework contains bonus questions at Bloom's Taxonomy levels of 'understanding', 'analyzing' and 'evaluating	B

Each of the three groups participating in the study consisted of 100 students (Table 1). The average cumulative GPA of the students before taking the class was similar ($p = 0.876$) in all groups. In the first group, students were taught using a traditional (TRAD) lecture mode, where more than 95% of the class time was instructor-centered. In contrast, the other two groups (AL and AL+BT) implemented in-class activities, including anonymous online polling and in-class discussion-based assignments, to promote students' active learning. The in-class activities were initially designed to tackle two out of nine topics, namely Fluid Statics and Differential Analysis of Fluid Flow, identified as challenging topics by students in the previous semesters. In a typical class of AL and AL+BT groups, the online polling was given throughout the class to engage and check for individual student's understanding. In addition, the in-class assignments were assigned toward the end of the class, during which a small group discussion was encouraged to complete the assignments. The major difference between the AL and the AL+BT groups was the type of problems given in the in-class activities. The problems assigned to the AL group required recalling facts (remember) or conducting simple calculations (apply), similar to those covered in a traditional class or commonly found in the textbook. On the other hand, the problems given in the AL+BT group addressed different Bloom's Taxonomy cognitive levels, i.e., the 'understand', 'analyze', and 'evaluate' levels. Furthermore, weekly homework was assigned to all groups. The homework problems assigned in all groups included True/False questions and problems at the "apply" level, while the AL+BT group had additional problems addressing different Bloom's Taxonomy cognitive levels, similar to the in-class assignments. The grading distribution in the AL and AL+BT groups are 10% Homework, 5% In-class activities, 10% Quizzes, 20% Midterm I, 25% Midterm II, and 30% Final Exam. Since there is no in-class activities in the TRAD group, its grading distribution is 15% Homework, 10% Quizzes, 20% Midterm I, 25% Midterm II, and 30% Final Exam. To encourage students to complete problems and focus on the thought process rather than the final answers (as well as reduce burden on graders), 80% of both in-class assignments and homework scores were graded for completion, while the other 20% was graded for accuracy. However, the bonus questions in the 'understand', 'analyze', and 'evaluate' categories in the homework (results shown in Figure 1) were all graded for accuracy.

Results

Leading Indicators

The number of students who submitted in-class assignments and those who earned partial/full credit on the Bloom's Taxonomy-based problems in the homework were used as two leading indicators for this teaching intervention.

In-class assignments

The in-class assignments covering two topics: Fluid Statics (Chapter 2 in [26]) and Differential Analysis of Fluid Flow (Chapter 6 in [26]), were given to the two active learning groups (AL, AL+BT) in weeks 2 to 4 and 9 to 11 during a 16-week-long semester. The number of students who submitted in-class assignments, calculated in a percentage, was recorded to gauge students' class attendance and engagement (Table 2).

Table 2. Percentage of students in the AL and the AL+BT groups who submitted the in-class discussion-based assignments. ICA (In-Class Assignments) 2-x covers fluid statics, and ICA 6-x covers differential analysis of fluid flow.

In-Class Assignments	Assignment Timelines	AL Group	AL+BT Group
ICA 2-1	Assigned in weeks 2 to 4	97%	96%
ICA 2-2		94%	88%
ICA 2-3		No ICAs given	92%
ICA 2-4		No ICAs given	86%
ICA 6-1	Assigned in weeks 9 to 11	90%	80%
ICA 6-2		93%	74%
ICA 6-3		94%	85%
ICA 6-4		91%	83%

Overall, both groups had decent numbers of attendance. In the AL group, the number of submissions is pretty consistent, with an average of 92% over the six assignments. In the AL+BT group, on average, 91% submitted the assignments for Chapter 2, and 81% submitted the assignments for Chapter 6. The lower number of submissions in Chapter 6 in the AL+BT group could be partly due to the class time offered in the morning (8:00-9:15 am) during Weeks 9-11 when several other MEEN classes also have midterms. Additionally, the weather in the southern US, where this university is located, also typically gets colder, potentially deterring students from showing up to an 8 am class.

Homework

Two homework assignments for the AL+BT group were revised to include five bonus sub-problems at three Bloom's Taxonomy cognitive levels. Sample homework problems can be found in Tables A1 and A2. The number of students who received credit on the bonus questions was documented to evaluate their performance on non-traditional homework problems (Fig. 1). In Chapter 2, 69%, 60%, and 52% of students received credit on the problems at the 'analyze', 'evaluate', and 'understand' levels, respectively. In Chapter 6, 68%, 60%, and 42% of students received credit on the problems at the 'analyze', 'understand', and 'evaluate' levels. This finding suggested that the type of problems could affect the student response. In both homework sets, students could respond best to the problems at the 'analyze' level. In addition to the problem categories, problem difficulty within the same Bloom's Taxonomy level also appears to play a role in the result. Figure 1A and 1B demonstrates that the number of students receiving credits on various problems at the two specific cognitive levels — the 'evaluate' problems in Chapter 2 and the 'understand' problems in Chapter 6 — significantly varied. For example, 76% of students received credit on the evaluate-I problem, while only 44% received credit on the evaluate-II problem. These two problems cover similar topics at different difficulty levels (Please refer to Table A.1 for problem examples).

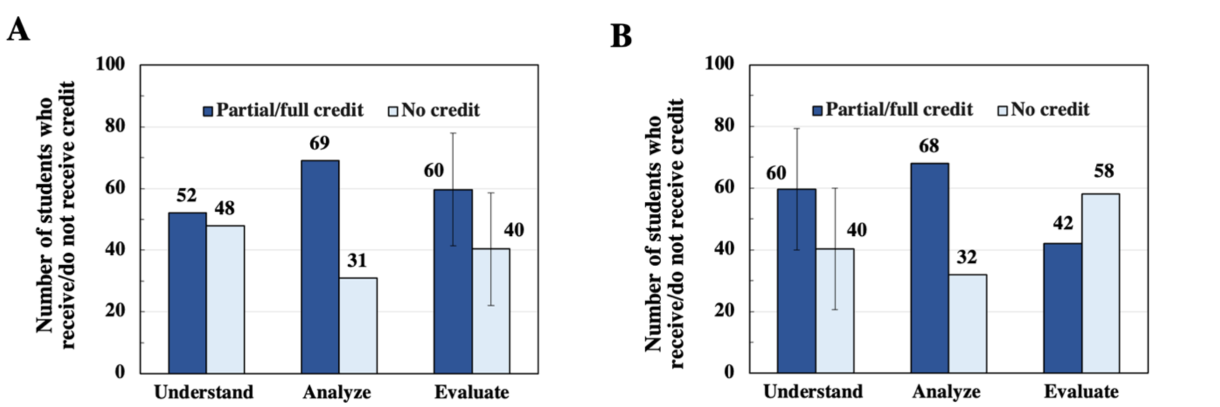

Figure 1: Number of students in the AL+BT group who received partial/full credit (dark blue) or no credit (light blue) on the bonus questions in the revised homework assignment. (A) Fluid statics (Chapter 2) bonus questions consisting of one 'understand', one 'analyze', and three 'evaluate' problems and (B) Differential analysis of fluid flows (Chapter 6) bonus questions consisting of three 'understand', one 'analyze', and one 'evaluate' problems. Error bars represent the standard deviations. Students in the TRAD and AL groups were not asked to complete the bonus questions.

Overall, the results from the two leading indicators suggested that more than 80% of students in the two active learning groups participated in the in-class assignments, and approximately 58.5% of students could respond to non-traditional questions at the 'understand', 'analyze', and ‘evaluate’ categories. Data collected from multiple iterations of this study in future semesters will be used to investigate if student performance is significantly dependent on the question categories.

<u>Lag Measures</u>
Formative assessments (quizzes) and summative assessments (exams) were used as lag measures to track the success of our project goal.

Quizzes
Two common quizzes, covering fluid statics (Quiz 1) and differential analysis of fluid flow (Quiz 2), were given to all student groups. The quizzes were take-home, open-book/notes, and one hour long. Each quiz consisted of a main section and a bonus section. In the main section, 20% of questions asked students to *recall* facts and basic concepts (True/False), and the other 80% of questions asked students to *apply* the concepts and show detailed analysis. In the bonus section, Quiz 1 consisted of two ‘understand’ and two ‘evaluate’ problems, while Quiz 2 consisted of one ‘understand’, one ‘analyze’, and one ‘evaluate’ problems. Sample quiz problems can be found in Appendix B.

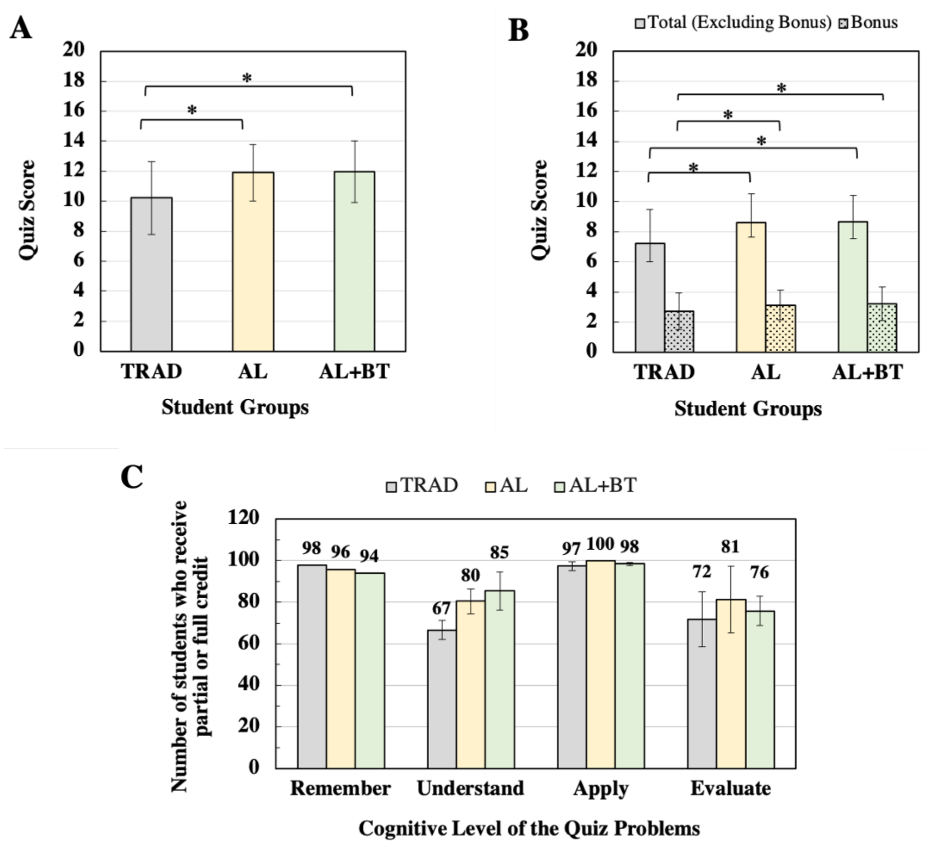

Figure 2. Student performance on Quiz 1. (A) Total quiz scores (including bonus) out of 14 points. (B) The breakdown scores of the main (10 pts) and the bonus (4 pts) sections. (C) The number of students who received partial or full credits on the quiz problems at different cognitive levels. Error bars represent the standard deviations. * indicates $p < 0.05$.

Figure 2 demonstrates the Quiz 1 score of all student groups. The total score averages are 10.2, 11.9, and 12.0, out of 14 points, in the TRAD, AL, and AL+BT groups, respectively (Fig. 2A). The total scores of the AL and AL+BT groups are significantly higher than the TRAD group ($p < 0.000$). However, there is no significant difference in the quiz score between the two active learning groups (AL and AL+BT). The breakdown scores also show similar results. Both scores in the main and the bonus sections of the TRAD group are significantly lower compared to those in the AL and the AL+BT groups (Fig. 2B). Specifically, higher numbers of students in the AL and AL+BT groups were observed to perform better on problems at the 'understand' level compared to the TRAD group (Chi-square analysis, $p = 0.014$) (Fig. 2C).

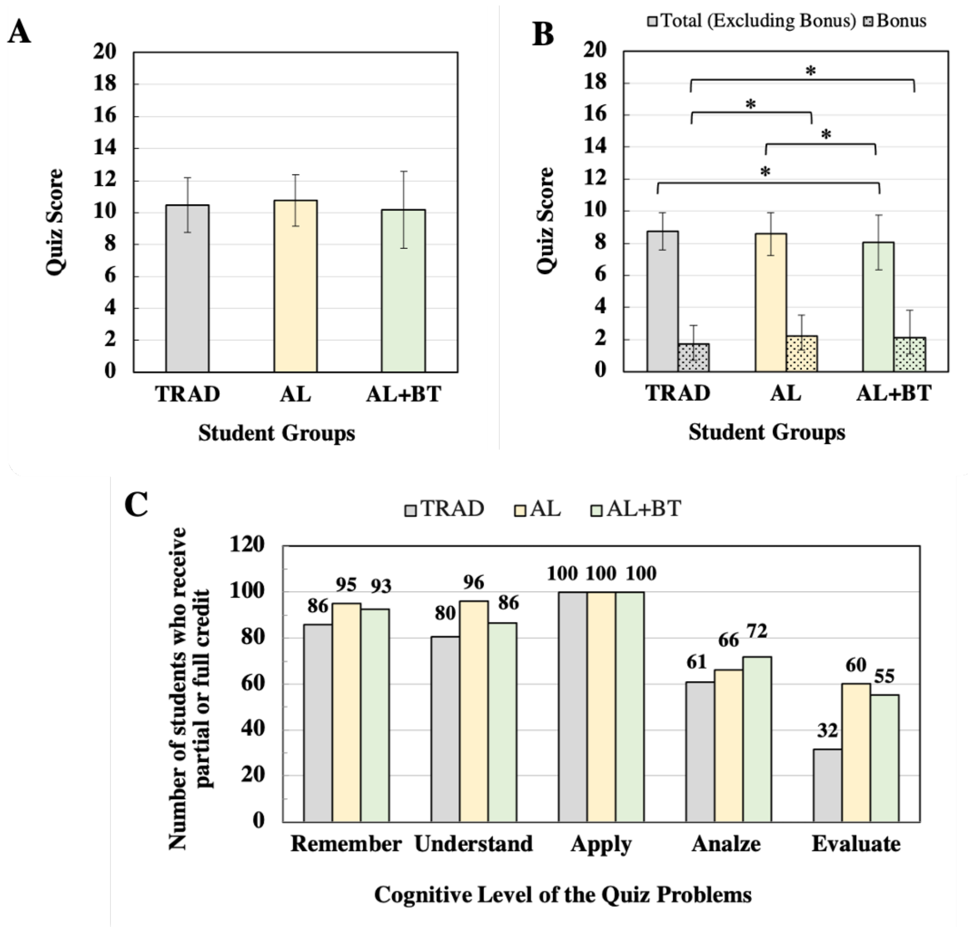

Figure 3. Student performance on Quiz 2. (A) Total quiz scores (including bonus), out of 13 points. (B) The breakdown scores of the main (10 pts) and the bonus (3 pts) sections. (C) The number of students who received partial or full credits on the quiz problems at different cognitive levels. Error bars represent the standard deviations. * indicates $p < 0.05$.

In Quiz 2, the total score averages are 10.5, 10.8, and 10.2 out of 13 points in the TRAD, AL, and AL+BT groups, respectively (Fig. 3A). No significant difference was observed among the scores of the three groups after performing a Kruskal-Wallis test. However, interestingly, the breakdown scores in Fig. 3B show that the main section scores of the TRAD and the AL groups are significantly greater than the AL+BT group (Mann-Whitney test, $p = 0.04$), although the number of students that received credits in the questions of the main sections (i.e., questions at the 'remember' and the 'apply' levels) is not significantly different (Fig. 3C). The discrepancies could be due to several factors, such as the decrease in class attendance of the AL+BT group before Quiz 2 (Table 2) and different graders for the three student groups. Although all quizzes were graded using the same grading rubrics, the three graders might have graded slightly differently, particularly on the 'apply' problems when partial credits were given to student problem-solving processes. Nevertheless, the bonus scores of the AL and the AL+BT groups are significantly greater than the TRAD group ($p = 0.004$) (Fig. 3B). Specifically, higher numbers of students in the AL and AL+BT groups were observed to perform better on problems at the evaluate level compared to the TRAD group (Chi-square analysis, $p = 0.001$) (Fig. 3C).

Exams

Two common summative assessments, Midterms 1 and 2, were given to all student groups. The tests were two-hour-long closed-book exams. Midterm 1 covered three chapters, including fluid statics (Chapter 2). Midterm 2 covered three chapters, including differential analysis of fluid flow (Chapter 6). Eighty percent of exams consisted of problems at the apply level, requiring students to solve problems and show their detailed analyses. The other twenty percent were problems at the remember level, including true/false questions and short descriptive answers. Sample exam problem can be found in Appendix C. In Midterm 1, students in the AL+BT group (average score = 90.4%) performed significantly better than the AL (average score = 86.2%) and the TRAD (average score = 81.7%) groups, respectively (Fig. 4A). This could be partly because more students in the AL+BT group conceptually understood the exam material compared to the others as shown in their quiz results (Fig. 2C). In Midterm 2, both students in the AL and AL+BT groups performed significantly better than the TRAD group ($p < 0.000$) but there was no difference between the two active learning groups.

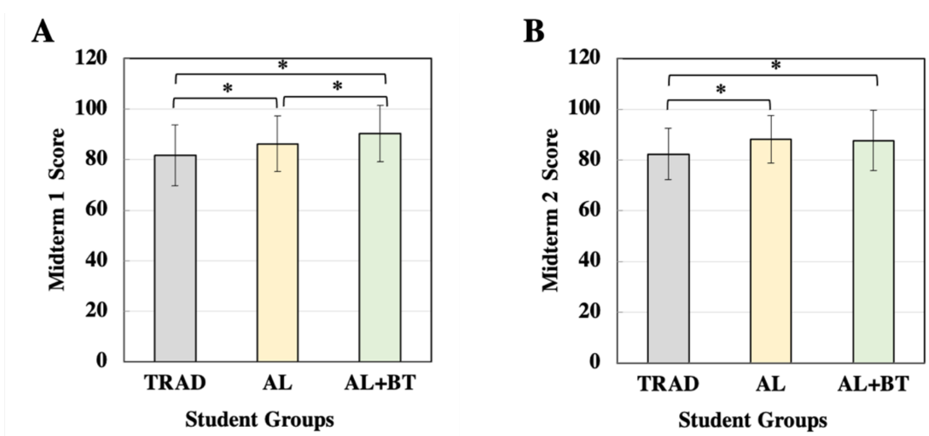

Figure 4. Student performance on (A) Midterm 1 and (B) Midterm 2 exams. Error bars represent the standard deviations. * indicates $p < 0.05$.

Overall, the results from the lag measures suggest that the active learning components enhance student learning and performance on both formative and summative assessments. Bloom's Taxonomy-based questions can offer an additional beneficial impact in some cases. Further analysis will be needed to evaluate its effects.

Survey Results

A class survey was generated using the Canvas learning management system. The survey's purpose is to collect student feedback on the impact of the in-class activities and the revised Bloom's Taxonomy homework questions on students' learning experiences and how the learning affects their metacognition. The survey was voluntary, anonymous, and conducted at the end of the semester.

The first part of the survey was given to the AL and AL+BT students. The responses from both sections are positive and consistent. Figure 5 shows that 91-95% of the students agreed or strongly agreed that the in-class activities and the bonus homework questions helped them learn concepts and perform better on the quiz and/or the midterm exam. In addition, 91% of the AL students and 88% of the AL+BT students would like to see similar in-class activities and solve similar bonus homework problems in other chapters of this course. When students were asked to compare the effect of the in-class activities to the effect of the bonus homework questions on their learning, the responses varied. More students in the AL group favored the bonus homework questions, while more students in the AL+BT group preferred the in-class activities. About one-third answered neutral, which could mean that students found both activities and bonus problems were equally helpful. Nevertheless, the varied responses could be due to the diverse background of students and their different learning styles. This result agrees with existing works indicating that multiple types of assignments/assessments are essential for students' learning [27, 28]. Lastly, more than 50% of the AL and AL+BT students thought that additional bonus problems do not increase the loading of their weekly homework.

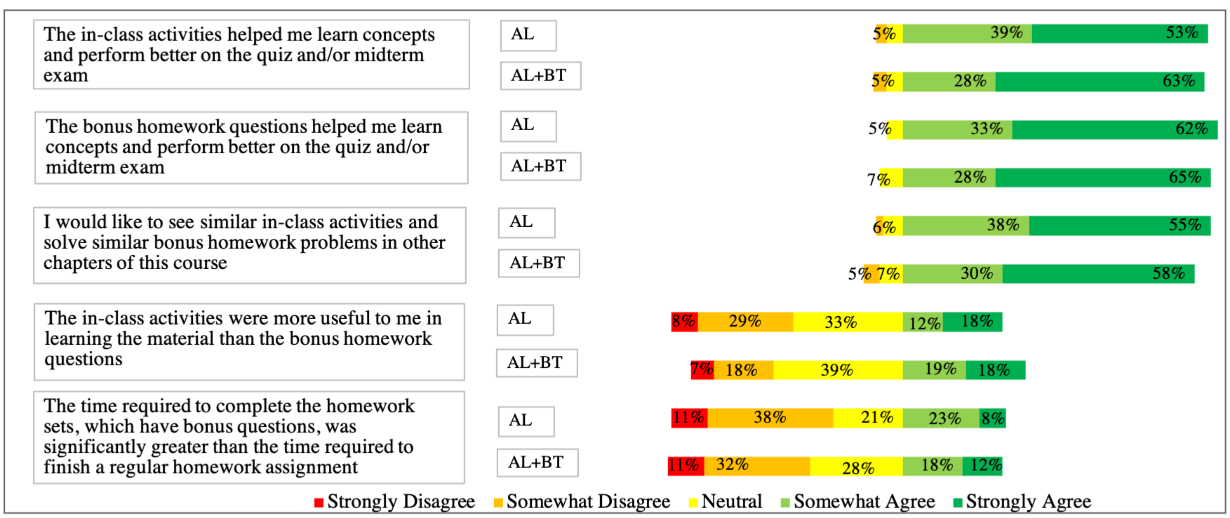

Figure 5. Survey responses on the impact of the in-class activities and the bonus homework questions on the learning experiences of students in the AL (n = 66) and the AL+BT (n = 57) groups.

The second part of the survey aims to understand the effect of class structure on students' metacognition. The questions given to the AL and the AL+BT students asked explicitly about the two chapters focused on this study, i.e., fluid statics and differential analysis of fluid flow, while the questions for the TRAD groups were not topic specific. Figure 6A demonstrates that 63% of the AL and 49% of the AL+BT groups agreed/strongly agreed that they are a better judge of how well they understand concepts of the focused chapters than other chapters. In addition, approximately 80% of the AL and the AL+BT groups agreed/strongly agreed that they are aware of the learning and exam preparation strategies used and found them useful for other chapters. Interestingly, a larger number of TRAD students (86-90%) agreed/strongly agreed to the similar questions (Fig. 6B). This high level of agreement is likely because the questions asked are applicable to the entire class's contents and not topic-specific like the questions put forth in the AL and AL+BT groups. Similarly, 75-79% of all student groups were able to accurately predict how well they did on the quizzes and exams (Fig. 6C). It should be noted that this question applies regardless of whether a student performed well or poorly on the summative assessments. However, more students in the AL and the AL+BT groups felt confident solving the bonus questions and quizzes compared to the TRAD group (Fig. 6C). Overall, most students in all groups seem to have metacognitive skills. However, it is unclear if the active learning and the revised Bloom's Taxonomy assignment further promote student metacognition. More data needs to be collected from different student groups in the future to unearth any underlying trends.

Limitations

Our empirical teaching intervention study is subject to certain limitations. First, while both instructors have similar educational training and years of teaching experience, their teaching philosophies and lecture delivery styles, like most instructors, have fundamental differences. These inherent distinctions could have influenced students' understanding of fundamental concepts in class and thereby how well they performed on quizzes and exams. Secondly, the authors did not track if students got zeroes on a specific question on the homework/quizzes because of not attempting that question (perhaps due to time limitations on the timed quizzes or starting the homework close to the deadline) or if they got it completely wrong. In future iterations of this study, the reasons for zero scores will be documented to avoid the possibility of overcounting students not getting partial/full credit on a particular problem. Additionally, the grading of the assignments was completed by three different graders for the three sections. While they followed the same detailed grading rubric, grading styles (e.g., being more liberal with partial credit) could potentially have affected the results. Further, while comparing metrics from the TRAD with the AL and AL+BT groups, it is not clear if the actual Bloom's Taxonomy questions or the method of delivery of the questions (i.e., active learning) influenced student performance. In the following semester, the authors plan to deliver the targeted Bloom's Taxonomy questions without active learning by eliminating the collaborative in-class activities, describing answers to the higher-order questions as part of the lecture, and having the 'understand', 'analyze', and 'evaluate' questions as part of the homework and quizzes. By comparing student performance from the two semesters, it will be apparent if the method of delivery plays a significant role in the teaching innovation process. Finally, the end-of-semester survey was only completed by a portion of the students in each section. Increased participation can be encouraged in future semesters by offering extra credits or other incentives.

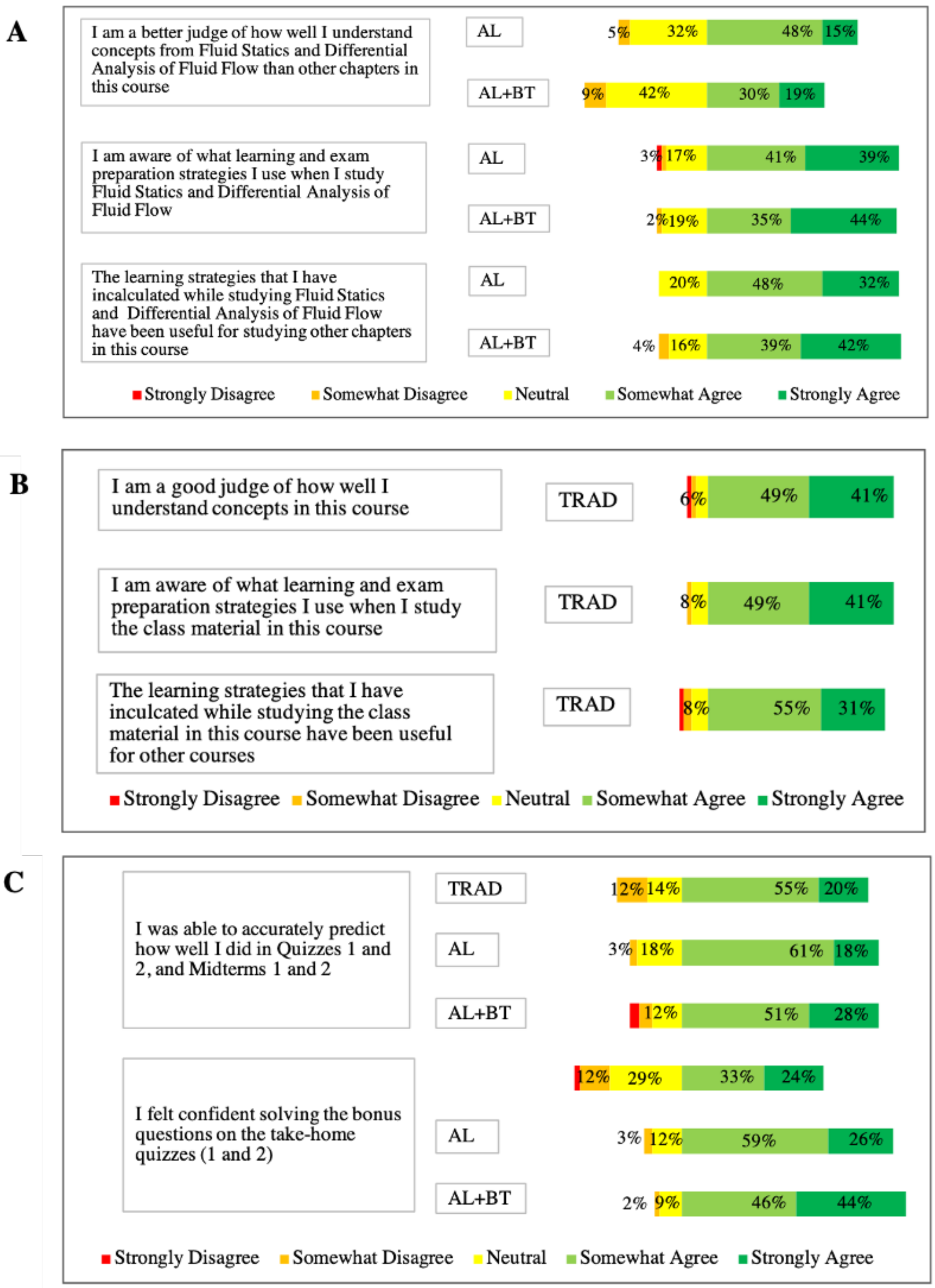

Figure 6. Survey responses on the impact of student learning experiences on their metacognition in (A) the AL (n = 66) and the AL+BT (n = 57) groups, (B) the TRAD group (n = 51), and (C) all groups.

Conclusion

This paper investigates the effect of minimal modification of three types of assessments — in-class activities, quizzes, and homework — using Bloom's Taxonomy-based questions on student learning and metacognition in a large undergraduate Fluid Mechanics class. Questions at three levels of the multi-tiered Bloom's Taxonomy model, namely 'understand', 'analyze', and ‘evaluate’, were added to the assignments that typically only include problems at the ‘remember’ and ‘apply’ levels. These changes were implemented in two traditionally difficult chapters: Fluid Statics and Differential Analysis of Fluid Flow. The number of students submitting in-class activities, the number of students scoring partial/full credit on the new questions in the homework, quiz scores, and exam grades were recorded and compared across three class sections — one with traditional lecture mode, one with the active learning environment, and the third with the added Bloom’s Taxonomy questions in an active learning backdrop. Results showed that more than 80% of students in the two active learning groups participated in the in-class assignments, and approximately 58.5% of students, on average, could respond to the bonus questions at the understand, analyze, and evaluate levels in the homework sets from the two chapters. Scores from the two quizzes, which included questions at all five Bloom’s Taxonomy levels, and two midterms, which only had ‘remember’ and ‘apply’ questions (to be in sync with other class sections conducting common exams but not participating in this research), demonstrated that active learning significantly improves student learning and class performance. Additionally, while Bloom’s Taxonomy-based questions delivered using active learning methodologies positively influence learning outcomes in some assessments, it could not be found to be true for all summative assessments conducted over the semester. An end-of-semester survey was conducted across all three class sections to gauge student satisfaction and understand the effect of this study on student learning and metacognition. Overall, students favored the inclusion of the in-class activities and bonus homework questions, and did not think that these required significant additional time to complete. The role of active learning and Bloom’s Taxonomy questions on the improvement of student metacognition was not apparent from the student responses in the first semester of this study. In the future, modifications will be made to other chapters of this course and implemented in class sections with different instructors to analyze whether instructor teaching styles influence the metrics recorded. A grader will be assigned to grade the same assignment across all sections to avoid grading discrepancies. Further, the role of the method of delivery of the higher order Bloom’s Taxonomy questions (i.e., active learning vs. incorporated in lecture slides under traditional lecture mode) will be investigated. Finally, minor extra credit incentives will be offered to ensure larger student participation in the end-of-semester survey.

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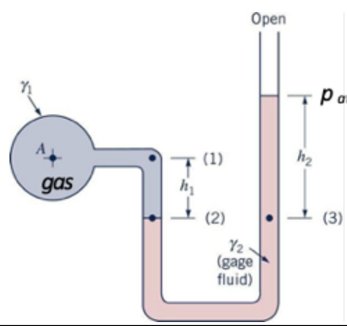
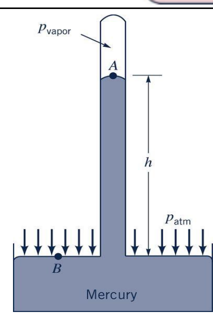
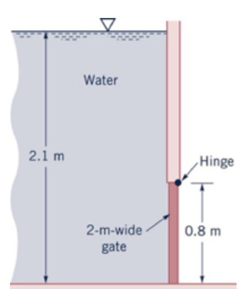
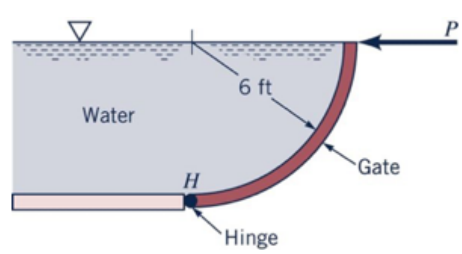
Appendix A: Sample Homework Questions

Table A1. Sample homework questions on Fluid Statics at different Bloom's Taxonomy categories. Problem schematics used in this table are from [26, 29].

Bloom's Taxonomy Categories	Questions
Remember	State True/False: For fluids at rest, the pressure gradient in the vertical direction at any point in the fluid depends on two factors: the specific weight of the fluid at that point and the absolute viscosity of the fluid
Understand	 ***Explain*** why the change of gas pressure between points (1) and (2) in a manometer can be neglected.
Apply	 Barometer is a device used to measure atmospheric pressure. At sea level, the height of mercury in the column is 30 inches. Given • p_{atm} = 14.7 lbf/in^2 • $\gamma_{mercury}$ = 847 lbf/ft^3 • γ_{water} = 62.4 lbf/ft^3 Neglect the vapor pressure inside the closed end ***Find*** • The mercury height (h, in inch) in the column • The water height (h, in inch) in the column if the water bath is used instead of the mercury bath
Analyze	 Consider fluid submerged adjacent to the vertical and the curve gates. ● Determine the fluid pressure equations as a function of height (p(z)) for the following two submerged surfaces.

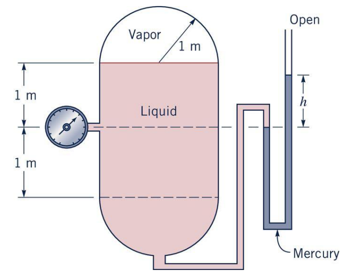
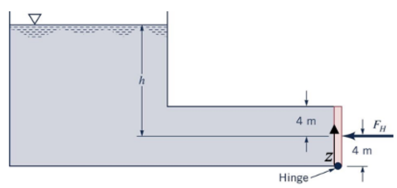
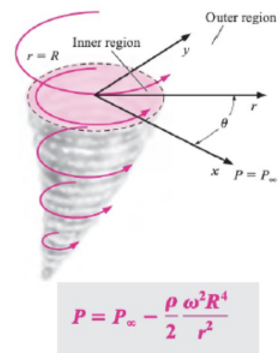
	● ***Compare*** your approach, solutions and d***iscuss*** why they are similar or different.
Evaluate - I	The cylindrical tank with hemispherical ends contains a volatile liquid and its vapor. Mercury is used as a gage fluid in the manometer.  ***Argue*** if it is practical to use water (the specific weight of 1000 N/m^3) as a gage fluid in the manometer instead of the mercury. Support your answer with valid reasons.
Evaluate - II	A 3-m-wide, 8-m-high-rectangular gate is located at the end of a rectangular passage that is connected to a large open tank filled with water. If the tank is closed and the air above the free surface is pressurized to 2  atm while the gate remains hinged at the bottom, ***evaluate*** if the maximum water depth would increase/decrease/stay the same. Support your answer with valid reasons.

Table A2. Sample homework questions on Differential Analysis of Fluid Flow at different Bloom's Taxonomy categories. Problem schematics used in this table are from [26, 29].

Bloom's Taxonomy Categories	Questions
Remember	How does fluid pressure in the Poiseulle flow change in a flow direction? ● Linearly decreases with pipe length ● Linearly increases with pipe length ● Decreases quadratically with pipe length ● Increases quadratically with pipe length ● Can't determine. Need more information
Understand	***Explain*** in your own words what each of the following assumptions means and which terms in the Navier Stoke equation can be neglected due to each assumption ● Newtonian Fluid ● Incompressible Fluid ● Steady State ● Laminar flow ● Fully-developed flow

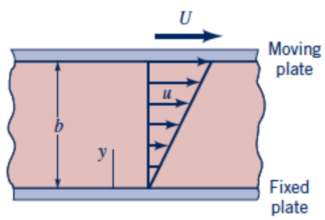
<table>
<tr><td></td><td>● No flow variation in the z-direction</td></tr>
<tr><td>Apply</td><td>



A horizontal slice through a tornado can be modeled by two regions
- An inviscid but rotational inner region of flow (r < R)
- An irrotational outer region of flow (r > R).

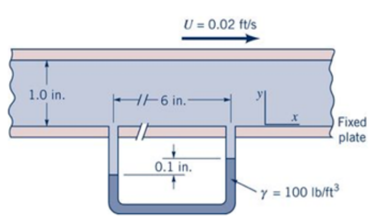
The flow is steady, incompressible, and the velocity field $V = (u_r, u_\theta)$
$u_r = 0$
$u_\theta = \omega r$ for 0 < r < R
$u_\theta = \omega R^2/r$ for r > R

Apply the Bernoulli equation between a point far away from the tornado ($r \rightarrow \infty$) and at any other point in the outer flow region within the same horizontal slice to *find* an expression for the pressure field in the outer region of flow. Express your answer in terms of p_0, ω, r, R, and ϱ. Assume as $r \rightarrow \infty$, $u_\theta \rightarrow 0$ and the ambient pressure is equal to p_0.
</td></tr>
<tr><td>Analyze</td><td>
An incompressible viscous fluid is placed between two large parallel plates as shown. The bottom plate is fixed, and the upper plate moves with a constant velocity, U. For these conditions the velocity distribution between the plates is linear and can be expressed as



$u = U\frac{y}{b}$

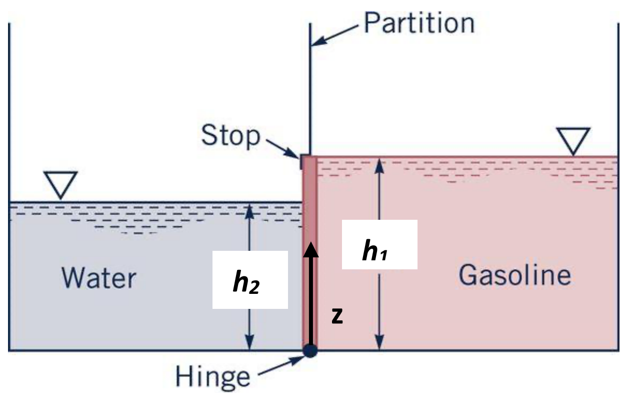
- Find the rate of angular deformation
-***Analyze*** how the rate of angular deformation that you calculated is similar/different to the 'rate of shearing strain' concept that we discussed in Chapter 1 ($\dot{\gamma}$=du/dy).
</td></tr>
<tr><td>Evaluate</td><td>



A viscous fluid is contained between two infinite, horizontal parallel plates as shown.
(a) At what distance from the bottom plate (in inches) does the maximum velocity in the gap between the two plates occur.
) Suppose the upper plate is now fixed, ***argue*** if the maximum velocity occurs at the same position as in part (a)? If not, does it occur above or below the position in part (a). ***Support*** your answer with valid reasons. No calculation is required.
</td></tr>
</table>

Appendix B: Sample Quiz Problem on Fluid Statics

An open tank has a vertical partition and on one side contains gasoline with a density of ϱ_g at a depth of h_1. A rectangular gate with h_1 height, w width (into the page), and hinged at one end is located in the partition. Water (with a density of ϱ_w) is slowly added to the empty side of the tank. (Schematics in the problem are from [26].)



(a) Derive an expression for the hydrostatic net pressure distribution for gasoline as a function of z. Assume the coordinate system starts at the bottom of the tank. (Apply level)

(b) Find an expression for the resultant hydrostatic force exerted by gasoline on the wall in terms of ϱ_g, g, h_1, and w. (Apply level)

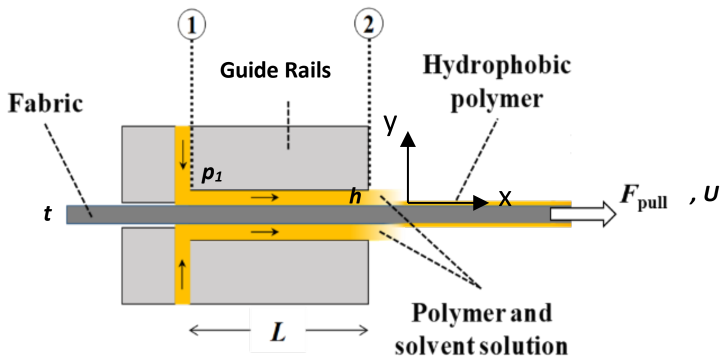
(c) Find the z-location of the resultant hydrostatic force exerted by gasoline on the wall in terms of h_1. (Apply level)

(d) If water is replaced by ammonia (having a density less than water), assess if the depth of ammonia will be higher/lower/stay the same compared to the water depth in order to keep the gate closed. Assume the gasoline level (h_1) remains constant. (Bonus, Evaluate level)

(e) Discuss whether we can neglect the effect of atmospheric pressure on either side of the vertical wall when calculating a net hydrostatic force on the gate. Support your answer with valid reasons. (Bonus, Understand level)

Appendix C: Sample Exam Problem on Differential Analysis of Fluid Flow

The figure below is a setup to coat water-proof polymer on fabric. The fabric is pulled through a pair of guide rails. A viscous hydrophobic polymer solution is applied through a small gap between the guide rails. The length of the rails is *L,* and its width is *W*, the gap between the guide rail and the fabric is *h*, the thickness of the fabric is *t*, the fabric is pulled at a constant velocity *U*, and the solution is delivered at a pressure of p_1 at Location 1. The solvent-polymer solution has a density ϱ and a viscosity μ.



(a) Each side of the fabric can be modeled as a Couette flow (i.e., the flow of a viscous fluid in the space between two surfaces, one moving tangentially relative to the other.) Simplify the x- components Navier-Stokes equations to determine the velocity profile of the polymer solution within the gap above the fabric. The origins of the given x-y coordinate start at the top of the fabric. (Apply level)

(b) Calculate the pulling force needed to pull the fabric at a constant velocity U, assuming the velocity profiles on the fluid within the gap above and below the fabric. Leave your answer in terms of the given parameters, e.g., ρ, μ, L, W, h, t, U, p_1. Note that the gage pressure at section 2 is zero. (Apply level)