ASEE'S VIRTUAL CONFERENCE
At Home with Engineering Education
JUNE 22 - 26, 2020 #ASEEVC
Paper ID #29301

Using Student-Faculty Collaborative Lectures to Teach High Level Hydrodynamics Concepts

Dr. Laura K Alford, University of Michigan

Laura K. Alford is a Lecturer and Research Investigator at the University of Michigan. She researches ways to use data-informed analysis of students' performance and perceptions of classroom environment to support DEI-based curricula improvements.

Mr. James A. Coller, University of Michigan

James Coller is an engineering PhD Candidate at the University of Michigan focusing on the development of a novel multi-layer network approach to understanding design complexity in unmanned maritime vehicles. James also completed his BSE and MSE in Naval Architecture and Marine Engineering in 2017 and 2018 respectively and a MS in Robotics in 2019 at Michigan. He spent three years during his undergraduate education as an Instructional Assistant for a first year design-build-test-communicate engineering course. His research interests include autonomous robotics for both land and marine environments, ship design for the U.S. Navy, and improving equity and inclusion in engineering learning environments.

Dr. Robin Fowler, University of Michigan

Robin Fowler is a Lecturer in the Program in Technical Communication and an Assistant Research Scientist in Engineering Education. She loves serving as a "coach" to engineering students as they engage in communicating their ideas to a range of stakeholders. She studies teamwork and team-based pedagogy, with a focus on inter-team communication and equity. She is one of the Faculty Innovators behind Tandem, a Center of Academic Innovation tool for supporting students working in teams.

Using Student-Faculty Collaborative Lectures to Teach High Level Hydrodynamics Concepts

Abstract

Introduction to engineering courses are increasingly team-based and project-based, with student teams designing and building real-world things. A popular project for introductory courses is remotely operated vehicles (ROVs). Our section of an intro to engineering class at a large Midwestern research university uses ROVs because they are fundamentally interdisciplinary: a successful design includes elements of mechanical engineering, electrical engineering, computer science, naval architecture, marine engineering, and others. However, over the years we have observed that students continued to struggle with an early understanding of the forces and moments that impact how ROVs move through the water – in other words, hydrodynamics. This lack of hydrodynamic understanding leads them to design vehicles that are frustrating to drive because they are not hydrodynamically stable.

Our objective was to give students a high-level understanding of basic hydrodynamics concepts (drag, stability, free body diagrams) such that their initial design choices are better informed. However, hydrodynamics is a complex and nuanced field of study, and teaching even high-level hydrodynamics concepts is challenging at best. A traditional lecture format teaching a formal introduction to hydrodynamics is not an option because our students do not yet have the background math and science knowledge necessary to understand the equations used in such an introduction. Using pure observation to convey high level concepts through experiential learning is ideal, and we do this in our lab sections, but students need to have some conceptual preparation before they do their lab-based learning. Because we were moving to an active learning format in which students work in their teams the majority of the class meeting time, we decided to take advantage of the small groups to create interactive lectures on hydrodynamics to prepare students for their labs on hydrodynamics.

The collaborative lectures on hydrodynamics start with a scaffolded Google slides presentation. Students make a copy of the presentation and share it with their teammates. The presentation uses pictures and diagrams to create a type of experiential learning in lieu of something like a recirculating water channel. The instructor presents the slides, but there are many “incomplete” sections. Each incomplete section is a time for the student teams to discuss a picture, a concept, or a linked video demonstration; come to a consensus on their interpretations of the concepts; or complete a quick example of each concept. A key component of the interactive lecture is that no “solution” slides are provided. The teams must work through the calculations or reflections to gain a complete set of slides. This forces all students to engage in the lecture. Answers are shared

out in the larger group and the instructor guides the discussion of the answers so as to ensure a common understanding of the concepts.

Our initial assessment shows a marked improvement in student understanding of the relevant hydrodynamics concepts necessary to designing an underwater vehicle. Students are able to converse more knowledgeably on hydrodynamics, and the ROV designs are more thoughtful and reasoned with respect to hydrodynamics. We believe that this approach of collaborative lectures with small groups will be beneficial to others needing to teach high-level concepts to students who do not yet have the background knowledge required for more formal teaching.

Introduction

In a first-year engineering course at a large Midwestern research university, remotely operated vehicles (ROVs) are used as a design project topic to teach fundamental engineering and communication skills. The course utilizes a design-build-test-communicate framework with the use of peer mentors [1, 2] to coach students through what is often their first team-based course in their post-secondary education [3, 4].

In the design of ROVs, the science of hydrodynamics governs how the vehicle will move in the water. Hydrodynamics is typically taught as a third year undergraduate course, requiring prerequisites in multi-variable calculus, calculus-based physics, and typically another statics or dynamics course [5, 6, 7]. Hydrodynamics is difficult to teach, even with upper level students [8]. Instructors have attempted to rethink how hydrodynamics is taught, including using virtual laboratories [9] in addition to project-based courses [10].

This first-year course focuses on a high-level understanding of hydrodynamics for informed decision making during the design process. Our previous method of teaching hydrodynamics concepts was to provide some background information in a coursepack plus one long, 80-minute lecture primarily focused on free body diagrams. This instruction took place in a traditional lecture style where students took notes and asked questions, but it usually resulted in the few students with prior knowledge of free body diagrams and/or hydrodynamics dominating the questions.

Previous work in post-secondary education shows that students can improve perception and understanding in active learning environments [11, 12]. Active learning may also help increase student retention [13]. Previous research also suggests that small group aspects of an active learning classroom are beneficial to student success [14, 15]. In particular, student collaboration results in gains for students because it forces them to flesh out their mental models and to compare their mental models with others', noticing differences and explicitly spelling out assumptions [16, 17, 18].

In understanding previous work, the goal of the instructors was to bring previously documented successful pedagogies to use in teaching hydrodynamics concepts to first year engineering students with the intention of improving students' ability to grasp the high level concepts over the course of one lecture before moving on to a laboratory environment to experiment and reinforce the concept knowledge.

Methods

The collaborative lectures are taught with students working in small groups. We use a flexible classroom that has movable tables and chairs, and we have the students help us rearrange the furniture (if needed) according to the diagram in Fig. 1. This layout is sometimes referred to as "studio style" and that is how we will refer to this arrangement in this paper. Each group station can seat up to six students (we have groups of four to six) and has its own display. The displays can be driven by either the instructor's computer/tablet or can be released for students to connect their own computer/tablet.

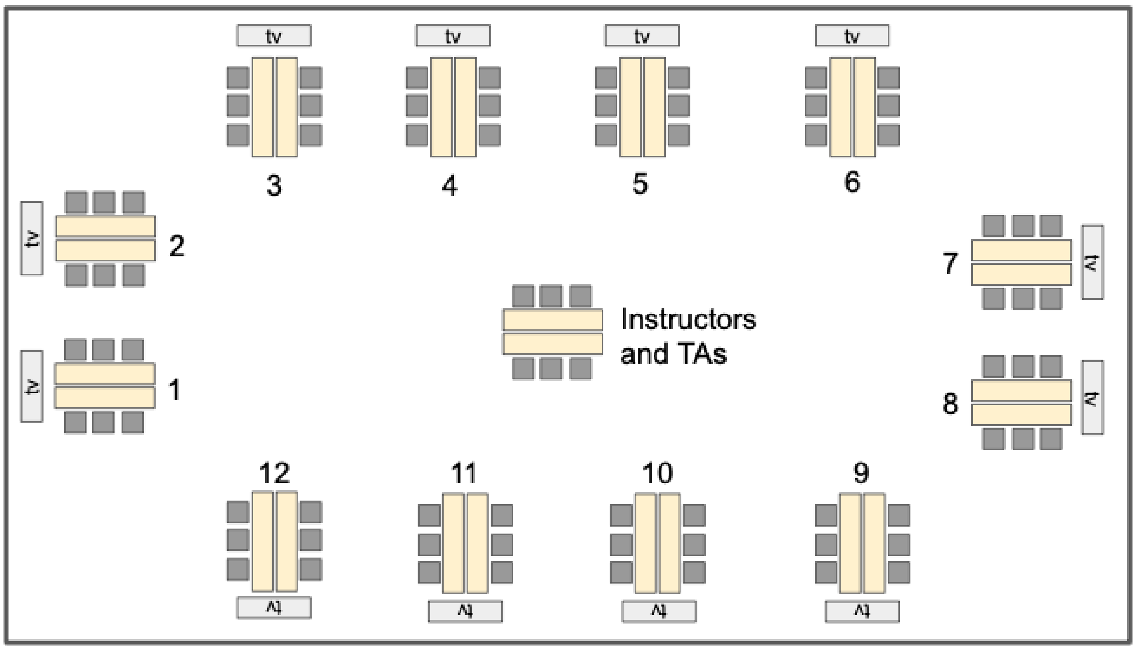

Figure 1: Suggested room layout for collaborative lectures. Small groups of 4-6 people are ideal. Displays at each group station can show either the instructor's computer/tablet or can be released for students to connect their own computer/tablet. Instructors and TAs have the center station.

On the first day, students are told which table to sit at (see station numbers on the diagram in Fig. 1). Using a studio style layout on the first day emphasizes to students that collaborative group work is an essential component of the course. Using the studio style on Day 1 also means that each student has a designated place that they know is already theirs, emphasizing their belongingness right from the start of class and helping to make all students feel welcome in engineering courses [19, 20, 21, 22]. An example of students working at a station is shown in Fig. 2.

Figure 2: A group of students working on the Intro to ROV Controls collaborative lecture. Photo used with permission.

There are three primary lectures/lecture activities that cover the high-level hydrodynamics that students need to learn to design their ROV prototypes:

1. Streamline visualization (hands-on demo)
2. Intro to ROV hydrodynamics and controls (collaborative lecture + hands-on demo)
3. Hydrodynamic stability (collaborative lecture)

These lectures happen within the first three weeks of the course. Each lecture/lecture activity is highly collaborative, as described in the next sections.

Streamline Visualization

The goal of the Streamline Visualization activity is for students to gain insight into the fluid-structure interaction that will affect their ROV. This activity occurs in a flipped-classroom style format on the first day of the course. Students are given a two page background on streamlines and how they show where the flow is disturbed; students read the background information before coming to lecture on the first day. We end the first day's lecture with a hands-on demonstration of the streamlines around an ROV. This activity takes approximately 30 minutes.

Initial Background Reading. The background information for the streamline visualization [23] explains:

> Anywhere the flow is disturbed (meaning, where the streamlines are not straight) contributes to the object's drag. So, the shape and orientation of the object is really important.

Note that the language used is approachable and non-mathematical. Some of our students have had calculus, but many have not, so we focus on explaining concepts in clear – but not oversimplified – language. We are aiming for students to use experiential learning to begin building patterns in their minds about how water moves past objects.

Hands-On Demo. The streamline visualization activity is described to students as Design-Build-Test-Communicate (DBTC) practice:

- **Design:** a visual that shows how water flows around an ROV to help determine center of drag (aka center of pressure)
- **Build:** prototype using dominoes falling as the ”streamlines” around the ROV
- **Test:** use a rod to start all lines of dominoes falling at once; record video; note where the dominoes fall “slower” around the ROV; interpret how the shape and orientation of the ROV contributes to “slower flow” and increased drag
- **Communicate:** make 1-2 slides on why you chose this design; picture(s) of the prototype; results of testing; conclusion on how well the prototype met the design needs

Each student group is given an “ROV” and a set of approximately 250 dominoes. Our “ROVs” are assembled using simple children’s toys, but the ROVs can be anything as long as they are suitably odd-shaped so the flow will be turbulent as it goes by the ROV. Students work in their small groups to design this flow visualization. Students are free to choose the orientation of the ROV, the viewpoint of the visualization (top, profile, etc.), and the arrangement of the dominoes. An example of a streamline visualization created by a student group is shown in Fig. 3.

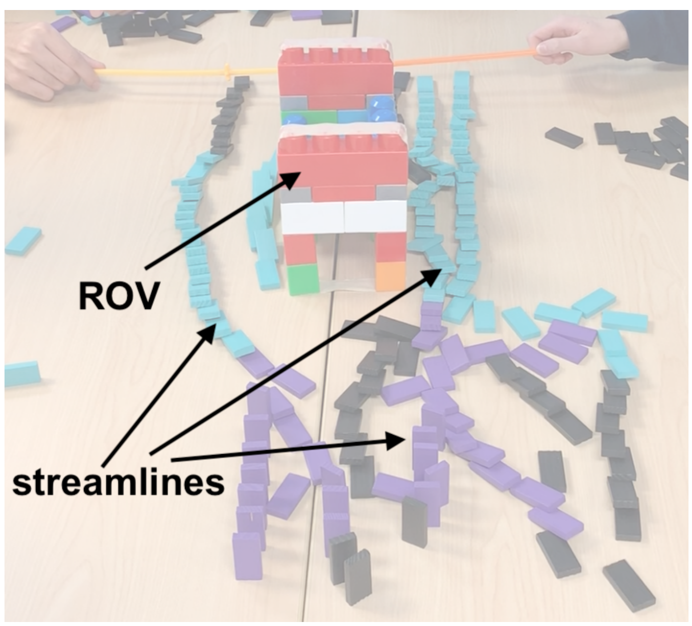

Figure 3: Example of the Streamline Visualization activity. Falling dominoes are used to simulate streamlines around an ROV. A video of the dominoes falling can be seen at `https://twitter.com/LauraKAlford/status/1214973042243203072?s=20`.

Intro to ROV Hydrodynamics and Controls

The goal of this collaborative lecture and hands-on demo is for students to gain insight into how their design choices will impact the forces on the ROV, which ultimately affects control. The collaborative lecture is approximately 60 minutes, and the hands-on demo is approximately 15 minutes.

Collaborative lecture. The collaborative lecture is a Google Slides presentation [23] that is viewable by all students in the class. The first slide includes this text:

> Have someone in your group make a copy of this presentation and share it with everyone else in your group. Replace the text in this box with your names because you're going to help author this presentation.

After all groups have successfully made their copies and shared with their group members, lecture proceeds in a traditional fashion, with students able to follow-along with the slides in front of them (albeit in a studio-style room layout) until a slide with an orange box appears. An example slide is shown in Fig. 4.

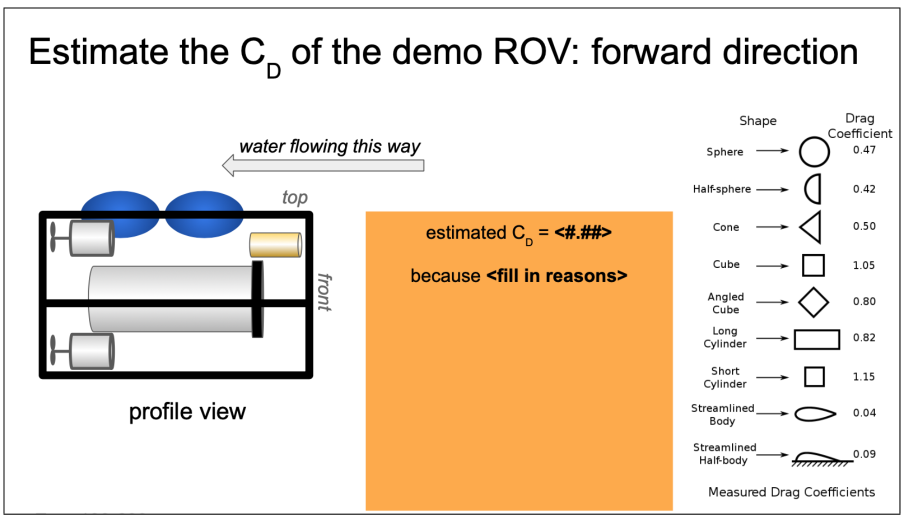

Figure 4: A slide requiring student collaboration. The orange box signals for their attention and contain instructions for how to complete the slide.
Drag coefficients image is public domain:
`https://commons.wikimedia.org/wiki/File:14ilf1l.svg`.

For each collaboration slide, we explain what the student groups need to do, then we give them time to complete the slide. The time each collaboration slide requires ranges from one minute to roughly ten minutes – enough time for groups to determine answers, but short enough to keep everyone moving through the lecture. After students have worked in their small groups, we bring them back to the large group for a discussion of their completed slides. Examples of what a completed version of the slide in Fig. 4 might look like are shown in Fig. 5.

Each group will have its own consensus on what the "answer" is on these collaborative slides. The instructors check that the numbers are reasonable and well-justified, not whether the answers are "correct" according to an answer key. In cases where there is a specific result we are looking

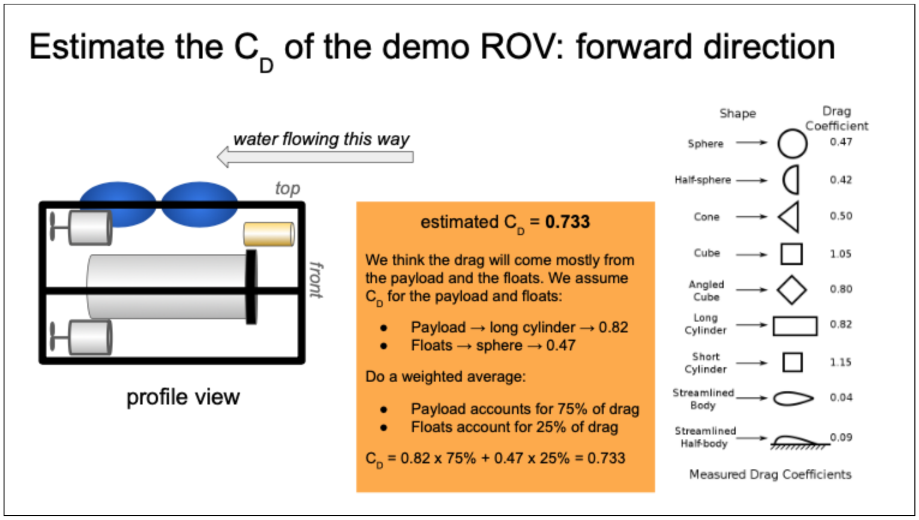

Figure 5: Sample versions of a collaboration slide that has been completed by a student group. Note that the numbers and reasons are not the same. Each group has its own consensus on what the "answer" is; the instructors check that the numbers are reasonable and well-justified, not whether the answers are "correct."

for, we walk around to several groups and have them write their results on a tablet that is projecting to all displays via Apple AirPlay. As a large group, we discuss whether the results should be the same (i.e., there is a "correct" answer), the results should be reasonably similar (i.e., there is a range of "correct" answers), and whether a result that is dissimilar should be reviewed (i.e., there is an "incorrect" answer).

One of the main takeaways from this lecture is an understanding of which forces can act on an object in the water and what level of control an operator has on those forces. The collaborative slide shown in Fig. 6 is the final slide of the collaborative lecture portion of this class meeting, which includes a table to summarize the forces.

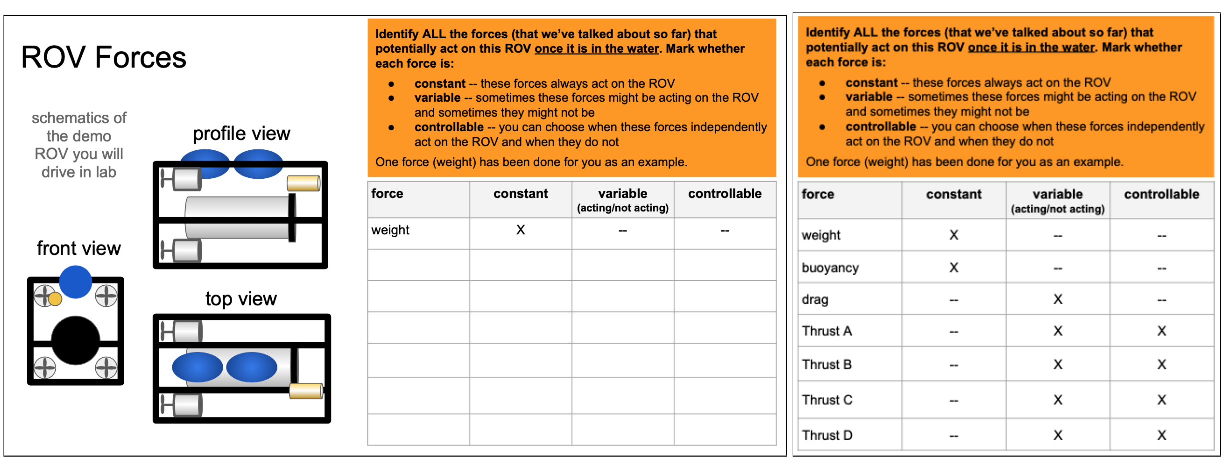

Figure 6: [Left] Collaborative slides that guides small group discussion of the forces that act on an ROV. [Right] Sample of a completed version of the forces table that would be created by a group of students.

Students discuss in their small groups (a) which forces belong in this table, and (b) whether that force is variable and/or controllable. Completing this table clarifies several common stumbling points for students (such as incorrectly including pressure as a force), and ensuring that everyone understands what forces to consider, and potential options to control them, when designing the ROV.

Hands-On Demo. In this course, students are limited to a maximum of four thrusters to use on the ROV. The limitation on thrusters is partially financial but mostly to practice working with design constraints. However, it is difficult for students to understand the implication of the limited number of thrusters on their future ROV's maneuverability without seeing the effects first-hand. Our students do have a lab in which they will drive a demo ROV, but to bridge the hydrodynamics and controls concepts in this lecture to the lab they will attend, we do a hands-on activity to demonstrate how different design choices on ROV controls will affect an ROV's ability to maneuver around various potential obstacles in the water.[23] This activity takes approximately 15 minutes.

First, each group is given an obstacle to create (e.g. something the ROV has to go under, circle around, go over, etc.). These obstacles are created with the movable furniture in the room. Then, each group is also given an ROV controller. The "controller" is a table listing which degrees of freedom (surge, sway, heave, roll, pitch, yaw) the ROV is able to move in and how fast it can move in the given degree of freedom. An example "controller" is shown in Table 1. Each group has a limited number of degrees of freedom they can directly control.

Table 1: A table representing a sample "ROV controller" that is given to a student group. Such an ROV would be able to move independently in surge, sway, heave, and roll, but would not be able to move independently in roll or yaw. This ROV would be able to move relatively slowly in surge and sway but move quickly in heave.

	surge	sway	heave	roll	pitch	yaw
slow	X	X				
medium					X	
fast			X			

Groups take turns to drive an "ROV," using their controller, around the obstacle that they created. The ROV is, in fact, one of the instructors, who is willing to sacrifice all dignity for the sake of education and comedy (`https://twitter.com/robinfowl/status/1171836467724734464?s=20`). The key to the demonstration is for the "ROV" to do *exactly* as instructed by the students – usually resulting in a lot of bonking into tables, chairs, and walls, because it's hard to control ROVs and students forget that there are no brakes underwater.

Hydrodynamic Stability

The goal of this collaborative lecture is to teach students how to use free body diagrams to perform a high-level analysis of the forces acting on an ROV to determine its hydrodynamic stability [23]. This lecture takes approximately 30 minutes, but could easily be extended to give students more practice with free body diagrams.

Introduction to Engineering is a first year course, and most of our students are not familiar with free body diagrams as a design tool. Therefore, we introduce free body diagrams as a tool to track forces and moments, show their directions and relative magnitudes, and visualize how an ROV will move through the water before the ROV is built. We emphasize that a quick high-level analysis of a potential ROV design using a free body diagram can reveal design pitfalls such as imbalanced forces causing an ROV to pitch down while moving forward instead of surging forward in a straight line.

The lecture starts with a diagram that reviews the forces acting on an ROV, as shown in Fig. 7. Discussing the moments that result from these forces can be difficult because some students have not taken college-level physics, and analyzing the forces and moments numerically is beyond some of our students current skill level. Instead, we discuss the relative directions and magnitudes of the forces and moments, focusing on which ones are large, small, or zero (Fig. 8).

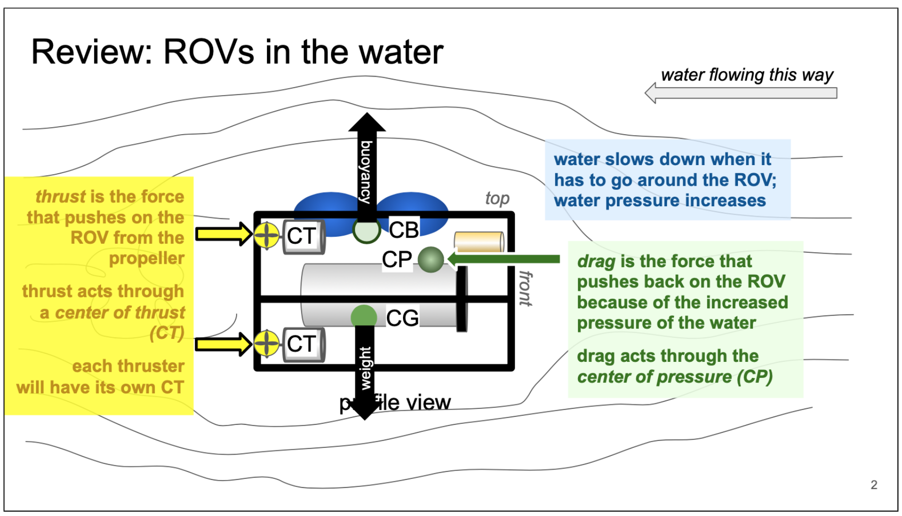

Figure 7: A slide including a diagram showing the high-level interaction of forces acting on an ROV.

After establishing a baseline for force and moment analysis that does not require numerical calculation, but rather intuition, we demonstrate how to use a basic free body diagram to analyze the motion of an ROV in the moment that the thrusters are turned on (Fig. 9).

The instructor walks students through how to use the large/small/zero analysis method to sum the forces, sum the moments, and predict how the ROV will move through the water. The predicted movements are highlighted in the pink box on the slide in Fig. 9. After watching the instructor demonstrate how to use this high-level free body diagram approach, students then practice the approach on several other sample ROV designs (Fig. 10), including a design iteration that attempts to correct a pitching motion by balancing the thruster moments.

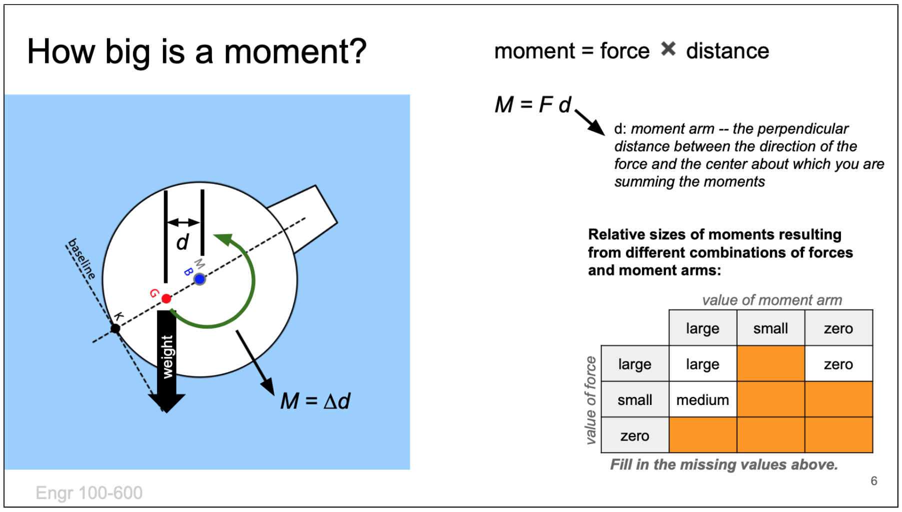

Figure 8: A collaborative slide guiding students to categorize the relative moments that result from different combinations of forces and moment arms.

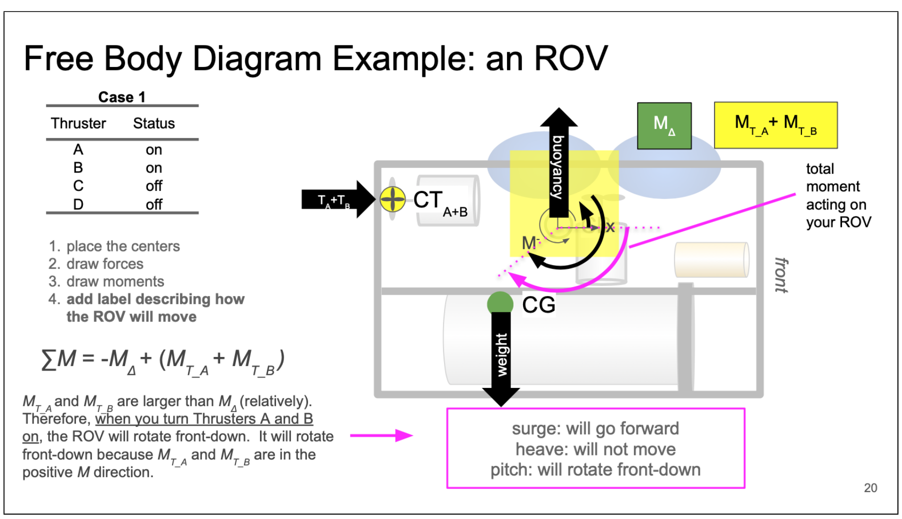

Figure 9: A slide demonstrating the use of a free body diagram to analyze the motions of an ROV. The pink box emphasizes what students should be aiming for in reporting the results of their analysis.

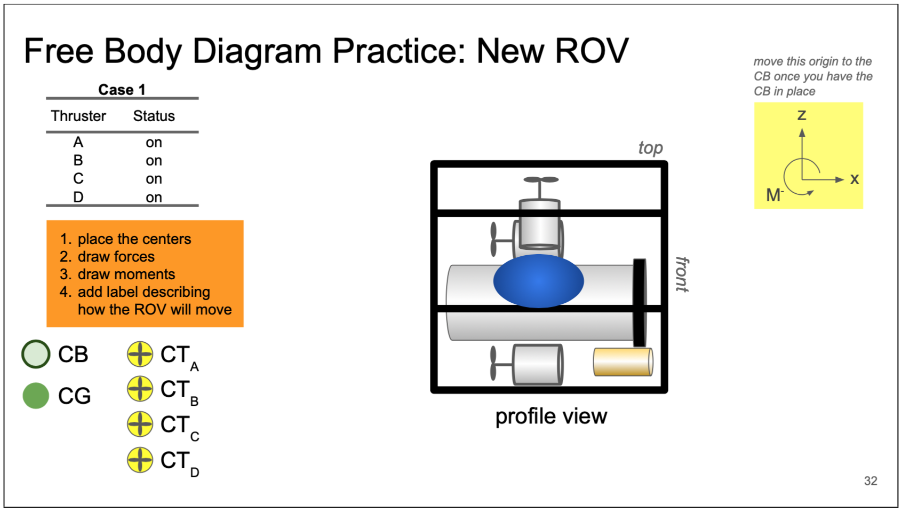

Figure 10: A collaborative slide students complete for practice with free body diagrams.

Discussion

We will discuss our perceived benefits and potential drawbacks of using collaborative lectures to teach high-level hydrodynamics concepts to first-year college students. We will also discuss some lessons learned regarding the use of flexible classrooms.

Benefits of Collaborative Lectures

We have seen a significant improvement in student comprehension of hydrodynamics since switching to the collaborative lectures three semesters ago. We do not have a formal assessment of this improvement as we do not really test on such high-level concepts. Our qualitative assessment is based on the improvement of the ROV designs themselves, our interactions with the students while discussing hydrodynamics concepts, and in the quality of the ROV presentations and reports produced by students in the course.

Motion and Controls. Students are more comfortable and knowledgeable about ROV movement during the lab immediately following the Intro to ROV Hydrodynamics and Controls lecture. They are able to understand and explain why the demo ROV moves the way it does, referring back to the slides used in the collaborative lecture. Students are now better able to extrapolate the concepts of drag, weight, buoyancy, and thrust, along with design choices affecting controls, to potential ROV designs. We see students using the concepts covered in lecture to analyze different designs early in the design cycle, when it is easy to make changes. The students also spend more time designing their control systems and thruster layouts with forces and moments in mind.

Hydrodynamic Stability. The Hydrodynamic Stability collaborative lecture has a clear benefit in decreasing the number of proposed ROV designs that inadvertently pitch up/down when attempting to solely surge; this design flaw used to be common in many students' ROV designs. The virtual moment balancing via the free body diagrams appears to drive home to students the importance of the aligning forces and centers.

Students produce an individual design proposal prior to being placed in teams. These individual design proposals now have much better rationale for the placement of the ROV's thrusters, payload, and flotation material. Students use the free body diagrams to justify their design choices, and we observed that students are noticeably better at predicting how their ROV would move through water and whether it is hydrodynamically stable, producing "better" designs in that the designs are more likely to result in ROVs that move the way the students are envisioning their ROV to move.

Another compelling example is from a team that wanted to include a horizontal thruster to independently control sway, but the only mounting location available on their design was not aligned with the center of buoyancy and would cause the ROV to roll and yaw in addition to sway. The team solved this problem by designing and 3D printing a "redirection tube" to bend the thrust around to either side of the center of buoyancy and eliminate the yaw-inducing moment (Fig. 11). The redirection tube worked beautifully, and that team happened to win the competition. We had not seen these types of design innovation prior to using these collaborative lectures on hydrodynamics.

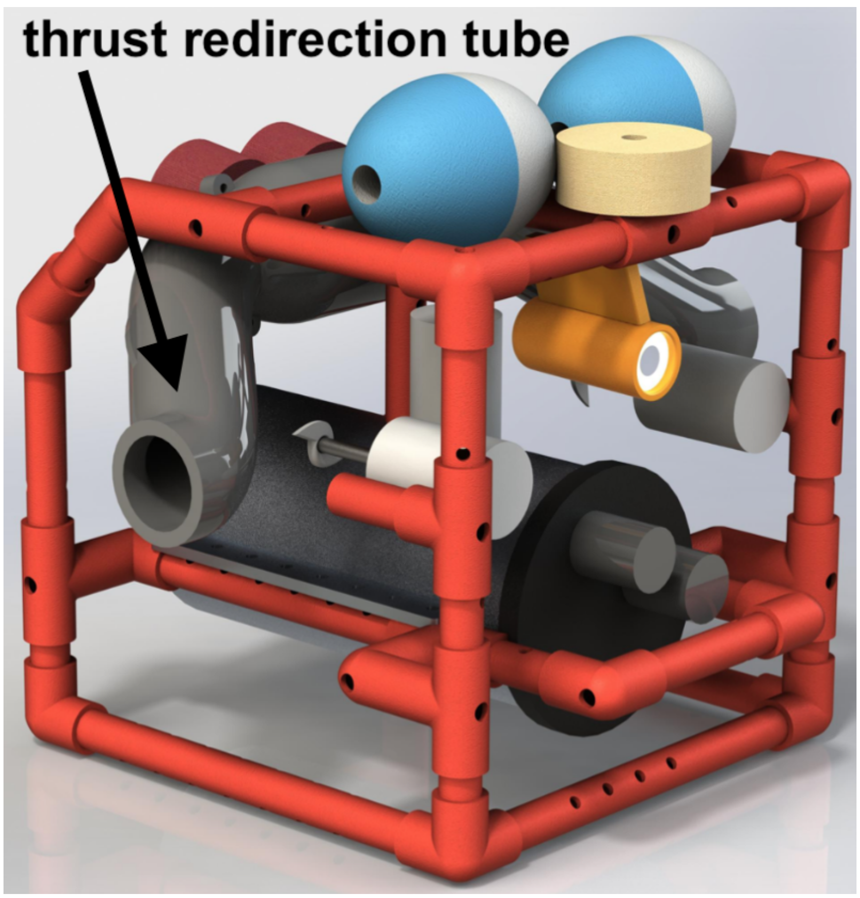

Figure 11: An ROV design that included a novel thrust redirection tube to improve hydrodynamic stability.

Drawbacks of Collaborative Lectures

We are extremely pleased with the results we have seen from switching to collaborative lectures for the hydrodynamics concepts; however, nothing is perfect. We discuss here some potential drawbacks of collaborative lectures.

Commonality. The primary drawback of a collaborative lecture is the lack of a common set of material available to each and every student. Traditional lectures have a common slide deck or handouts provided to all students. A collaborative lecture will have some level of partial commonality, but it will not have 100% commonality.

Instructor's Energy. Another potential drawback to a collaborative lecture is the required energy it takes on the instructor's part to give such a lecture. These are high-energy lectures with significant movement throughout the classroom and significant engagement with students, which may be difficult for some instructors. This type of collaborative lecture may be difficult for an alternate lecturer to give, should the primary lecturer be unavailable on the scheduled day. Additionally, it constrains class size, as a lecturer can usefully interact with a maximum of perhaps ten or twelve teams.

Student Interaction. The success of a collaborative lecture is heavily dependent on the engagement of students in their small groups. In general, increased learning in collaboration comes from students externalizing their mental models and comparing those to others; for such learning to occur, students need to be willing to engage and even to disagree productively [24]. Previous research has shown that some elements of collaborative learning may be difficult for co-located student groups meeting face-to-face [3, 24, 25, 26]. For example, negotiations in diverse groups may be affected by power dynamics in conversations that affect students' willingness to present an unpopular perspective to even to engage at all. The impact of gender and underrepresented minority status on willingness to disagree in first year engineering teams were briefly examined in [3], but the results were not significant. However, it should be noted that there were individual instances of repressed expressions in that study due to personality conflicts in small group settings, in which women in particular felt they were disadvantaged.

Additional research has also been performed on examining gender impact in small group learning environments, which have shown that women participate less, or differently, in small groups [25, 27]. These impacts should be understood by instructors, as they may predict inequitable group experiences and inequitable learning from this pedagogical choice.

Room Layout. Lastly, a collaborative lecture necessarily requires a classroom set up for small groups, as shown in Fig. 1. Institutions may have limited availability and capacities of such classrooms. Classroom logistics is discussed further in the next section.

Logistics of Flexible Classrooms

We are fortunate to teach in a flexible classroom. Flexible classrooms are often created to accommodate both classes that are taught in traditional lecture style (all students facing one direction) and classes taught in studio style (students arranged in small groups). We share here some of the things we have learned about using flexible classrooms, since the studio-style room setup is crucial to teaching a collaborative lecture.

Capacity. Flexible classrooms need a lot of space for maneuvering, both in terms of rearranging the furniture and for students and especially instructors to get around to different student groups. In our experience, an additional 30-40% capacity is needed for classes that are taught in flexible classrooms. For example, a 60 person class would need to be in a room that can seat around 80 people in a traditional lecture arrangement where the tables and chairs are arranged in rows facing one direction. A room that seats 50 people in a traditional lecture arrangement would seat approximately 35 people in a studio-style arrangement. Note that these rooms should not be considered "under capacity" when assigned to classes that use studio-style teaching.

Displays. If displays are to be used by students in small groups, in addition to being classroom displays driven by instructors, then the displays should be sized and mounted appropriately. We recommend a TV that is approximately 42" and is mounted so that the bottom of the TV is a few inches higher than the table surface. Using larger TVs and/or mounting the TVs higher than the tables makes it too difficult for students to comfortably see the displays at their group stations, and then students will not use the displays for their collaborative work. In addition, the technology to drive the multiple displays in flexible classrooms *must* be robust so that instructors do not lose valuable teaching time to troubleshooting technology. Instructors may have a minute or two available to reboot the system to see if "have you tried turning it off and on again" helps, but only if the system can quickly come back online.

Sound System. A microphone system is critical when teaching in a studio-style arrangement because the instructor is not going to be facing everyone all the time, which means their voice won't be carrying to all corners of the room. A microphone will enable all students to hear the instructor's voice no matter where they are sitting in the room. A microphone also makes it easier to regain students' attention when they are busy working in their small groups. It is noisy when a large group (say, 60-80 people, subdivided into small groups) is engaged in active learning. Without a microphone, instructors have to yell to get their students' attention to clarify instructions, share out results, or to move students to the next activity. Yelling can sometimes make the instructor sound angry, when all they are really trying to do is be heard above the noise. Using a microphone allows the instructor to use their normal voice and still be heard. For additional accessibility, we recommend including a system that can do real-time captioning on the displays, so that deaf and hard-of-hearing students also know what the instructor is saying.

Scheduling. It takes a decent amount of time (at least 15 minutes, if not more) to switch from a more traditional lecture setup (with rows of tables and chairs all facing the same direction) to a small group/studio setup (lots of group stations) and vice-versa. The tighter the space, the longer it takes to rearrange the furniture. Students are usually happy to help change from one setup to another, but changing the room layout can cause stress on everyone if classes are scheduled back-to-back. A 30 minute buffer between classes that need very different setups would help immensely. Alternatively, if it is possible to schedule classes that had similar setups (studio vs. traditional lecture vs. "theater in the round" vs. whatever) then that would help with transitions between classes.

Conclusions & Limitations

Teaching hydrodynamics concepts to first-year engineering students is a difficult task, but incorporating active learning strategies through the use of collaborative lectures and hands-on learning in the classroom, in addition to simplifying concepts, can help students grasp concepts that would otherwise not be introduced until several years later in their post-secondary education.

In this paper we have outlined several active learning techniques used in a first-year engineering course, including having students complete lecture slide examples in small groups and acting out vehicle dynamics with the help of instructors. These techniques are used in addition to a hands-on interactive laboratory and limited background reading at a high level for the students.

After these strategies were incorporated into the course, students were perceived to increase retention and comprehension of hydrodynamics concepts which have improved their designs, increased the technical content of their written communication, and improved the innovative strategies used by the students in their designs.

These active learning and collaborative lecture strategies come with a requirement to have a flexible space for teaching. Having larger classrooms with small group stations and large reliable displays for collaboration are important aspects to the success of the student learning. Additionally, ensuring the room is well equipped with appropriate technology and sound systems allows the instruction to flow more smoothly.

Finally, it should be noted that the results of this paper come with several limitations. There is no quantitative data available to back up the authors' perceptions of increased student understanding. This study was also carried out with a limited number of students each year at one university.

Acknowledgements

Many thanks to Mustapha Baltaji, Kaavya Ramachandhran, Zaynab Alsaedy, Berry Matthews III, Taylor Kessinger, and Henry Beckstein for their permission to use their image in the picture in Fig. 2.

References

[1] James Coller, Magel Su, Laura Alford, Stephanie Sheffield, and Robin Fowler. Assessment of Peer Mentoring of Teams in a First-Year Design-Build-Test-Communicate Class. In *2017 ASEE Annual Conference & Exposition Proceedings*, Columbus, Ohio, June 2017. ASEE Conferences. doi: 10.18260/1-2--27636. URL `https://peer.asee.org/27636`.

[2] Robin Fowler, Laura K Alford, James A Coller, Stephanie Sheffield, and Magel P Su. Student Perceptions of Teamwork Support. In *2019 ASEE Annual Conference & Exposition*, page 14, Tampa, FL, June 2019. American Society of Engineering Education. URL `https://peer.asee.org/33296`.

[3] James A Coller, Magel P Su, and Robin Fowler. Disagreement in Engineering Student Teams: Analyzing the Impact of Gender and Conversational Medium. In *2018 ASEE Annual Conference & Exposition Proceedings*, page 10, Salt Lake City, UT, June 2018. American Society of Engineering Education. URL https://peer.asee.org/30337.

[4] Laura K Alford, Robin Fowler, and Stephanie Sheffield. Evolution of Student Attitudes Toward Teamwork in a Project-based, Team-based First-Year Introductory Engineering Course. In *2014 ASEE Annual Conference & Exposition*, Indianapolis, IN, June 2014. American Society of Engineering Education. URL https://peer.asee.org/20445.

[5] James Buchholz, Pablo M Carrica, and Jae-Eun Russell. A Naval Hydrodynamics Undergraduate Curriculum for the Midwestern United States. In *2018 ASEE Annual Conference & Exposition Proceedings*, Salt Lake City, UT, June 2018. ASEE.

[6] Hang S Choi. Innovation of Naval Architecture & Ocean Engineering Curriculum at Seoul National University. In *2002 ASEE Annual Conference & Exposition Proceedings*, Montreal, Canada, June 2002.

[7] Eugene Niemi. Development Of An Ocean Engineering Course As A Technical Elective For Mechanical Engineers. In *2004 ASEE Annual Conference and Exposition Proceedings*, Salt Lake City, UT, 2004.

[8] Alvaro Suarez, Sandra Kahan, Genaro Zavala, and Arturo C. Marti. Students' conceptual difficulties in hydrodynamics. *Physical Review Physics Education Research*, 13(2), November 2017. ISSN 2469-9896. doi: 10.1103/PhysRevPhysEducRes.13.020132. URL https://link.aps.org/doi/10.1103/PhysRevPhysEducRes.13.020132.

[9] Shanjun Xu, Sven Esche, Constantin Chassapis, Ruiqing Jia, El-Sayed Aziz, and Songyun Gao. A Virtual Laboratory On Fluid Mechanics. In *2006 ASEE Annual Conference and Exposition Proceedings*, Chicago, Illinois, 2006.

[10] Eric Leonhardt. Board # 67 : Tunnel Hull Design Project: Engaging Entry-Level Students in Vehicle Design with a Wing-in-Ground Effect Vessel Design Project. In *2017 ASEE Annual Conference & Exposition Proceedings*, Columbus, Ohio, June 2017. ASEE Conferences. doi: 10.18260/1-2--27903. URL http://document-repository.dev/27903.

[11] Robert A. Bloodgood. Active learning: A small group histology laboratory exercise in a whole class setting utilizing virtual slides and peer education. *Anatomical Sciences Education*, 5(6):367–373, 2012. ISSN 1935-9780. doi: 10.1002/ase.1294. URL http://anatomypubs.onlinelibrary.wiley.com/doi/abs/10.1002/ase.1294.

[12] J. Patrick McCarthy and Liam Anderson. Active Learning Techniques Versus Traditional Teaching Styles: Two Experiments from History and Political Science. *Innovative Higher Education*, 24(4):279–294, 1999. ISSN 0742-5627. doi: 10.1023/B:IHIE.0000047415.48495.05. URL http://link.springer.com/10.1023/B:IHIE.0000047415.48495.05.

[13] John M. Braxton, Jeffrey F. Milem, and Anna Shaw Sullivan. The Influence of Active Learning on the College Student Departure Process: Toward a Revision of Tinto's Theory. *The Journal of Higher Education*, 71(5): 569–590, September 2000. ISSN 0022-1546, 1538-4640. doi: 10.1080/00221546.2000.11778853. URL https://www.tandfonline.com/doi/full/10.1080/00221546.2000.11778853.

[14] Peter Armbruster, Maya Patel, Erika Johnson, and Martha Weiss. Active Learning and Student-centered Pedagogy Improve Student Attitudes and Performance in Introductory Biology. *CBE—Life Sciences Education*, 8(3):203–213, September 2009. ISSN 1931-7913. doi: 10.1187/cbe.09-03-0025. URL https://www.lifescied.org/doi/10.1187/cbe.09-03-0025.

[15] Diane Ebert-May, Carol Brewer, and Sylvester Allred. Innovation in Large Lectures: Teaching for Active Learning. *BioScience*, 47(9):601–607, October 1997. ISSN 00063568, 15253244. doi: 10.2307/1313166. URL https://academic.oup.com/bioscience/article-lookup/doi/10.2307/1313166.

[16] Robert L Jorczak. An information processing perspective on divergence and convergence in collaborative learning. *International Journal of Computer-Supported Collaborative Learning*, 6(2):207–221, 2011.

[17] Ulrike Cress and Joachim Kimmerle. A systemic and cognitive view on collaborative knowledge building with wikis. *International Journal of Computer-Supported Collaborative Learning*, 3(2):105, 2008.

[18] Evren Eryilmaz, Jakko van der Pol, Terry Ryan, Philip Martin Clark, and Justin Mary. Enhancing student knowledge acquisition from online learning conversations. *International Journal of Computer-Supported Collaborative Learning*, 8(1):113–144, 2013.

[19] C. M. Steele. A threat in the air: How stereotypes shape intellectual identity and performance. *American Psychologist*, 52(6):613–629, 1997. URL `http://dx.doi.org/10.1037/0003-066X.52.6.613`.

[20] A. J. Gomes, A. N. Santos, and A. J. Mendes. A study on students' behaviours and attitudes towards learning to program. *Proceedings, 17th ACM Annual Conference on Innovation and Technology in Computer Science Education (ITiCSE)*, 2012.

[21] Jennifer M. Grossman and Michelle V. Porche. Perceived gender and racial/ethnic barriers to stem success. *Urban Education*, 49(6):698–727, 2014. doi: 10.1177/0042085913481364. URL `https://doi.org/10.1177/0042085913481364`.

[22] Joan Peckham, Lisa L. Harlow, David A. Stuart, Barbara Silver, Helen Mederer, and Peter D. Stephenson. Broadening participation in computing: Issues and challenges. *SIGCSE Bull.*, 39(3):9–13, June 2007. ISSN 0097-8418. doi: 10.1145/1269900.1268790. URL `http://doi.acm.org/10.1145/1269900.1268790`.

[23] L. K. Alford. Collaborative lectures and activities for teaching high level hydrodynamics concepts. URL `https://drive.google.com/drive/folders/1PKvbgK-w2m0fEJGxY7GB6z9E2_HyXU5H`.

[24] Robin R. Fowler. *Improving engineering student team collaborative discussions by moving them online: an investigation of synchronous chat and face-to-face team conversations*. PhD thesis, 2014.

[25] Robin R Fowler. Talking Teams: Increased Equity in Participation in Online Compared to Face-to-Face Team Discussions. *The ASEE Computers in Education (CoED) Journal*, 6(1):14–22, 2015.

[26] Michael Prince. Does active learning work? a review of the research. *Journal of engineering education*, 93(3): 223–231, 2004.

[27] Laura Hirshfield and Milo D Koretsky. Gender and Participation in an Engineering Problem-Based Learning Environment. *Interdisciplinary Journal of Problem-Based Learning*, 12(1), November 2017. ISSN 1541-5015. doi: 10.7771/1541-5015.1651. URL `https://docs.lib.purdue.edu/ijpbl/vol12/iss1/2`.

Appendix

The collaborative lectures and hands-on activities described in this paper may be found online at `https://drive.google.com/drive/folders/1PKvbgK-w2m0fEJGxY7GB6z9E2_HyXU5H`.

The collaborative lectures and hands-on activities include:

- Streamline Visualization:
  - ”Streamline Visualization Activity” doc, includes background information
- Intro to ROV Hydrodynamics and Controls:
  - ”Intro to ROV Hydrodynamics and Controls” slides, also uses the ”ROV Centers Calculation Practice” spreadsheet
  - ”ROV Controls Activity - Background Information” doc
  - ”ROV Controls Activity” doc, also uses the ”ROV Controls - Group Info” spreadsheet (two tabs)
- Hydrodynamic Stability:
  - ”Hydrodynamic Stability” slides