# Enhancing the Connection to Undergraduate Engineering Students: A Hands-on and Team-Based Approach to Fluid Mechanics

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## Abstract

This article provides information about the integration of innovative hands-on activities within a sophomore-level Fluid Mechanics course at New Mexico Tech. The course introduces students to the fundamentals of fluid mechanics with emphasis on teaching key equations and methods of analysis for solving real-world problems. Strategies and examples for moving beyond a traditional lecture-based course are shared, with links highlighting various media used in the course. Implementation of an end-of-semester survey, examples of student performance on select assignments, and qualitative feedback from students indicate the effectiveness of these hands-on activities designed to increase student engagement.

**Keywords**
Engineering education, Multimedia pedagogy, Teamwork

## Introduction

The National Academy of Engineering's Educating the Engineer of 2020 report includes a call for engineering faculty to "enhance and personalize the connection to undergraduate students" and "to understand how they learn and appreciate the pedagogical approaches that excite them" (34). A recent *U.S. News* article reported recommendations such as "Developing more hands-on programs" to keep "students engaged in their STEM disciplines" from an expert panel at the *U.S. News* STEM Solutions conference devoted towards curbing STEM student attrition (Williams). Several previous studies have investigated pedagogical approaches in engineering classrooms and noted the benefit to methods that go beyond traditional lecture-based classrooms.

Project-Based Learning (PBL) is considered one of the most effective tools used in engineering education. It has been linked with an increase in student motivation, tied to improvement of communication skills, and seen as a catalyst in helping students develop self-learning abilities. As noted by Savage, Chen, and Vanasupa, "A project, based on solving a technical design problem, gives students a contextual environment that makes learning relevant and focused. Solving the problem drives learning, rather than the traditional 'teach by telling' lecture format" (2). Multiple researchers have tested PBL approaches in the classroom (Hadim and Esche, Mills, Parker et al., Asa and Gao). Mokhtar et al. implemented Project-Based Learning in a Mechanical Engineering program and note multiple benefits. (For an excellent resource providing PBL methodology as well as results from case studies, also consult Du, de Graaff, and Kolmos, 2009).

In Froyd's "Promising Practices in Undergraduate STEM Education" white paper, eight promising practices, each of which is evaluated against the standards of implementation and student performance are presented. The practices rated the highest include designing in-class activities to actively engage students and organizing students in small groups. Prior literature regarding the value of teamwork is extensive and includes work by Felder et al., Rugarcia et al., Woods et al., Hirsch and McKenna.

Incorporating electronic media in the classroom has also received pedagogical attention. Numerous studies pertain to the use of multimedia case studies including Mehta et al. and Sankar et al. Liberatore et al. share their study of YouTube Fridays, a method where a student-led activity selecting YouTube videos pertaining to course topics positively impacted students' ability to relate to real-world phenomena and solve open-ended problems (1).

McIntyre's study of a novel way to engage engineering students at Auburn included students divided into teams and assigned case study exercises in an introductory engineering course. Student interest in these cases was evaluated qualitatively in terms of communication, decision making and application of preparatory knowledge. The findings were that the greatest enthusiasm and interest occurred when there wasn't an existing correct or wrong answer. Teamwork and extended discussion expanded students' perspectives of problems featured in cases and "the lack of a 'right or correct' answer gives the students an open intellectual vista in which to assume the role of a practicing engineer and think beyond the single answer paradigm" (43). Along those same lines, Leifer offers a model for using projects in a Kinematics and Dynamics class where flexibility enables students to demonstrate creativity in a way that enhances learning.

This article contributes to the body of existing literature regarding hands-on engineering pedagogy and offers a case from a sophomore-level fluid mechanics classroom. Beginning with background information on the course, we then detail the implementation of the activities and assignments used in the course to connect the goals of the project with trends reported by prior research. We then include an evaluation of the activities by students, including results from a student survey regarding their experiences in the Spring 2014 course. Following these shared results we offer takeaway messages for engineering educators.

## Background

Required for all Civil Engineering, Chemical Engineering, Environmental Engineering, Mechanical Engineering, and Petroleum Engineering majors at our institution is ES 216, Engineering Fluid Mechanics. The course focuses on teaching students about fluid and flow phenomena.

Following are the course objectives:

- An understanding of fluid mechanics fundamentals, including concepts of mass and momentum conservation.
- An ability to apply the Bernoulli equation to solve problems in fluid mechanics
- An ability to apply finite control volume method to real-world problems
- An ability to apply dimensional analysis to real-world problems
- A knowledge of laminar and turbulent flows
- An ability to associate fundamentals of fluid mechanics to real-world applications

Typically two sections of the course are taught each semester, with enrollment in each section ranging from 50-74 students. In the past the course has been taught with traditional lecture-style format where the instructor is on center stage and the classroom is a lecture hall with fixed rows of seating.

### Novelty of Our Approach

Fluid Mechanics, a core course in engineering curricula at most institutions, is one students typically struggle with. With its subject matter including a heavy emphasis on equations, students may be challenged by the many derivations and assumptions required. At our own institution (and we are comfortable speculating at most institutions), the course has been mainly taught via traditional lecture classroom. Lacking in the literature are cases applying non-traditional teaching techniques. Some of the techniques we rely on were not pioneered by us, hence they are not truly innovative. However, we believe our application of them to Fluid Mechanics is innovative and, more importantly, offers novel options for readers considering new approaches to their own Fluid Mechanics courses or other engineering courses involving fundamental theories and equations.

| Project Name | Brief Description | Knowledge Points | Real-world application |
|---|---|---|---|
| Transmixing Safelock | Build a device to measure force on float with and without fluid flow. | Buoyance force, and drag force from fluid flow around solid object. | It is a commercial product that needs improvement. |
| Torricelli's law | Build and Measure velocity of water discharging from a container. | Application of Bernoulli equation, surface tension, major and minor head loss. | Perfume dispenser, discharge of water in hydro power plant. |
| Laminar flow fountain | Build a device that can maintain laminar flow to as high Reynolds number as possible. | Laminar and turbulent flow regime, factors that affect flow behavior, and how to control. | Laminar flow fountains in parks, and at airports (Detroit e.g.). |
| Flettner rotor boat | Build a boat with rotating cylinders attached. As wind blows across the rotating cylinder, part of the wind energy is converted to propulsion of boat. | Forces of flowing fluid on solid object. Design. | It was first used in 1925, and still actively researched by individuals and companies. |
| Falling of raindrops on windshield | Build and measure the falling of water film on a piece of glass, at different angles. | Flow instability, dimensional analysis (organization of data), determination of critical parameters. | Improve the efficiency of windshield wipers, or design of the air nozzles in wiperless windshield. |

Table 1: Fluid Mechanics Hands-on Team Assignment

## Implementation

The objective of this project was to enrich student experiences in a required Fluid Mechanics course through the incorporation of hands-on activities and assignments and creative media use designed to engage students in ways that a traditional lecture-based classroom setting cannot. This objective was in part guided by the recommendation put forth in the National Academy of Engineering's Engineer of 2020 report that the "iterative process of designing, predicting performance, building and testing…be taught from the earliest stages of the curriculum, including the first year" (p.33). Designing a sophomore-level course in this manner was intended to impact students' enthusiasm and success in their chosen field and make them more prepared for the academic challenges facing them in the junior and senior years. The use of teams, incorporation of a substantial hands-on project, and integration of multimedia and stories were included in the course during the Spring 2014 semester.

### Guidance from Instructor

Within the syllabus, instructions for how the course will be structured are included, and in-class time is spent during the first week clarifying expectations about the role of the instructor and the roles of the students. The first teams to serve as team of the week (more information about team of the week is included in the next section) are given coaching by the instructor separately outside of class so that they provide a good model for the remaining teams to follow. Throughout the rest of the semester, the instructor provided guidance to the teams who sought help during office hours.

### Role of Teams

To encourage teamwork and also provide help with classroom management, at the beginning of the semester, students were randomly divided into eight teams, each with between 8-9 members. During this first week, the team chose the individual who would serve initially as leader and each team member was tasked with emailing a profile (name, major, class standing, a few sentences of introduction, and a photo) to the team lead. Leaders compiled these and shared them with the rest of the class.

Throughout the remainder of the course, teams were required to sit together during class time (with the teams' locations in the classroom changing at the midpoint in the semester to ensure no team would be sitting in the back of the classroom the entire semester). Each team rotated the leadership role among members, providing each member the opportunity to lead during the semester. Part of the team leader role required the leader to collect and hand back homework, saving the course instructor time and making the course grader's job of recording grades in a spreadsheet easier. When working on specific assignments, teams were required to decide upon appropriate roles to involve each member to allow for effective collaboration and take advantage of each individual's strengths.

Teams also took turns serving as "team of the week," a role that required all members of a particular team to play a key role in facilitating class discussion during their assigned week. Members of the team of the week were called on to answer questions during the lecture component of the course. In addition they were called on to summarize the contents of the lecture during the last few minutes of each class.

Dividing students into teams also allowed for incorporation of a substantial hands-on assignment with multiple components that required students to work together within their teams to successfully complete.

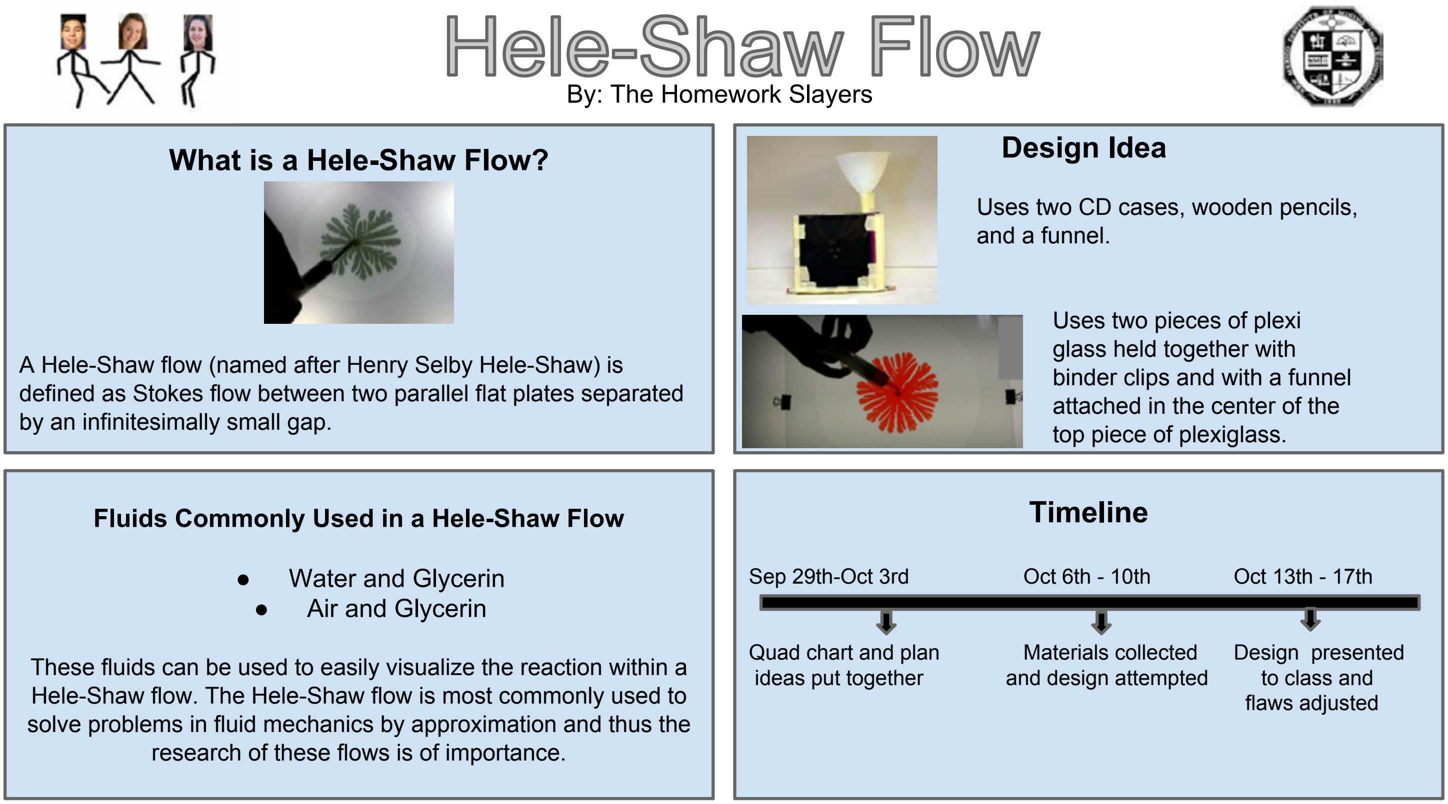
### Hands-on Team Assignment

Table 1 summarizes the different topics included in the key team assignment.

Each team was assigned one of these topics and was required to work outside of class to build, test, and observe a device that allowed them to cement their understanding of main fluid mechanics concepts through hands-on application. Teams were encouraged to seek instructor feedback during their work on their project, and many did, meeting with the instructor during office hours to share preliminary concepts and partial designs.

In addition, the teams received guidance from the course instructor through their submission of quad charts. (Part of their process involved brainstorming and developing a quad chart capturing their initial ideas to share with the course instructor). Following is an example of a quad chart.

Since teams were large, for this assignment there was one individual acting as team leader and then sub-teams assigned to specific tasks. Team members all worked




together to develop a 5-7 minute presentation summarizing their work which they shared with the instructor, classmates, and invited guests during class time. Within these presentations (during which each member of the team was required to participate), teams clarified the roles each members played in the project, provided background about the particular fluid mechanics concept or law their project revolved around, and demonstrated their device through SolidWorks drawings, photographs of the construction of their device, animated video of their testing, and shared data from their experiment. The following link from a team presenting on laminar flow fountain features the PowerPoint slides the team used during their presentation (infohost.nmt.edu/~twei/ES216-S14). Another team working on the same topic, Team 6, included a Go-Pro video of their experiment and tested the inclusion of an LED blue light in their device. That video footage can be viewed at: infohost.nmt.edu/~twei/ES216-S14.

The following photos depict some of the teams' project outcomes:

## Beyond Equations: Use of Media and Human Interest Stories in Lectures

Fluid mechanics instruction inevitably requires teaching students essential equations and calculations, and those featured during each lecture were presented on two large screens at the front of the classroom using Smart Board technology. To ensure student engagement and active participation, however, additional strategies were implemented throughout each lecture.

Creative use of media to illustrate course concepts and feature real-world examples was not only used by students in their presentation of key concepts. The course instructor also took advantage of students' interest and engagement with video clips and included them within course lectures. Table 2 provides examples of the kinds of videos used for teaching main course components.

To further engage students, the course instructor challenged two of the teams who were not satisfied with the videos they found about Torricelli's law on YouTube. These teams were given the opportunity to create their own video to demonstrate this concept and encouraged to assume roles of Producer, Director, Scriptwriter, Narrator, and Sound effects coordinator. An example from one of these teams can be found at: (http://www.youtube.com/watch?v=Bq_E1Kq1xuY)

**Left: Demonstration of Laminar Flow Fountain outside the classroom (team 5 and 6). Right: Investigation of liquid movement on glass (team 8).**

| Fluid Mechanics Concept | Video and Source | Purpose |
|---|---|---|
| Visualization of fluid motions | http://web.mit.edu/hml/ncfmf.html | These 1960s videos are classic on the education of fluid mechanics |
| Fundamental principles Laminar/turbulent flow | http://www.iihr.uiowa.edu/research/publications-and-media/films-by-hunter-rouse/ | Explain fluid mechanics in a series of six videos |
| Almost everything about fluid mechanics | http://www.youtube.com | Pro: you can find almost anything related to fluid mechanics<br>Con: you need to sift through many examples |

Table 2: Use of Video in Fluid Mechanics Lectures

| Rate your opinion | Not at all | A little | Some | A lot |
|---|---|---|---|---|
| Division of class into teams is helpful | 2 | 15 | 24 | 17 |
| Doing a hands-on project has increased my understanding in fluid mechanics | 1 | 1 | 23 | 33 |
| Multimedia has increased my interest in fluid mechanics | 0 | 6 | 20 | 32 |
| Story time has increased my interest in fluid mechanics | 2 | 8 | 16 | 31 |

Table 3: Student Assessment of Hands-on Team Project

The course instructor also made an effort to include human interest stories in the lectures. Beyond introducing a figure such as Bernoulli or Euler in terms of the law or theory they developed, the instructor included a brief "story time" in the middle of each lecture to tell a relevant story about historical figures with contributions to fluid mechanics. These stories, such as one about Euler, who was blind during the last couple of decades of his life but continued to publish through dictation of papers and books, were intended to pique the interest of students and help make these figures (and their contributions) more memorable.

## Evaluation

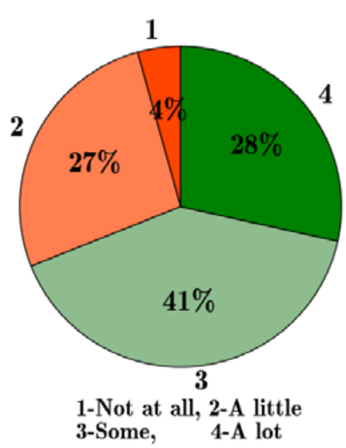
A brief survey (see Appendix A) at the end of the Spring 2014 semester asked ES 216 students to rate the role of the hands-on activities in the course, assess how helpful working in a team was, and evaluate the effectiveness of multimedia activities and story time incorporation within the lectures. Of the 74 enrolled students in the course, the return rate was over 78%, with 58 students completing the survey. Results were as follows:

The following pie charts help to highlight the value students assigned to each of the four features of the hands-on team project represented in Table 3 as well as provide further information regarding the logistics and benefits of each pedagogical method.

As indicated by the quantitative survey results, a strong majority of the students viewed the incorporation of hands-on collaborative projects as valuable and contributing to their overall learning experience. Pedagogical approaches that moved beyond traditional lecture format, such as sharing multimedia examples and breaking up lectures with stories about prominent figures and concepts in the field helped to engage students and sustain their interest in the course.

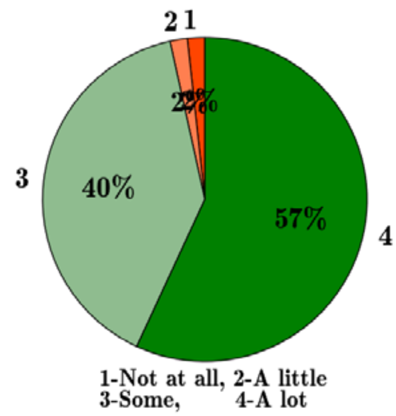
In addition to the quantitative assessment collected by the survey, the open-ended portion of the survey provided students the opportunity to offer qualitative feedback regarding their impressions of the course, in particular regarding the value of collaborative and hands-on projects and the incorporation of multimedia and stories. Approximately half of the 58 respondents completed the open-ended assessment. A sample of their responses is presented in Table 4.

As depicted in the responses shared in Table 4, the qualitative feedback from students supported the results of the quantitative survey. The students were overwhelmingly positive about the experimental techniques used and noted that these techniques engaged them much more than traditional lectures. They also noted that the hands-on projects as well as multimedia use and incorporation of stories helped in their development of skills such as networking, communication, and critical thinking and problem solving.



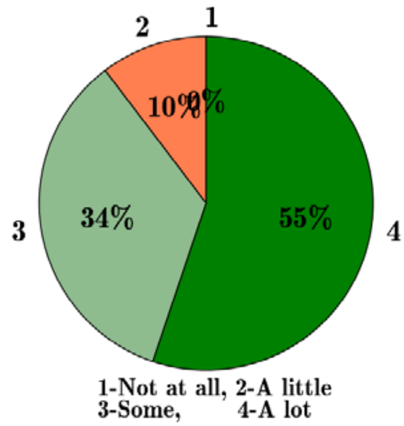

**Division of Students into Teams**

| Logistics | Benefits |
|---|---|
| * 1st lecture: team formation (counting 1-8)<br>* Weekly:Team lead rotation<br>* Mid-semester: Seating rotation (front/back) | * Facilitate team discussion<br>* Teamwork skills<br>* Networking skills<br>* Leadership<br>* Communication skills |



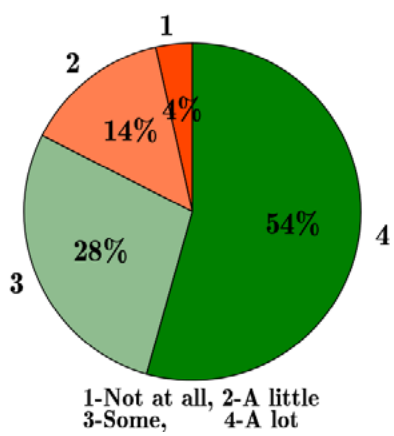

**Incorporation of Hands-on Project**

| Logistics | Benefits |
|---|---|
| * 1st week: assign one to each team<br>* 2nd week: contract and Quad-chart<br>* Weekly: progress memo<br>* Presentation | * Teamwork/leadership<br>* Project management<br>* Communication<br>* Hands-on (real world) |




**Use of Multimedia**

| Logistics | Benefits |
|---|---|
| * Weekly<br>* Show relevant videos on fluid mechanics<br>* Ask questions before video<br>* Discussion after video<br>* Resources: NSF-NCFMF, IIHR, Youtube | * Memorable, enjoyable<br>* Connection to real world<br>* Varies pace of the class |




**Incorporation of Story Time**

| Logistics | Benefits |
|---|---|
| * Middle of lecture<br>* Story about historical figures (From Archimedes to G. I. Taylor): their contributions and impacts | * Stimulate interest<br>* Encourage students to follow the footsteps of giants<br>* Create relaxed atmosphere |

## Takeaways For Engineering Educators

The pedagogical approaches implemented in our Fluid Mechanics course are ones that can certainly be applied in other contexts. To engineering educators considering how to design lower-level courses with high enrollment, we encourage you to adapt some of the practices shared here in order to both facilitate student understanding of key concepts and increase student engagement. While the innovations we describe do not come without challenges, we view the rewards as worth the potential difficulties. In particular, we present the following takeaway messages, noting challenges to be aware of:

- Prepare for confusion at the beginning. As many students are new to the techniques described, they tend to be confused at the start of the course. Taking ample time to overview the setup of the course and the expectations during the first week of class is absolutely necessary. We have learned that even if you clearly detail the course structure and assignments in the syllabus, unless you take the time to present it in class and answer face-to-face questions from students, not all students will have a good understanding of how the course will work. It can take up to two or three weeks to establish the dynamics of the class, and students then become aware of what they are expected to do.
- Celebrate the mistakes! The first time teaching a course with a student-led approach is bound to result in some class sessions, activities, or even as-

| | |
|---|---|
| Re: Teams | *The group project is a great way to give people a realistic example of engineering. You are not always going to like who you are working with, but you have to get over it and be productive.* |
| Re: Teams | *The teams are an amazing idea. It forced me to go outside my normal group of friends and meet new people. It also gave me experience working with my peers to accomplish a goal. The project was so much fun. I learned more about Reynolds number, laminar, and turbulent flow than I would have in a classroom.* |
| Re: Teams | *All the teams sit together in class. I like this part about the class because usually I don't get to know my classmates very well. This was really good practice for me to build my networking skills and also to practice my presentation skills.* |
| Re: Hands-on Project | *The group project was great to practice communication and working with others to accomplish a goal.* |
| Re: Hands-on Project | *The best part of the class is all of the hands-on work and interaction during class.* |
| Re: Hands-on Project | *I like the projects in the class. They help prepare for more real-world activities.* |
| Re: Hands-on Project | *It's exciting that it isn't all book work.* |
| Re: Multimedia | *The best part of this class is the 'older' black and white videos helped with certain concepts.* |
| Re: Multimedia | *The visual aids (movies, examples) are extremely helpful in terms of understanding concepts.* |
| Re: Multimedia | *The videos prevent monotonous lectures and give other teaching perspectives.* |
| Re: Story time | *Story time is effective at relaying information about prominent figures in the field. It is also effective at relaying the usefulness of things learned and their history.* |
| Re: Story time | *Stories are a nice break from the monotony of lecturing. They are informative, interesting, and very effective at engaging the class during the long Tues/Thurs. time slot.* |
| Re: Story time | *Story time makes learning interactive* |

**Table 4: Student Qualitative Feedback of the Value of Collaborative and Hands-on Projects**

signments that do not align with original expectations. Sometimes the mistakes will be yours as the instructor, and other times your students will make the mistakes. Recognizing that mistakes can be an incredibly powerful teaching tool and having the flexibility to accommodate them within your course is key. One mistake we made was dividing the class into team sizes that included 8 or 9 students. While this division helped minimize the number of teams we had to manage, it created logistical challenges for the team when trying to find a mutual meeting time, evenly distribute tasks, etc. The communication and cohesiveness of the team broke down quickly. Limiting the team size to 5 members, a practice we've since adopted, has helped the teams work more effectively, but the downside is that has created more teams for us to manage.

- Resist the temptation to control every aspect of the course, and instead put the onus on students. As previously mentioned, setting up and teaching a course using these techniques is more time consuming than traditional lecture format. While it is important to put in the necessary work up front, once the students are familiar with the course format and expectations, you can allow them to take more and more ownership in the course. For example, last semester, we had a competition on the best sketches about pathline, streakline and timeline (flow visualization techniques). The only thing the course instructor did was assign the homework and share evaluation categories. The class set up an online survey to allow each student to vote, collected the votes, and sent the results of the top three to the course instructor.
- Consider the methods we have shared and then customize them according to what will work for your institution and your course and your students. You know your setting and your audience better than we do, but the techniques we've described are ones that can be modified according to your interests and needs.
- Recognize that developing and delivering a hands-on, student-led course requires more time and organization on your part up front. Allot necessary time when planning to ensure you design a syllabus and in-class plans that include realistic time estimates, appropriately sized teams, and an efficient workflow for students receiving your feedback and submitting assignments. Especially for new instructors or instructors teaching a course for the first time, it may require too much time and be better to wait until you are more familiar and comfortable with a course to adopt these practices.
- Prepare yourself that you may have to convince your students of the value of a hands-on approach to learning. Many of your students may not have experienced anything but lecture courses in their educational history; they may enter your class expecting you to be center stage. If you disavow these notions from the start of the semester, we believe you'll find that students will easily come around to what may be a new way of learning for them.

## Conclusion

While this article presented an example of innovative approaches in one engineering classroom, the strategies shared are ones that could easily be implemented at other institutions and adjusted to accommodate different engineering topics. Emphasis on hands-on projects and the use of multimedia and stories not only helps to excite and engage students during class time, but these approaches also have the potential to help students achieve a richer understanding of course content and learn to approach engineering problems with a view that encourages multiple solutions. Working collaboratively provides students with experience solving problems and negotiating the dynamics of working with others from different perspectives, a skill that will be crucial to students later on in their careers as engineers. As engineering educators continue to develop curricula involving problem-based learning, future studies investigating the evolution of students' skills from the first-year all the way through graduation would provide helpful insights to further inform our understanding of the impacts of these approaches.

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# Appendix A: End-of-Semester Survey

**Background:**

Gender: Male ❑; Female ❑

Race: White ❑ ; African American ❑ ; Native American ❑ ; Hispanic ❑ ; Asian ❑ ; Other ❑

Major: ______________________________

**On a scale of 4 (A lot-4, Some-3, A little -2, Not at all-1)**

1.1 Doing a hands-on project has increased my interest in fluid mechanics: ________

1.2 Division of class into teams has helped my teamwork skills: ________

1.3 Division of class into teams has helped my communication skills: ________

1.4 Video time has increased my interest in fluid mechanics: ________

1.5 Story time has increased my interest in fluid mechanics: ________

1.6 Being called on in class has increased my interest in fluid mechanics: ________

1.7 Being called on in class has helped my confidence in speaking in front of people: ________

1.8 Being called on in class has helped keep my attention throughout class: ________

1.9 Review at the end of class has helped my confidence in speaking in front of people: ________

1.10 Overall I have had a positive learning experience in this class: ________

1.11 I will recommend this class to my friends: ________

2. The best part of this class is____________________________________________________________________

3. The worst part of this class is ___________________________________________________________________

4. List one or two changes you think will improve this class:

5. What obstacles did you encounter in doing your project? (check all that apply)

- Finding the time to do the work
- Getting adequate input from my advisor
- Getting the equipment/material needed
- Learning the knowledge needed for the project
- Making the project 'work'
- Having a place to work on the project
- Collaborating with my teammates
- Other