Undergraduate Engineering Students Creating Low Cost Labs and Demonstrations of Fluid Mechanics Principles Through At-Home Experiments

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Abstract

This paper presents how students designed low cost fluid mechanics experiments that can be conducted at home using everyday materials. Besides space and manpower requirements, student laboratory experiments often require the use of expensive and complex equipment to demonstrate high-level fluid mechanics theories and phenomena. Over the Covid-19 pandemic, many of these instructional laboratory experiments had to be conducted at home – or not at all – leaving students challenged to experiment with these concepts in a real-world setting rather than using an engineered mechanism. Additionally, universities around the world that do not have direct access to expensive equipment need to have practical experiments that can teach students how fluid mechanics principles apply to real-world settings. One approach that addresses the issue of budget, equipment, space, and accessibility is designing at-home fluid mechanics experiments using low cost everyday materials. At-home experiments allow students to use critical thinking alongside their coursework to develop unique approaches to fluid mechanics.

This study focuses on two engineering cohorts in fall 2024 and fall 2025 – totaling 106 students – developing at-home experiments while highlighting eight experiments that exceeded in the following academic criteria: cost, theory connection, accessibility, and learning outcomes. Students taking the fluid mechanics course are tasked with a semester long project to develop an at-home experiment, connecting to key topics covered during the semester. At the conclusion of the design and experimentation process, students submitted a complete lab write-up of their findings (including materials, supplies, and procedures) as well as gave an oral presentation. Students completed written surveys after conducting their experiment to reflect on their knowledge of their chosen topic. Initial findings showed students had a stronger grasp of key principles and deepened appreciation for fluid mechanics. The study results provide insight into future experiments with fluid mechanics that can be conducted in a variety of settings and how effective they are for student learning. Instructors can then take these experiments, expand upon the core concepts, and refine them to create a professional experiment that can be conducted at home and at a low cost.

The experiments covered within this paper are as follows: Airfoil Design using SolidWorks, Internal Pipe Flow Demonstration, Viscous Fluid Properties at Different Temperatures, Hydraulic Jump and Sluice Gate Experiment, Open Channel Flow Demonstration, Fluid Statics Demonstration, Momentum and Energy Experiment, and Bernoulli Principle Demonstration.

1. Introduction

Many engineering students entering their sophomore or junior year of university will take a class studying fluid mechanics. While taking the class, students are challenged to perform laboratory experiments to better understand, measure, and visualize various fluid phenomena in a sophisticated setting. Many of these experiments involve expensive apparatuses located typically on campus requiring students to conduct these experiments all in person. Over the course of the COVID-19 pandemic, access to these apparatuses became limited to students, making for practical experimentation within the fluid mechanics course impossible while students stayed at home. As the core principles of fluid mechanics surround the world daily – especially at home where piping, sinks, and showers are readily available – engineers should be able to rise to the challenge of furthering their understanding of fluid mechanics through experimentation at home.

In fall 2024 and fall 2025 at James Madison University, junior engineering students taking a four credit fluid mechanics course had a final course project focused on designing and executing a unique at-home experiment that covers one of the core topics from the semester. From this experience, 106 engineering students designed a variety of at-home experiments with the intent to keep costs low, be easily conducted and repeatable, and demonstrate expertise on their chosen topic. Concluding the experiment, students were asked to reflect on the experience, with the overwhelming majority claiming it furthered their understanding of chosen topic and reached a level of mastery beyond lecture and homework. Overall, this experience was able to provide a positive learning opportunity for students as well as provide insight into experiments that could be recreated at home for students taking classes virtually. As the world moves into a more digital age, it is important to consider all aspects that come with continuing to teach future engineers about fluid mechanics.

2. Background

2.1 Traditional Equipment

The course of fluid mechanics heavily relies on laboratory experiments for students to learn about fluid phenomena and how to properly test those cases. Traditional experimental equipment typically needs dedicated lab space and precise hours of operation for students to use them while costing universities thousands of dollars.

A very standard piece of equipment is a Digital Hydraulic Bench that comes with a variety of additions for testing different fluid phenomena. This piece of equipment is great for getting hands on experience with the core principles covered in lectures and can give students a way to accurately measure and test different patterns. However, these lab benches can be thousands of dollars and require space with proper utilities to function correctly, something a university may have but not a student, especially at-home [1].

Additionally, in aerodynamic fluid experiments, wind tunnels are used to analyze the effects of drag and lift on a variety of objects. Universities that have a wind tunnel need a space larger than a traditional classroom – often a dedicated lab space – to keep and maintain it for student use [2]. This challenges universities with limited spaces to house large test instruments allocated for one course and unique circumstances. Being able to test and experiment effectively within a smaller space allows for more flexibility for both the university and the students.

2.2 At-Home Lab Education

During the COVID-19 pandemic, many universities across the United States had to shift classes from being in person to a remote setting. This challenged both students and instructors to shift their class work to be completed remotely. Upper level engineering courses typically require a lab component to do along with the work students complete, and during the COVID-19 pandemic universities had to improvise to give students the proper educational experience to be successful in future professional settings.

One approach was to provide students with take-home laboratory kits. Students can use provided materials to follow typical lab instructions using at home equipment like a faucet or bathtub [3]. Physical hardware – like manometers and pressure sensors – are given to students which must be used to conduct the lab experiments in a scientific manner. Experiments typically fall into three categories: traditional labs where students told exactly what to do, experimental labs which encourage creativity and discovery, divergent labs where a problem is introduced and students must address the problem alongside the lab. Each of these lab types allowed students to expand their knowledge on the base material they learned in class by providing different scenarios and theories to practice through a lab experience [4].

While working on experiments, taking accurate measurements is a fundamental basis that scientific research relies on. For the study of fluid mechanics, accuracy is a major challenge without the use of high-cost precision equipment. To combat this, labs focus on solving more than one factor can create noise within data collection and result in poor execution of analyzing results [5]. Two approaches to combat measurement accuracy are to utilize appropriate error assumptions and to conduct experiments using modular materials. Precision equipment can identify smaller changes compared to items like a ruler or baking scale making small measurement errors to occur. Students should be able to thoughtfully recognize these limitations and report their findings using key assumptions when discussing actual results compared to theoretical results. Additionally, having modular equipment that can change in length or volume allows for multiple trials following one principle while getting a variety of data points to compare. This allows for clear understanding across circumstances rather than focusing on one core problem [6]. At-home experiments should require minimal materials while allowing for the most learning to take place for students so they can be prepared for professional endeavors.

2.3 Low Cost Access Education Materials

As higher education prices continue to rise over the years; students and faculty are looking for ways to reduce the financial burden of education. One study focused on providing students with free textbook access throughout their semester of taking an introductory physics course. Students found the free textbook allowed them to shift some of their focus away from the cost of the course onto the material of the course. For most students, the material covered in the free textbook was of equal quality in content compared to a traditional paid textbook [7]. Kinzli et.al challenged their students to create a low cost demonstration with their students by setting a strict $60 budget to demonstrate a fluid mechanics, hydrology/hydraulics, or water resources [8]. Low cost solutions within education are a large portion to making high level education more accessible for those with financial burdens and allows for more resources to be put towards future educational needs.

Computer aided design (CAD) software is utilized both in an educational and professional setting. CAD software allows students to create and test their own designs without having any material costs. With most engineering programs incorporating CAD software as a university benefit, there are no extra costs for experimentation. Computational fluid dynamics (CFD) is a large area of focus within the course of fluid mechanics and allows students to conduct simulations like wind tunnels, internal and external pipe flow, and structural analysis. Laboratory experiments that utilize CAD software give students the opportunity to gain experience more about how fluids behave and how to better analyze these behaviors [9].

3. Student Fluid Mechanics Project Scope

Third year engineering students taking the fluid mechanics course were presented with a variety of topics and real world application throughout the course of a semester long class. Two cohorts of students, 54 students in fall of 2024 and 52 in fall of 2025, studied the core topics of fluid mechanics and conducted a set of seven unique labs almost every week. Halfway through the semester, students were introduced to details of the final course project: designing an at-home experiment dedicated to one of the core fluid mechanics topics covered in class. Students were encouraged to critically think about each of the core topics and how they may fit into an at-home experiment. Four weeks before the last day of classes, students chose a given course topic and created a unique at-home experiment for their topic. Students were given the choice between the following topics:

- Properties of Fluids
- Fluid Statics
- Bernoulli’s Equation Applications
- Momentum Analysis
- Internal Flows
- External Flows
- Open Channel Flow
- Dimensional Analysis/Modeling

The experiments designed were to be easily accessible, use low cost materials, and be replicable for future engineering students. Students were limited to a budget of $25 to create their experiments at home to provide experience with simplification and modeling of an experiment. In addition to deepening understanding of theoretical principles, it would provide hands-on learning, foster creativity, and prompt critical thinking about accuracy, approximations, assumptions, and modeling. Over the final four weeks of the course, students would conduct these experiments and report on their findings at the end of the semester.

Alongside designing an experiment, students were required to write a full report documenting the process, the experiment, and the results found. Reports included the procedure and set up for each of the experiments such that it could be recreated from the given report. All information regarding their materials was required to show how inexpensive or expensive the experiment was to conduct. Students were encouraged to have a creative demonstration of their chosen fluid mechanics topics, with those having high creativity awarded additional points towards their grade. Before the report was turned in, a peer evaluation process was conducted where each student reviewed the work of two other students, provided feedback, and discussed their experiments together. The rubric shown in Figure 1 is how students evaluated each other and how they were graded on their final submissions.

	Course Project Report Scoring Sheet					**COMMENTS**
WRITING QUALITY (Form and Style)	**Language and Mechanics** - Professional tone and language (no figurative language or jargon, no contractions), appropriate perspective, proper punctuation, grammar usage and spelling.	Excellent 10 pts	Good 8 pts	Fair 6 pts	Poor 4 pts	
	Organization - Good transitions across paragraphs and sections, appropriate format, proper presentation of visuals (tables, figures, etc.) with inclusion of captions, proper references, etc.	Excellent 10 pts	Good 8 pts	Fair 6 pts	Poor 4 pts	
	TOTAL Writing Quality Score					______________ / 20
CONTENT (Technical Clarity & Depth)	**Background and Introduction** – Identification of real-world fluid systems, relevance, and interest in this system.	Excellent 10 pts	Good 8 pts	Fair 6 pts	Poor 4 pts	
	Description of Experiment – Outlining of key goals, topics covered, learning outcomes, and experimental approach.	Excellent 15 pts	Good 12 pts	Fair 9 pts	Poor 6 pts	
	Materials and Supplies – Detailed list of needed materials, use of each material, and links/locations of purchase.	Excellent 10 pts	Good 8 pts	Fair 6 pts	Poor 4 pts	
	Procedure – Experimental set up, detailed instructions on each step, demonstration of procedure, and data collection process.	Excellent 15 pts	Good 12 pts	Fair 9 pts	Poor 6 pts	
	Data Collection and Experimental Results – Necessary equations provided, example of data collection, sample calculations, and full experiment results.	Excellent 10 pts	Good 8 pts	Fair 6 pts	Poor 4 pts	
	Theoretical Results – Assumptions clearly stated, equation analysis, numerical results, uncertainty and percent error.	Excellent 10 pts	Good 8 pts	Fair 6 pts	Poor 4 pts	
	Learning and Discussion – Restate learning outcomes, reflection on personal experience with experiment, and potential discussion questions with answers.	Excellent 10 pts	Good 8 pts	Fair 6 pts	Poor 4 pts	
	Creativity (Bonus) – Creative demonstration of fluid topic(s) using a unique, yet simple, experimental set up.	Excellent 20 pts	Good 15 pts	Fair 10 pts	Poor 5 pts	
	TOTAL Content Score					______________ / 80
TOTAL PROJECT SCORE						______________ / 100

Figure 1: Student report grading rubric

Finally, in addition to the final report and in lieu of a final exam for the course, students were to give a three to four minute presentation outlining their experiment. Presentations consisted of showing what the experiment was and how it connected to the broader fluid mechanics topic they studied. The goal was to demonstrate deep understanding of the fluid mechanics principle studied and show confidence in applying these principles.

4. Student Reflection and Learning

After students completed their project reports and presentations, they were asked to write a short reflection answering the following questions to gauge their learning experience throughout the project:

1. How did this project impact your understanding of the material? Did it enhance your comprehension or reveal areas where you need more practice?
2. Did you enjoy performing the project? What aspects did you find particularly engaging or challenging?
3. What recommendations do you have for improving this project? Are there any specific changes you would suggest?
4. Should this project be included in future classes?

Each of these questions follows four key goal insights into the student experience within the project: understanding of material, enjoyment, suggestions for improvement, and future use of the project. Of the 106 students who completed the project, 92 students completed the reflection survey before the end of the semester. This reflection survey was graded based on completion which awarded additional points towards their final grade, with those having a higher level of detail awarded more points. Responses could have been impacted by this incentive to provide clearer details; however, the results show most students had standardized opinions regardless of response length.

A thematic coding method was used to analyze the student responses following the four goals and unique sub goals to define the clear impacts on student experiences with the project [10]. Goals were derived from the project scope and were matched to each of the questions. Each of the 92 responses were reviewed and were grouped based on their connection to each goal. The free open source qualitative data analysis software Taguette was used to organize each of the responses into simplified groups matching each of the goals [11].

4.1 Understanding of Material

Improving conceptual understanding and reinforcing prior knowledge are key goals for this project so students can show what they know and improve on their specific expertise. Additionally, a baseline of positive experiences for understanding was observed. Overall, students had a positive experience and reported that this project improved their understanding of the material learned (results seen in Table 1).

Table 1: Student understanding code results

Theme Goal	Number of Students	Percent of Responses
Overall Positive Learning Outcome	82	89%
Improved Conceptual Understanding	69	75%
Reinforced Prior Knowledge	61	66%

Many students had positive learning within this material, some stating "it force[d] me to deeply understand the topic in order to explain and demonstrate it" and "[the] lab solidified concepts we had only discussed theoretically."

4.2 Student Enjoyment

Part of the project's goal was to foster creativity and give students hands on experience working on a project they are passionate about. Many students noted the creative aspects that gave them challenge and how they rose to meet it. Most students enjoyed the project and had a positive experience while working on their unique project (results seen in Table 2).

Table 2: Student enjoyment code results

Theme Goal	Number of Students	Percent of Responses
Overall Positive Project Experience	88	92%
Feeling Creatively Motivated	79	86%
Enjoyed the Hands On Experience	72	78%

Almost all students enjoyed this project and had a good experience within making their own at-home experiment. To some, "[it] was my favorite project I've done all year" and "designing my own experiment was extremely satisfying."

4.3 Suggestions for Improvement

Goals for this section were determined implicitly through student responses. Clearer expectations, options for group work, and extended presentations were the top emerging goals found from this question. Students feedback was focused on the structure of the project rather than the actual experience of designing at-home projects (results seen in Table 3).

Table 3: Students suggestions for improvements code results

Theme Goal	Number of Students	Percent of Responses
Clearer Project Expectations	41	45%
Optional Group Work	56	61%
Extended Presentation Time	48	52%

Students had constructive feedback about "more clarity earlier in the semester" and "the rubric could have been more specific." To some, "engineering is collaborative, and this project would benefit… and allow for more complex experiments." If this project were to be conducted again, it would benefit from some of these changes students suggested to improve student experience.

4.4 Future Project Use

Most students that responded wanted to see this project used in the future classes. Some students suggested modifications to the scope of the project, with those who did having more detailed suggestions to the previous question (results seen in Table 4).

Table 4: Student recommendations for future use of project code results

Theme Goal	Number of Students	Percent of Responses
Suggested for Future Use	89	97%
Future Use with Modifications	11	12%

Almost all students suggested to keep the project for future classes, as to some "it [was] a much better assessment of learning than a final exam" and "encourage[d] students to think like engineers." Some changes to be made with "group options and longer presentations" with "small adjustments" could improve the overall project for the next cohort of students.

5. Experiment Highlights

Over the course of two semesters, 106 students completed the final project for the fluid mechanics course to create a low cost at-home experiment. Many students demonstrated creativity and engineering prowess within their projects, with the best being highlighted here. These experiments cover a wide range of topics covered in a fluid mechanics course and have different elements which can be iterated on to be more accessible. As these are student concepts, they can be refined further in a university setting to be utilized in a wide variety of classrooms, in person or at home.

Each of the students had access to campus facilities including a 3D printing lab, fabrication shop, on site machinist, and laser cutting machine. Materials used from these spaces were considered within the cost, but a dollar figure was not always available. These spaces were used by less than half of the projects to create their experiments and only four utilized these spaces for experimental testing, the rest were conducted off campus.

Abridged versions of the projects that demonstrated elevated levels of creativity and academic rigor were selected to be presented within this paper. Each of the students' project reports submitted were between 10 to 15 pages, so a concise sample was derived to reflect the experiment and student results from conducting the project. Full write up for each report is available upon request.

5.1 Airfoil Design using SolidWorks

Overview

Students have access to SolidWorks, a CAD software that utilizes fluid flow simulations to visualize how fluids move through or around an object. One student's approach was to visualize and test an airfoil to find the stall angle of that given airfoil. They utilized the foundational properties of drag and lift, worked to find the optimal coefficient of drag with proper airfoil angle, and compared against professional NACA 2412 airfoil test.

Simplified Procedure

1. Determine initial assumptions (take off speed, airfoil design, fluid properties)
2. Import airfoil design and set up SolidWorks fluid simulation using assumptions
3. Vary the angle of the foil, measuring the force of lift and calculating the lift coefficient C_L
4. Plot the results and compare them to find the optimal lift angle.

Results and Outcomes

In this test, the tested airfoil had a stall angle of 21 degrees. Compared directly to the NACA 2412 test foil with a stall angle of 22 degrees, there is a clear connection between the simulations. Seen in Figure 2.a is the SolidWorks set up and CFD approach, with the parabolic results shown in Figure 2.b comparing the coefficient of drag to lift angle.

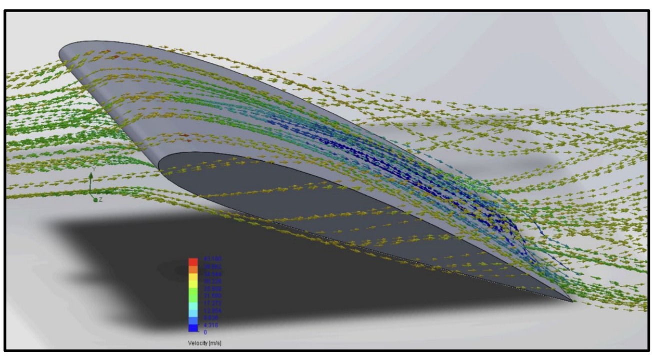

Figure 2.a: Airfoil SolidWorks CFD at 22 degree attack angle

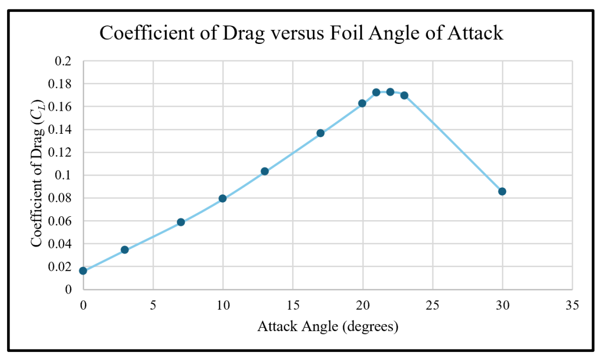

Figure 2.b: Student graph comparing coefficient of drag versus foil angle of attack

Cost Requirements

SolidWorks is a free resource to use for student projects. Applying this experiment to other CAD software would require a fluid simulation application, otherwise there would be no additional cost.

5.2 Internal Pipe Flow Demonstration

Overview

Municipalities that have a water tower with a large network of pipe connections experience frictional losses when pumping water. This experiment examines frictional losses inside of pipes with varying lengths to determine total losses within the system. Using a gallon jug as a water tower and nylon tubing as the pipes, the system could be tested at a variety of lengths.

Simplified Procedure

1. Determine initial assumptions (tank height, tank volume, fluid properties)
2. Connect nylon tubing to jug base allowing for fluid flow and mark starting volume on jug
3. Release the water through the nylon tube, measuring total time to fill one cup (8oz)
4. Repeat each tube length, replacing the tube connected and refilling jug

Results and Outcomes

From the measured results, various properties of the pipe network could be calculated such as average fluid velocity, friction factor, total pressure loss, and Reynolds number. This lab utilizes many equations covered in class to find various parameters about the overall system and reinforces the importance of pipe friction when designing large networks. Seen in Figure 3.a is the theoretical experimental design and Figure 3.b shows the physical design working.

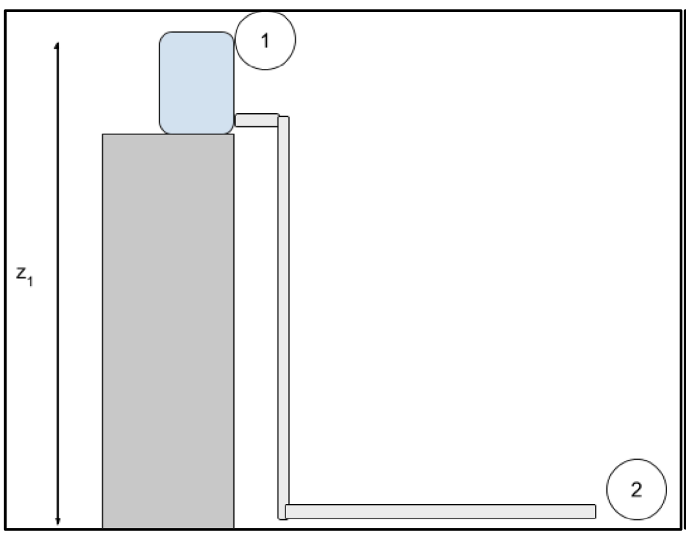

Figure 3.a: Theoretical tower jug design

Figure 3.b: Physical design created and beginning of initial measurement

Cost Requirements

In total, the cost requirement was \$12, with the nylon tubing costing \$4.50, connector \$4.50, and gallon jug \$3. Various items were also needed to create this set up, such as a kitchen knife, measuring cup, tape measure, stopwatch, and hot glue, all items typically found at home.

5.3 Viscous Fluid Properties at Different Temperatures

Overview
Temperature is a core consideration when working with flowing fluids as they behave differently and exhibit changing viscus properties in changing temperatures. This experiment examines the changing viscous behavior of two liquids at different temperatures: honey and syrup. Using the principles of fluid properties, the viscosity of each liquid can be experimentally derived and compared to the expected theoretical results.

Simplified Procedure
1. Cut a plastic straw 5in in length and cover the bottom with a notecard
2. Pour 3mL of test liquid into the straw, remove the notecard at the bottom, and record time it takes for 90% of the test liquid to drip out
3. Heated liquids should be placed in a mug inside a pot of boiling water and brought to specified temperature before being poured into the straw
4. Test multiple liquid samples three times and compare results to theoretical results

Results and Outcomes
The results showed a clear distinction in viscous behavior between the room temperature and heated liquids, allowing for a clear visualization of how properties change under different temperatures. The found viscosities did differ significantly from standardized results with large margins of error, however still maintained the core principles of viscous flow behavior. The boiling set up used household items seen in Figure 4.a and used kitchen items seen in Figure 4.b.

Figure 4.a: Heating of test liquid in mug using boiling water

Figure 4.b: All test equipment used from home kitchen

Cost Requirements

The bottle of honey used cost $5 and the syrup $3, totalling $8 of additional student cost. Many of the materials that were used to conduct the experiment are common in most kitchens like a pot, mug, and measuring spoons. The equipment used in this experiment is common for most at-home kitchens, making the purchase of additional materials less nessecary.

5.4 Hydraulic Jump and Sluice Gate Experiment

Overview

Sluice gates are used in hydraulic structures to regulate the flow of water through a channel which results in a hydraulic jump after. This experiment examines how the changing height of water behind the sluice gate impacts the height of the hydraulic jump following. A 3D printed structure was used to simulate a sluice gate and measure the resulting hydraulic jump.

Simplified Procedure

1. Design and 3D print sluice gate structure using university materials (seen in Figure 5.a)
2. Open sluice gate to specified height, then regulate faucet flow behind the gate so water level is maintained, a hydraulic jump forms, and then measure the flow rate (seen in Figure 5.b)
3. Measure the hydraulic jump after the gate and repeat for a variety of sluice gate heights

Results and Outcomes

The printed sluice gate accurately recreated common structures and demonstrated the resulting hydraulic jump accurately. Found results directly connected to theoretical equations with less than a 10% error.

Figure 5.a: 3D Printed sluice gate design with improper flow

Figure 5.b: Proper flow through sluice gate resulting in hydraulic jump

Cost Requirements
The largest cost requirement is that of the 3D printed sluice gate, however engineering students can 3D print projects for free. This cost can vary by university and 3D printing materials, so the cost may be relative depending on accessibility. Otherwise, items such as a measuring cup for flow rate and faucet are common household items.

<u>5.5 Open Channel Flow Demonstration</u>

Overview
Open channel flow concerns the flow of large volumes water moving from one location to another. This experiment analyzes the changing depth of a trapezoidal channel and how slope impacts the changing depth. Using the Manning equation, the experimental and theoretical results can be compared and analyzed.

Simplified Procedure
1. Cut plastic corrugated board to length of 2ft with a trapezoidal shape to create a channel
2. Raise on end of the channel higher to create desired channel slope (seen in Figure 6.a)
3. Turn on faucet and reach steady flow state, measuring flow rate, starting channel height and ending channel height (seen in Figure 6.b)
4. Compare the tested results to the theoretical approximations

Results and Outcomes
The experiment was able to demonstrate fluid channel flow and the varying heights across the length of the channel due to the slope. There were variations within the results, due to limitations in fully developing the steady flow. However, results demonstrated the properties of the Manning equation within a 10% region of error.

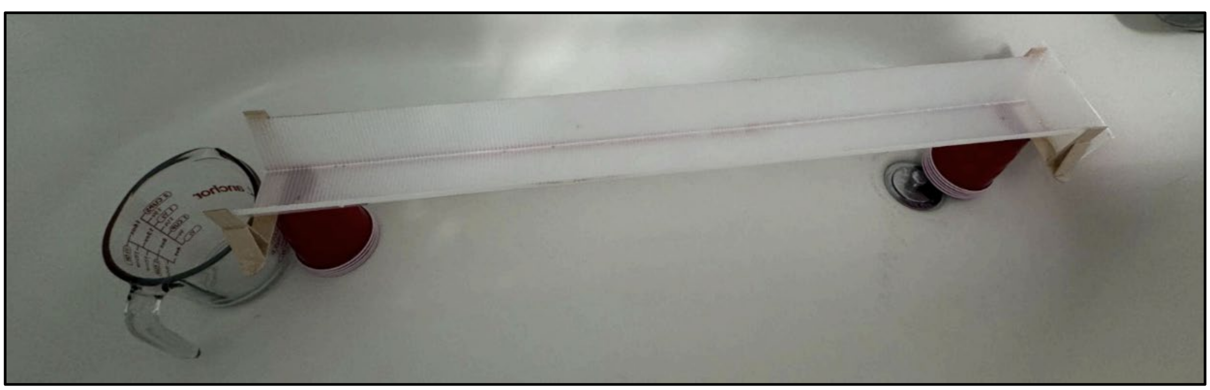

Figure 6.a: Trapezoidal channel set up in tub at specified slope

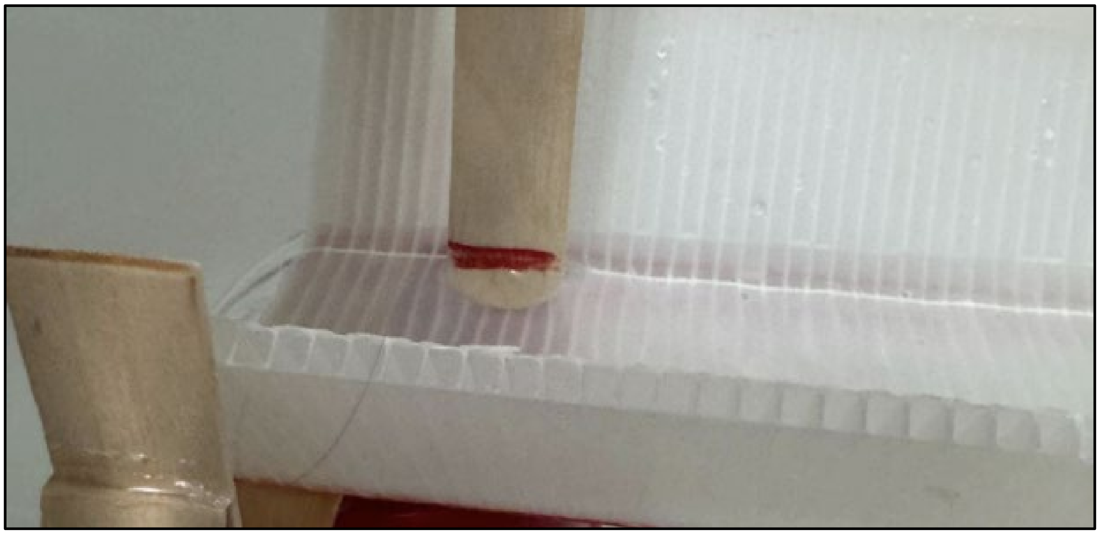

Figure 6.b: Rough measurement taken at end of channel

Cost Requirements
The plastic corrugated board used cost $5 and required hot glue to set up. Additionally, a faucet, measuring cup, and protractor were used to ensure proper flow within the channel.

5.6 Fluid Statics Demonstration

Overview
Hydrostatic forces acting on structures are critical when designing for proper safety and material selection. This experiment demonstrates the hydrostatic force of water acting on a dam and the amount of force applied by the water. Using the hydrostatic force equation, the height of the hydrostatic force can be derived. Here, a gate will open as soon as the hydrostatic force's moment is less than that of the gates weighted force moment.

Simplified Procedure
1. Construct moment gate (seen in Figure 7.a and 7.b) and determine necessary weight requirement for desired water height
2. Place necessary weight at specified distance and fill other side with a full tank of water
3. Using a straw as a syphon, reduce the water level until the gate starts to open
4. Record the height of the water level and repeat for different hydrostatic force requirements

Results and Outcomes
The experiment resulted in a 4% variation between the theoretical water level and the actual measured water level. This experiment clearly demonstrates the acting hydrostatic force water on dam and clearly demonstrates the need for proper reinforcement structures. Additionally, it reinforces material both covered in a fluid mechanics course and a statics course.

Cost Requirements

In total, the student spent $34 on all the materials for this experiment. However, the total materials used accounted for $20 with the potential for a smaller 3D printed version to be made for $10. The fabrication shop aided in the creation of this experiment to ensure proper wood cutting and sealing of the gate.

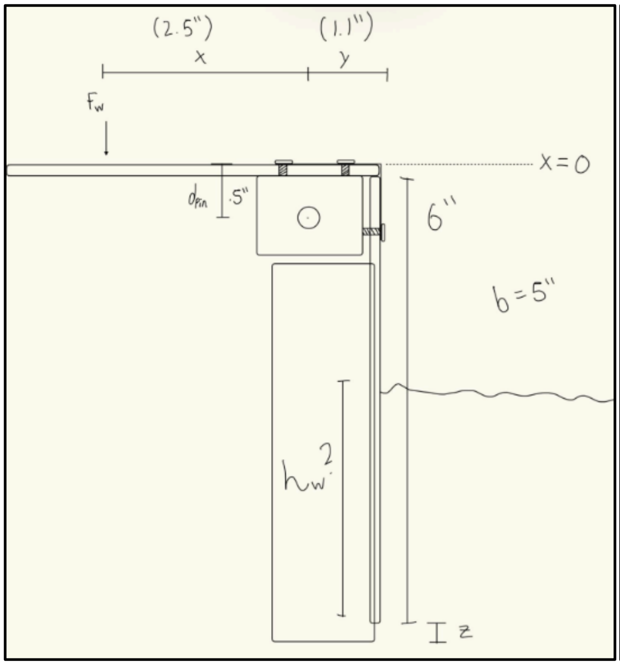

Figure 7.a: Sketch design for hydrostatic gate

Figure 7.b: Hydrostatic gate setup with water bottle as a variable weight

5.7 Momentum and Energy Experiment

Overview

Water wheels generate power through the flow of water running across the blades to output mechanical power. This experiment focuses on the conservation of momentum principle by creating a 3D handheld water wheel to output power to a measurable LED. Output power to the diode and water flow rate was compared to determine the efficiency of water wheel and relative flow rates for given power requirements.

Simplified Procedure

1. Select LEDs to be tested and determine their required current and voltage requirements
2. Place wheel with LED connected under faucet, adjusting flow rate until the LED turns on
3. Measure the flow rate of the water, height of the wheel and, where possible, the voltage and current output of the LED
4. Repeat multiple times for each tested diode and calculate the efficiency and power requirements

Results and Outcomes
Output efficiency of the water wheel was 20%, low compared to a similarly designed Pelton turbine with between 80% to 90% efficiency. However, there were clear differences between the two LEDs tested, each with a different power requirement and resulting flow rate differences. The main principles of the conservation of momentum and power generation were observed successfully, but designs could be improved for higher efficiency. Seen in Figure 8.a is the designed water wheel system and Figure 8.b demonstrates it in operation.

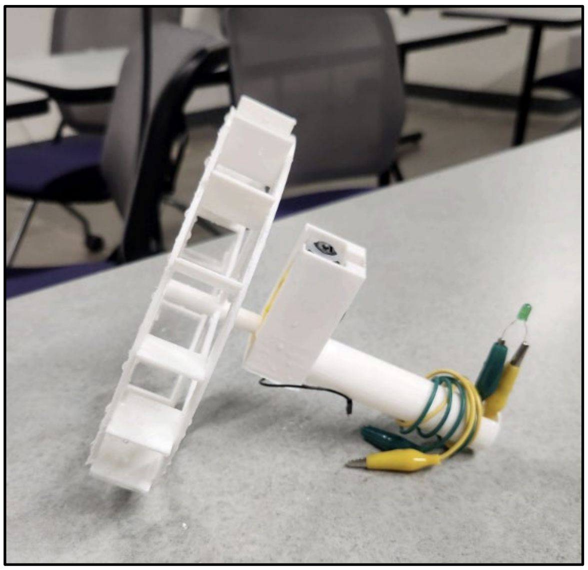

Figure 8.a: Water wheel desing with gearbox and LED attachment

Figure 8.b: Operating water wheel lighting LED

Cost Requirements
Main costs come from the gear box connecting the turbine to the LED, costing $10 for four gear boxes. Additionally, LED, wiring, and 3D printing costs were estimated at around $6, however the student utilized campus facilities. Future projects would benefit from creating a kit multiple students could use to experiment with.

5.8 Bernoulli Principle Demonstration

Overview
Bernoulli's principle is one of the core foundations for understanding fluid behavior accounting for fluid pressure, velocity, and height. Many students experimented with this principle, each with a different variation of giving fluid some height, releasing the fluid horizontally, and measuring the distance traveled. Students then compared estimated results with actual results to gain a clear understanding of how pressure, velocity, and height impact fluid behavior.

Simplified Procedure

This procedure takes ideas from multiple projects to show a concise approach to experimenting with Bernoulli's principle.

1. Poke a hole in bottom of an empty bottle, measuring the diameter and then covering with tape
2. Fill the bottle to desired height and measure the distance between the water level and hole
3. Set bottle on flat surface with a towel and measuring tape horizontal to the outlet hole
4. Remove the tape quickly and let water flow, then measure the distance travelled
5. Use kinematic principles to determine outlet velocity and compare the theoretical results

Results and Outcomes

Students conducting a similar experiment noted errors between 5% - 20% between the theoretical and experimental results. It helped to reinforce student ideas regarding Bernoulli's principle, particularly the impact height has on fluid pressure and velocity. Visualization reinforced classroom learning but experimental testing could be refined for a more rigorous approach. Seen in Figure 9 is a demonstration of the common set up for this experiment.

Figure 9: Filled bottle with outlet demonstrating Bernoulli's principle

Cost Requirements

The use of various plastic bottles, cups, and containers kept this experiment type cheap, around \$2 – \$5 depending on additional needs. Improvement to the rigor of this experiment could increase the cost of materials but should not exceed the \$25 requirement.

6. Conclusion

As higher education continues to evolve, adapting to global events and online learning, accessibility continues to impact student learning. For engineering students taking fluid mechanics, gaining hands on experience is crucial to their deeper learning of the material. At-home experiments provide a way for students to gain experience within the subject matter while adapting for limitations for materials and related costs. Students who took part in creating their own at-home experiments had agency to further their understanding of their chosen fluid mechanics topic and felt creatively motivated as an engineer. These experiments challenged students to deepen their critical thinking skills as engineers by taking ownership of their own fluid mechanics experimentation. Instructors can use these experiments as a baseline for designing at-home experiments, giving students the ability to creatively learn while being accessible. The continued effort to make engineering education more accessible will be a long endeavor, this paper should service as a push forward not only for the topic of fluid mechanics, but to challenge students abilities to learn in a variety of situations.

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