A Miniaturized Hydroelectric Dam Benchtop Kit for Remote Hands-On Learning in Undergraduate Fluid Mechanics

Ms. Eve M. Maramba, University of Florida

Eve M. Maramba is a third-year mechanical engineering student at the University of Florida. She is a lead researcher in the GatorKits Lab headed by Dr. Matthew J. Traum. Her research at UF focuses on employing mechanical engineering principles to further engineering education, with topics that stem from 3D printing manufacturing to experiments with fluid simulations. Her previous summer research at Northwestern University centered on advanced robotic manufacturing and direct energy deposition. Her goal is to continue mechatronics and manufacturing research and eventually earn her PhD. Outside of academics, she also participates in Gator Battlebots, the Society of Women Engineers, and Engineering Leadership Circle. Eve M. Maramba has earned Dean's List all three years and is a Benacquisto Scholar.

Genevieve Ipasu, University of Florida

Genevieve U. Ipasu is a second-year mechanical engineering Student at the University of Florida. Her undergraduate research is through the GatorKits Lab headed by Dr. Matthew J. Traum. She works under Eve M. Maramba to aid in creating ABET standard fluid mechanics lab kits to further engineering education. Outside of the lab, Genevieve is an active member of the Southern Scholarship Foundation, serving as one of the Social Chair and Media Coordinators. She is also a member of the UF chapter of the National Society of Black Engineers, and plans on continuing academic work throughout the summer.

Chloe Leander, University of Florida

Chloe I. Leander is a second-year mechanical engineering student at the University of Florida. She is an undergraduate assistant in the GatorKits Lab headed by Dr. Matthew J. Traum. She works under Eve M. Maramba to aid in creating ABET standard fluid mechanics lab kits to further engineering education. Outside of research, she is the Fundraising Chair for Society of Women Engineers, an active participant in the University of Florida Philharmonic Orchestra and has been on the Dean's List every semester. She also has an upcoming co-op with Georgia Pacific in the Fall of 2026.

Dr. Matthew J. Traum, University of Florida

Dr. Matthew J. Traum is a Master Lecturer and Instructional Full Professor in the Department of Mechanical & Aerospace Engineering at the University of Florida (UF) where he leads GatorKits Laboratory as PI. He is a Fellow of Sigma Xi, the International Scientific Research Honor Society, and he is an elected Sigma Xi Director representing the Southeast Region. Dr. Traum is an experienced educator, administrator, fundraiser, and researcher. As of 2026, he has co-authored 1 book chapter, published 90 refereed journal and conference papers, written an engineering design Open Educational Resource (OER) textbook, and attracted over $1.43 Million in funding as PI or Co-PI. Prior to UF, Dr. Traum was founding CEO of Engineer Inc., a successful education technology social enterprise and pioneer in STEM instructional lab kits for remote learning.

Previously, Dr. Traum was an Associate Professor and Director of Engineering Programs at Philadelphia University. He also served on the Milwaukee School of Engineering faculty as well as co-founding the Mechanical & Energy Engineering Department at the University of North Texas – Denton.

Traum received Ph.D. and M.S. degrees in mechanical engineering from MIT, and he holds two B.S. degrees from the UC Irvine in mechanical engineering and aerospace engineering.

A Miniaturized Hydroelectric Dam Benchtop Kit for Remote Hands-On Learning in Undergraduate Fluid Mechanics

Abstract

Hands-on learning is a cornerstone of engineering education and is codified in accreditation standards such as ABET Criterion 3 Outcome 6, which requires students to design and conduct experiments, analyze and interpret data, and draw conclusions using engineering judgment. Need for experimentation makes fully online engineering instruction challenging. Prior research shows that hands-on "engineering kits" enabling remote experimentation can achieve learning outcomes equal to or exceeding those of traditional in-person laboratories. Once widely implemented, such kits can expand access to engineering education for students facing barriers to physical attendance including family care obligations, chronic illness, full-time employment, study abroad, or financial constraints.

To extend the capabilities of remote laboratory instruction, a miniaturized hydroelectric dam benchtop simulator was developed for an undergraduate mechanical engineering fluids course. The kit allows remote learners to assemble, operate, collect data from, and analyze a dynamic fluids experiment regardless of their location. The setup consists of a 2-liter graduated cylinder fitted with a threaded outlet connected to a small turbine-generator. Water flows under hydrostatic pressure through the turbine, generating measurable electrical power before being captured in a reservoir then recirculated by a pump into the graduated cylinder to maintain steady-state operation.

In a pilot implementation, students in a junior-level fluids class tested the experiment in a simulated remote environment for extra credit in the course. These participants had prior experience with fluid lab kits but had not previously used this specific hydroelectric dam setup. Students measured turbine power output using a multimeter to record voltage across a variable resistor serving as the electrical load. Comparing measured power output to the theoretical hydroelectric power equation enabled calculation of turbine efficiency and comparison with benchmarked data. Students also explored the effects of varying electrical load, head pressure, and flow rate on turbine-generator performance and stall onset.

Following the experiment, students completed surveys assessing both their learning gains and perceptions of the kit's educational value. If survey results confirm comparable learning outcomes and favorable attitudes relative to in-person labs, the miniaturized hydroelectric dam simulator will be integrated into future fluids course offerings. This pragmatic educational approach broadens access to authentic, hands-on engineering experiences while reducing the logistical and financial burdens of traditional laboratory instruction.

Keywords: Remote Hands-On Learning, Hydroelectric Dam Simulator, Engineering Education Kits, Fluid Mechanics Instruction, Experiment Accessibility

Introduction

The importance of hands-on and applied learning for effective engineering education is undisputed. From their freshman Engineering Introduction class to their final Capstone senior design project, engineering students in ABET accredited programs engage with applied "design spines". These pragmatic curricular elements illustrate practical applications of theory and provide foundations for real-world practice that must be mastered as part of their transition from students into engineering professionals. Curriculum-embedded hands-on engineering instruction has historically occurred in teaching labs. However, brick-and-mortar labs have limitations and are increasingly seen as less attractive than alternatives, especially as engineering curricula become more flexible, accessible, and available remotely online [1]. Brick-and-mortar labs are expensive for new programs to set up and are costly for established programs to maintain [2]. They limit student throughput to the number of available workstations [3]. While sometimes promoting groupwork, labs often induce the "alpha effect" where one student performs the activity while others passively watch [4]. They limit accessibility, forcing students to come to campus to perform experiments, which precludes any remote learning modality for students with chronic illnesses, family / childcare obligations, socioeconomic constraints, active co-ops /internships, or other obligations that prevent them from being physically present [5]. In short, legacy brick-and-mortar labs make engineering inaccessible to numerous students.

Educational lab kits provide a modality for enabling curriculum-integrated hands-on engineering learning experiences without reliance on brick-and-mortar labs. While adoption of kits was an inevitable evolution in engineering education because kits achieve equal or better student learning outcome attainment, adoption in engineering remains slow relative to other applied STEM fields [6]. Slower kit diffusion into engineering curricula occurs for two reasons. First, universities have invested in and established brick-and-mortar labs and do not see the need for alternative modalities [7]. Second, faculty tend to adhere to legacy curricula and are uncomfortable or unsure how to incorporate new technologies, including kits, into their teaching [8]. Nonetheless, kits became an essential stopgap during COVID-19 when most college campuses locked down, and the pandemic accelerated their acceptance and adoption as a viable hands-on engineering teaching modality [9]. Nonetheless, there remains skepticism in the engineering education community about the ability of small portable kits to fully replace brick-and-mortar labs, especially when it comes to providing students individualized support through remote hands-on activities [10] and for replicating measurable phenomena relevant to engineering with high fidelity [11]. As shown in Figure 1, one can deploy simple kits built from graduated cylinders, aquarium pumps, pressure gauges, and viscosity cups in basins of water to illustrate simple phenomena like vena contracta, Bernoulli's equation in vertical free jets, hydrostatic pressure, and fluid viscosity. However, at the scale of a portable kit, can one replicate the functions of complex energy-thermal-fluids system such as a hydroelectric power plant that normally requires a complex brick-and-mortar teaching lab to simulate?

This paper illustrates that, yes, the core functions of a hydroelectric power plant can be replicated inexpensively and with high fidelity at the scale of a portable educational kit. The proposed kit-based hydroelectric power plant simulator was implemented at pilot scale and deployed with a small (N = 10) group of engineering students as an extra credit activity in a required junior level fluid mechanics course within the Mechanical & Aerospace Engineering Department at the University of Florida. Due to the small sample size of the pilot-scale study, qualitative analysis of results from an IRB-approved survey was used to extract student impressions and feedback on using the kit as compared to other experiences elsewhere in the curriculum with brick-and-mortar labs.

Background

The seminal paper by Starks et al framed the initial development and first practical deployment of a mechanical engineering fluids educational lab kit for remote instruction [12]. The authors described the methodology underpinning each fluids kit experiment and showed what an equivalent brick-and-mortar experiment looks like alongside a scaled down kit version. Starks et al envisioned kit deployment in an all-online fluids lab class capable of demonstrating ABET Criterion 3, Student Outcome 6: “an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions” [13]. Achievement of this outcome is often measured in lab classes. Students in the proposed online course would either pick up or be mailed their lab kit, allowing them to conduct lab experiments remotely on their own and at home. This learning modality was anticipated to be as effective or more effective than brick-and-mortar labs. Interestingly, Corter et al reported that engineering students learning with remote labs rate this modality as less effective than traditional learning; however despite this perception, students who completed remote labs performed better on assessments than peers who learned through conventional modalities [14]. In Starks et al students’ experiences were evaluated via surveys and homework assignments, which demonstrated the students’ positive feelings towards the education they received and that the class enabled them to meet the learning requirements.

Figure 1: Educational fluids kits illustrating (Left) horizontal jets with flowrates metered by vena contracta, (Center) vertical free jets using an aquarium pump, (Right) hydrostatic pressure, and (Front) viscosity.

Traum et al expanded on one of the experiments proposed by Starks et al with a “Conservation Laws and the Radial Hydraulic Jump” kit experiment. This work’s goal was to demonstrate that a lab kit could be created to teach fluids that would be easy to set up and use while still outlining critical fluids knowledge [1]. This paper outlines the theory behind the hydraulic jump phenomena, describes the lab setup, and recommends metrics for assessment. After students completed the kit-based lab activity, they were evaluated indirectly via survey questions and directly via their performance on their graded homework. The surveys showed positive reactions and held helpful constructive criticism. The graded homework showed adequate or above adequate understanding in all predetermined categories. The paper outlines benefits to the students of using kits to learn including ability to carry out experiments on their own and at their own pace. There are also benefits to the institution such as increasing course enrollment without need to increase physical teaching infrastructure as well as decreasing the cost of lab classes [15].

A later paper by Traum and Mendoza Zambrano gave an example of a full-scale fluids experiment that could be converted to a kit setup using only a small number of inexpensive off-the-shelf parts. The paper calls this a "turn-key" lab activity, meaning a lab setup that could be used at home or in a teaching lab and accessible by nearly any institution owing to how inexpensive and easy it is to implement [5]. The experiment described teaches students about the unsteady term in Bernoulli's equation, which is nearly always ignored in undergraduate fluids courses. The experiment calls for students to measure the time it takes for water to drain out of a burette and compare it to Bernoulli's equation with and without the unsteady term. This paper also outlined the benefits of "turn-key" lab activities: these kits enable high achievement of student learning outcomes at significantly reduced cost compared to brick-and-mortar labs. The described burette kit was created for $25, making it an affordable option for in person or online classes.

Mérida and Rivera-Jiménez evaluated a low-cost, desk-scale flow characterization experiment designed to support blended and online learning in undergraduate chemical engineering laboratories. The modular experimental setup enables students to explore concepts such as cavitation, head losses, and pump arrays while connecting theory to practice. Using a mixed-methods assessment across seven semesters with N = 334 students, the study shows that both take-home kits and desk-scale, in-person implementations consistently received high student ratings, improved conceptual understanding, and grew student confidence [16]. These results demonstrate that desk-scale experiments can effectively reinforce fundamental fluid mechanics concepts while replacing or supplementing brick-and-mortar labs with rigorous kit-based hands-on activities.

Raikar and Mérida describe an inter-institutional outreach initiative that uses a low-cost, desk-scale fluid flow experiment to introduce high-school students to chemical engineering through hands-on learning. The authors integrate a mini fluid flow kit into a pre-college summer enrichment program, allowing students to explore fundamental concepts such as frictional losses, pressure drop, flow rate, and pipe geometry using safe, water-based experiments with real-time data acquisition. [17] Observations from the summer program indicate strong student engagement and positive reception, including accessibility benefits for students with limited lab exposure.

The focus of this current paper is to determine if a hydroelectric dam can be simulated in a portable kit. Hydroelectric dams have long been the inspiration for hands-on engineering teaching laboratory experiments. For example, De Sousa et al describes use of virtual reality (VR) to instruct electrical engineering students on the workings of a hydroelectric dam. The VR's goal is to fully communicate the theory and practices underpinning the dam' function while adding an active element that improves the learning experience [18]. The paper proposes advantages of VR in engineering education. VR training could hypothetically surpass the cognitive stages that traditional learning provides and therefore create a more effective and lasting learning experience. The course had three elements: 1) educating students on the working of the Tucurui hydroelectric plant, 2) allowing them to solve problems with simulated maintenance issues, and 3) giving them a visualization of the plant workings under different operating conditions. Finally, the paper explained how students' performance would be evaluated. When the students' performance was compared to previous semesters on the same subject without VR, it was found that students who learned with VR enjoyed better learning experiences. The paper concluded that VR could lead to quicker and easier learning for electrical engineering students, benefiting the industry overall. This result demonstrates not only the learning opportunities afforded by hydroelectric dams, but also the potential of new teaching modalities to better the student experience.

Another example of the educational opportunities that hydroelectric dams present is the paper by Bourbourakis et al on the transformation of the Small Hydroelectric Power Plant (SHPP) of Agia in Crete from a functioning power plant into a museum, information center, and showcase of environmental sustainability and education [19]. The paper makes a case for the importance of communicating environmental values to children, both as a model for future environmentally conscious behavior and as a possible ethical benefit. In 2011, the SHPP was granted to the Region of Crete for conversion into a public asset for promotion of Renewable Energy Sources (RES). In 2020, ownership of this RES Center was given to the Regional Development Company of Crete. Its charge was expanding public awareness of scientific and sustainable elements surrounding hydroelectric dams and serving as a source of recreation due to an abundance of native flora and fauna in the area. From here, the paper discusses renovations to the plant before explaining the RES Center's role in the discussion of building and running hydroelectric dams. The manuscript concludes by stating that sites like the RES Center are pivotal for informing the public of sustainable energy practices. This paper demonstrates that teaching students about hydroelectric dams in a hands-on capacity can not only make them better engineers but also more aware of the intrinsic responsibility for environmental stewardship embedded in engineering practice.

A final example of the benefits of a collaborative, hands-on approach to learning engineering principles through dam building is a paper by MacVicar et al. These researchers investigated a concept for earthen dam experiential learning. Students at the University of Waterloo were experiencing motivational difficulties in their early engineering coursework because course content seemed to have little applicability to their desired careers [20]. So, a second-year project was devised giving students the opportunity to design, build, test, and then destroy a dam while engaging with and overcoming real-world obstacles to those goals. These obstacles included physical, financial, and community considerations. The benefits of this program included meeting new engineering education requirements and introducing underclassmen to design projects.

The design project was a two-day undertaking that split students into groups and required them to build earthen dams in bathtubs. To make the experience realistic, stakeholders from different organizations and companies met and designed challenges. Designing the dams introduced technical questions about preventing failures like slumping and seepage, which allowed students to apply theory and equations related to dam performance. The designs were then budgeted, built, and tested. Researchers noted that students were very invested in their dams at this point in the process, and faculty were excited to see how the dams performed. After testing, students were surveyed about their experience. The authors reported that the dam exercise carried many benefits that could be applied to future events of a similar nature. It exposed students to new advanced engineering principles while incorporating aspects of their current learning. It provided a safe environment to learn and grow without academic pressure. Also, it created a fun, collaborative project that could motivate students to continue their engineering journeys. From this work the benefits of a fun, motivating hands-on lab that also encourages teamwork are apparent. Thus, the literature indicates that hydroelectric-dam-based engineering fluid labs can be technically successful and are enjoyed by students due to real-life applicability and the hands-on experiences they provide.

Experimental Methods & Materials

The hydroelectric power plant kit-based experiment was implemented as an add-on to a pre-existing kit that had already been deployed in an ongoing junior-level fluids course. The fluids class included a Virtual Exchange (VE) with a counterpart Egyptian institution, Aswan University, which is located near the Aswan High Dam on the Nile River [21]. The VE's hallmark was that both institutions had identical copies of the fluids lab kits, allowing students to collaborate on the same experiments despite being physically separated in North America and Africa [22]. Wanting to add a hydroelectric dam simulation experiment to the kit to tie hands-on engineering learning activities to functions of the Aswan High Dam, collaborating faculty at both institutions discussed how to implement an experiment to replicate the hydroelectric power generation function of the dam. There is a beautiful, memorable, and relevant quote attributed to the artist Michelangelo in reference to his sculpture, David: "I saw the angel in the marble and carved until I set him free" [23]. Since both universities already had identical kits in their possession, development of the hydroelectric dam simulation experiment was driven by availability of hardware and materials from the existing kits both institutions had in their possession. The only elements that could be added were components available in both countries. It was recognized that most of the desired hydroelectric dam experiment already existed "within the marble" of the available kits, and creating the desired experiment was a matter of "setting it free" by organizing the available components in the right way.

As shown in Figure 2, a 2000 mL graduated cylinder was placed atop a wire shelving unit to provide elevation. The cylinder possessed a threaded hole at the bottom used for a different hydrostatics experiment. So, fittings were selected to plumb a Wonofa 5-volt Micro Hydro Portable Water Charger into the base of the graduated cylinder. This miniature water turbine generator is available (with 12-volt output) in Egypt. This assembly was placed in a 40-quart plastic containment tub. The tub was filled with water and a Yokgrass 3000 Liter/hr (800 Gallon/hr) submersible aquarium pump was placed in the water. Tubing attached to the pump outlet lifted water from the tub to the cylinder. In this way, the graduated cylinder filled with water to establish a hydrostatic head, which pressurized the turbine inlet causing it to spin. Water then ran through the turbine and spilled into the tub keeping the lower water reservoir's height above the pump inlet. Once in steady state, this arrangement provided a cycle of hydrostatically pressurized running water with a fluid free surface inside the graduated cylinder akin to a dam's lake reservoir that generated measurable turbine power output. The list of materials used to set up this experiment is given in Table 1.

Table 1: List of materials used in the hydroelectric dam simulation lab kit

Part	Quantity
Yokgrass 3000 Liter/hr Submersible Adjustable Water Pump	1
Black Wire Shelf Organizer	1
Stainless Steel Washers	2
2" Binder Clip	1
Vinyl Tubing, 1/4" ID x 3/8" OD – 1m long	1
2000 mL Polypropylene Graduated Cylinder with 1/4" NPT Hole	1
250mL Polypropylene Graduated Cylinder	1
Plastic Tee Fitting: 1/4" x 1/4" x 1/4" FNPT	1
Plastic Hex Pipe Plug: 1/4" MNPT	1
Plastic Coupling 1/4" MNPT to 1/4" MNPT	1
Plastic Coupling 1/4" FNPT to 1/4" FNPT	2
Plastic Adapter Fitting: 1/4" MNPT to 3/8" OD Quick-Connect	1
Brass Pipe Reducer Fitting: 1/4" FNPT x 1/2" FNPT	1
Wonofa 5-volt Micro Hydro Portable Water Charger	1

18" Clear Acrylic Ruler	1
8" Wrench	1
Digital Multimeter	1
Ten-Ohm Resistor	1
Alligator Clips	6
Female Connector Wire (stripped ends)	1
40-Quart Plastic Tub (Hefty branded)	1
On/Off Electrical Switch (for pump)	1

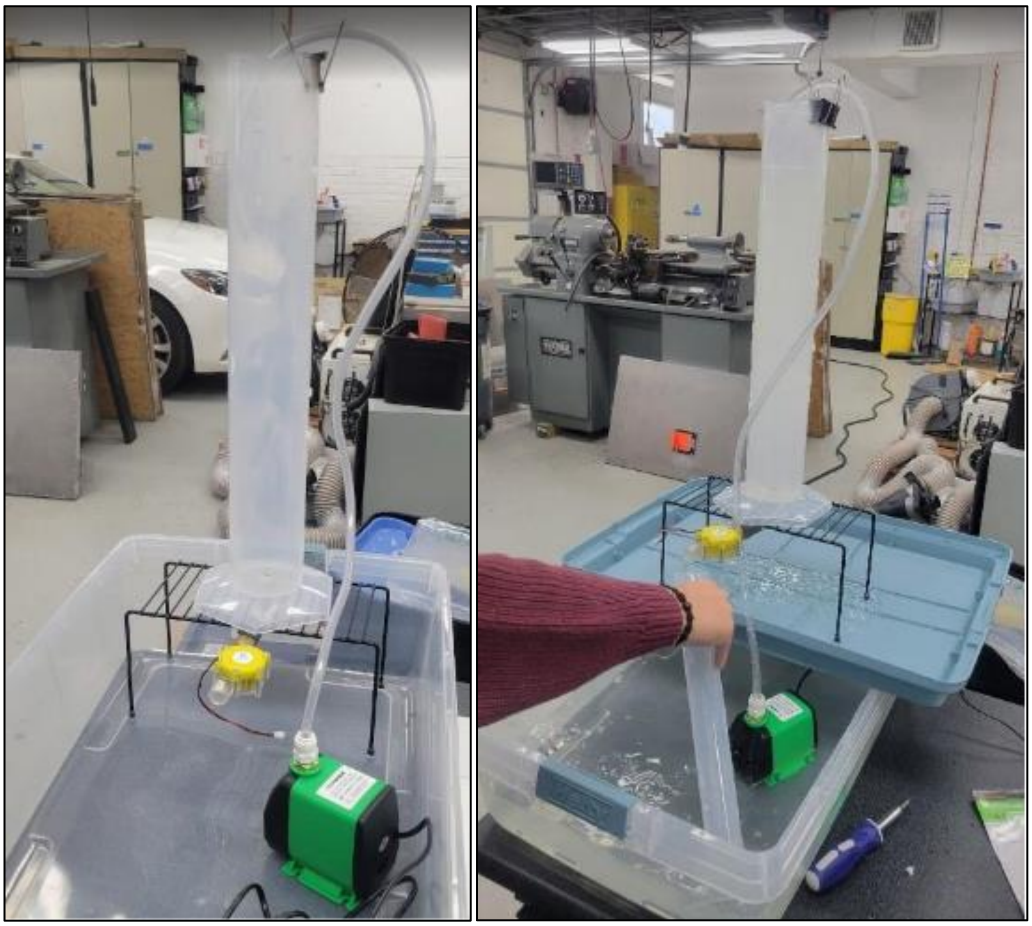

Figure *2*: Hydroelectric dam simulation kit at two points in the experiment.

Theory

The setup mimics a hydroelectric dam because a constant hydrostatic head is developed in the graduated cylinder above the turbine. A constant water volume flow rate runs through the turbine, and the turbine turns a generator which creates electricity. Electrical power is driven across a resistor of known resistance while voltage across this element is measured by an inexpensive voltmeter. When the system reaches steady state, the resulting electrical power (P) can be measured. The setup is represented by the hydroelectric equation,

$$P = \rho g h \dot{V} \eta \quad (1)$$

where ρ is the density of water flowing through the turbine, g is gravitational acceleration, h is the height of the water above the turbine, $\dot{V}$ is the water's volume flow rate through the turbine, and the system efficiency is η.

Volume flow rate, $\dot{V}$, is determined using a 250 mL graduated cylinder and a (cell phone) stopwatch to perform a timed volume capture. Hydrostatic head, h, is measured from the turbine inlet to the water's free surface with a ruler. Thus, all variables in Equation 1 can be measured except for system efficiency. Thus, the goal of the experiment is to calculate that efficiency. Barring guidance from the manufacturer on the turbine's nameplate efficiency, an initial estimate of 10-20% was assumed as a benchmark based on the turbine's small size and tiny inlet orifice. This internal orifice creates a dramatic reduction from the 1/2" MNPT inlet flow fitting and is likely there to generate a jet inside the turbine housing causing the blades to spin. The dramatic drop in available flow area incurs substantial energy loss. Once multiple experiments are run, tabulated efficiency values will be averaged to determine target values for follow-on classes.

Pedagogical Methods

Add-on components to set up the hydroelectric simulation experiment using the available lab kit base were provided to ten volunteer students. As incentive, these participants were offered extra credit representing a 1.5% grade increase for completing the experiment. In parallel a different extra credit lab experiment was offered to the whole class to ensure equal grading treatment for all. Most students working on the hydroelectric experiment elected to stay in the lab and work in pairs. Class Learning Assistants were available while the students were running the experiment to help with potential questions and troubleshooting. Students first solved for turbine efficiency. They did this by measuring the volumetric flow rate from the turbine through timed water catches. Due to the low profile of the setup in the tote bin on the wire stand, some teams elected to use the bin's lid to elevate the apparatus (Figure 2, Right) to make water easier to catch out of the turbine. Students then measured water height in the graduated cylinder above the turbine inlet, and they measured power output from the turbine. Gravity and density of water were assumed textbook values of 9.81 m/s^2 and 1000 kg/m^3 respectively. The resulting calculated efficiency determined by some groups was outside the expected range, likely due to measurement or calculation errors. However, some groups measured about 13% system efficiency, which is in the anticipated range.

With an initial efficiency calculated, students were told to assume this measured system efficiency was constant, and they were then challenged to predict the output power when the height of water in the graduated cylinder was changed. Water height was modulated by adjusting the aquarium pump inlet opening area to change the flow rate through the system. When the system reached its new equilibrium, the hydrostatic head and volume flow rate were measured again, and Equation 1 was used to predict the power output under the assumption that previously measured system efficiency was fixed. Students then measured the actual power output via multimeter and calculated the difference between their prediction from Equation 1 and what was measured. Each student pair was asked to write a brief report outlining their process, predicted versus measured power, and any explanation for mismatches between theory and experiment.

To test students' impressions and sentiment toward using this hydroelectric simulation educational lab kit, a five-question open-ended survey was administered, and the questions are provided in Table 2. The survey and study were approved by UF's IRB prior to deployment with these participants. The ten students who volunteered to run the hydroelectric experiment were told they were part of a study and were given the opportunity to provide informed consent for their participation or to opt out. After completing the experiment, participants filled out the open-ended survey questions.

Table 2: Survey questions given to students after running the hydroelectric dam experiment

#	**Question**
1	Describe how running the experiment impacted your understanding of hydroelectric dams.
2	What do you think were the most important transferable knowledge/skills gained by this experiment?
3	Were there any obstacles to conducting/understanding the experiment?
4	How could we improve this experiment for future students?
5	Did this experiment clarify your understanding of fluid dynamics? If yes, how?

Results & Discussion

For the first survey question, all students wrote in their answers that the experiment increased their fluids knowledge. Many of them specifically referenced turbine, pump, or dam knowledge. For example, one student stated that the hydroelectric dam setup allowed "the relationship between power and flow rate to be visualized." Another student wrote that the experiment increased their understanding because "physically measuring water height, flow rate, and turbine output made the dam equation and efficiency concepts feel much more concrete and intuitive." These responses demonstrate that the kit did increase students' perception that their fluids knowledge grew, giving them the learning experience of a lab without need for a brick-and-mortar facility or equipment.

In answering the second question, most students stated that the most important transferable skill that they had gained was the use of a multimeter when finding the power output of the turbine. One student wrote that they learned "General use of equipment and knowledge of multimeter." Other answers included a new understanding of power and interpreting experimental data. Some examples of these answers are "Understanding how a centrifugal pump works," "calculations for power and efficiency," and "setting up equipment, troubleshooting, and taking systematic measurements." In short, students felt that this lab covered pragmatic areas of instruction that pure lectures could not cover, namely providing physical intuition about electromechanical power conversion and capture that accompanies fluids flowing through turbomachinery.

When asked about obstacles in survey question 3, most students cited a lack of instructions when using the multimeter. The electrical setup was relatively complex for a fluids lab, and most of the questions during the lab revolved around multimeter use. Furthermore, using different multimeters in the lab often led to varying answers. One student wrote that "Using the multimeter was confusing and unclear," and another mentioned that "We found our values to be very different from the experiment data" while working with multimeter data. Interestingly, other researchers implementing fluids educational kits with chemical engineering participants also noted student difficulty in working with electronics for data acquisition [24]. To correct this issue in the mechanical engineering fluids kits, future labs containing this experiment will include a custom Printed Circuit Board (PCB) with colored plugs for the turbine lead wires, a potentiometer to manually vary load on the turbine generator, and a display that reads generated power. This approach will refocus the activity on the fluids elements relevant to the course while deemphasizing the electronics needed for data collection.

As expected, student notes about improving the experiment in response to question 4 focused on having more guidance about multimeter use, turbine setup, and general power calculations. Students wrote that they needed more guidance in "how to use the multimeter, how to wire the turbine, and how to get power from the multimeter reading." While the lab can be credited for taking students into unfamiliar territory, the activity in its current form remains too focused on the nuance of data collections electronics, which detracts from focus on the core fluids learning the lab intends to target.

For the final question, most students wrote that the lab activity did increase their fluids understanding specifically in hydroelectric dams. Some mentioned that they learned more about the "basic principles behind hydroelectric power" and that the lab "made abstract fluid dynamics concepts like pressure, potential energy, and flow relationships much more intuitive." However, a few students noted that they felt they did not learn much. One student helpfully included that they felt that much of the material involved in the lab had already been covered in class and was otherwise self-explanatory, stating "most of what I'd feel like I had learned I already understood from the prior 3 labs and lectures during this semester". Due to this feedback, future versions of this lab will cover some higher-level aspects of hydroelectric dam design, turbine geometry, and simulation. Notably, with the addition of a potentiometer, the resistive load on the turbine generator can be varied, and system responses to this new variable can be characterized. Moreover, the design of the turbine itself can be evaluated, especially the narrow inlet orifice as an example of minor loss and the shape of the blades as an example of Reynolds Transport Theorem applied to angular momentum conservation leading to the Euler Turbine Equation.

Conclusion

This work demonstrates that the essential physics and systems-level behavior of a hydroelectric power plant can be reproduced with high instructional value using a low-cost, portable benchtop laboratory kit. Students were able to test the hydroelectric equation by directly measuring hydrostatic head, volumetric flow rate, and electrical power output. System efficiency was then calculated and assumed constant for follow-on predictive experiments. The resulting experiment allowed students to engage meaningfully with energy-thermal-fluids concepts that are typically difficult to convey outside of large, capital-intensive brick-and-mortar laboratories.

Results from this pilot deployment indicate that the kit-based hydroelectric dam simulation successfully deepened students' conceptual understanding of hydroelectric power generation while also exposing them to transferable experimental skills, particularly in electromechanical measurement and data interpretation. Student feedback suggests that the experiment filled an instructional gap commonly present in undergraduate fluids courses by explicitly linking fluid mechanics to electrical power generation. At the same time, the feedback highlighted areas for refinement, including clearer guidance on multimeter use, improved standardization of electrical measurements, and opportunities to further scaffold unfamiliar content. These observations provide actionable direction for future iterations of the kit and underscore the importance of intentional instructional design when introducing interdisciplinary experiments.

Despite the small sample size and qualitative nature of the assessment, the findings support the broader claim that portable educational lab kits can replicate complex energy–fluids systems with sufficient fidelity to meet learning objectives traditionally associated with physical laboratories.

Acknowledgements

The educational lab kits enabling experiments described herein were provided by the HEAT Program implemented by the University of Florida. The HEAT Program is supported by the J.

Christopher Stevens Virtual Exchange Initiative (JCSVEI). JCSVEI is a U.S. Department of State Bureau of Educational and Cultural Affairs program administered by the Aspen Institute.

References

[1] M. J. Traum, F. Hadi, "A Miniaturized Circular Hydraulic Jump for Remote On-Line Fluid Mechanics Instruction," *Journal of Online Engineering Education*, Vol. 10, No. 1, Article 3, June 2019.
[2] K. Achuthan, S. S. Murali, "A comparative study of educational laboratories from cost & learning effectiveness perspective," *Software Engineering in Intelligent Systems: Proceedings of the 4th Computer Science On-line Conference*, Vol. 3: Software Engineering in Intelligent Systems, pp. 143-153, Springer International Publishing, 2015.
[3] S. K. Esche, "Remote Experimentation—One Building Block in Online Engineering Education," *Proceedings of the 2002 ASEE/SEFI/TUB International Colloquium on Global Changes in Engineering Education*, Berlin, Germany, 2002.
[4] K. L. Tonso, "Teams that Work: Campus Culture, Engineer Identity, and Social Interactions," *Journal of Engineering Education*, Vol. 95, No. 1, pp. 25-37, 2006.
[5] M. J. Traum, L. E. Mendoza Zambrano, "A Fluids Experiment for Remote Learners to Test the Unsteady Bernoulli Equation Using a Burette," IMECE2021-12356, *Proceedings of the ASME International Mechanical Engineering Congress and Exposition*, Virtual Online, November 1-5, 2021.
[6] A. Van den Beemt, S. Groothuijsen, L. Ozkan, W. Hendrix, "Remote labs in higher engineering education: engaging students with active learning pedagogy," *Journal of Computing in Higher Education*, Vol. 35, No. 2, pp. 320-40, August 2023.
[7] N. T. Jones, S. R. Niemi, M. J. Traum, "A Hands-on Learning Module Pipe-flow Velocity Profile Interrogator Laboratory Kit for Remote Online Fluid Mechanics Instruction," *Proceedings of the American Society for Engineering Education Annual Conference*, Virtual Online, July 26-29, 2021.
[8] F. Blin, M. Munro, "Why hasn't technology disrupted academics' teaching practices? Understanding resistance to change through the lens of activity theory," *Computers & Education*, Vol. 50, Issue 2, pp. 475-490, 2008.
[9] D. S. Gaikwad, S. R. Niemi, M. J. Traum, "Hurricane- & Pandemic-Resilient Instructional Engineering Labs Enabled Via Portable Kits," *Proceedings of the American Society for Engineering Education Southeastern Section Conference*, Charleston, SC, USA, March 13-15, 2022.
[10] T. O'Mahony, M. Murray, M. Hill, R. Onet, M. Neag, L. de la Torre Cubillo, D. Zhou, "A Take Home Laboratory to Support Teaching Electronics: Instructors Perspectives and Technical Revisions," *Journal on Teaching Engineering*, Vol. 3, No. 1, pp. 15-29, December 2024.
11 N. T. Jones, S. R. Niemi, M. J. Traum, "Mysterious Negative Velocity Profile in a Miniaturized Velocity Profile Interrogator Solved Remotely," *Proceedings of the American Society for Engineering Education Southeastern Section Conference*, Virtual Online, March 8-11, 2021.
[12] J. Starks, F. R. Hendrickson, F. Hadi, M. J. Traum, "Miniaturized Inexpensive Hands-On Fluid Mechanics Laboratory Kits for Remote On-Line Learning," *American Society for*

Engineering Education (ASEE) Annual Conference and Exposition, Columbus, OH, June 25-28, 2017.
[13] ABET, “Criterion 3. Student Outcomes,” 2025-2026 Criteria for Accrediting Engineering Programs, 2025. URL: https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2025-2026/#GC3
[14] J. E. Corter, S. K. Esche, C. Chassapis, J. Ma, J. V. Nickerson, “Process and learning outcomes from remotely-operated, simulated, and hands-on student laboratories,” *Computers & Education*, Vol. 57, No. 3, pp. 2054-2067, 2011.
15 A. D. Lacerna, J. L. Parker, M. J. Traum, “An Inexpensive Multidisciplinary Teaching Lab Kit for Remote Dual Enrollment Introductory Engineering Courses,” IMECE2023-111032, *Proceedings of the ASME International Mechanical Engineering Congress and Exposition*, New Orleans, LA, USA, Oct. 29 - Nov. 2, 2023.
[16] F. Mérida, S. M. Rivera-Jiménez, “Refining Flow Characterization Desk-Scale Experiments and Blended Learning in Engineering Education: A Framework for Assessment,” *American Society for Engineering Education (ASEE) Annual Conference and Exposition*, Portland, OR, USA, June 23–26, 2024.
[17] N. B. Raikar, F. Mérida, “Work-in-progress: Elevating Chemical Engineering Outreach Through Collaborative Efforts Showcasing Fluid Flow Experiments,” *American Society for Engineering Education (ASEE) Annual Conference and Exposition*, Portland, OR, USA, June 23–26, 2024.
[18] M. P. A. de Sousa, M. R. Filho, M. V. A. Nunes, A. D. C. Lopes, “A 3D learning tool for a hydroelectric unit,” *Computer Applications in Engineering Education*, Vol. 20, No. 2, pp. 269-279, 2012.
[19] P. J. Bourbourakis, G. J. Tsikalakis, “Transforming a power plant into an Educational Centre: Agia Small Hydroelectric Power Plant,” *IOP Conference Series: Earth and Environmental Science*, Vol. 1123, No. 1, p. 012057, December 2022.
[20] B. MacVicar, A. Clow, C. Muirhead, R. Al-Hammoud, J. Craig, “Design, Construction, and Destruction in the Classroom: Experiential Learning with Earthen Dams,” *Journal of Hydraulic Engineering*, Vol. 146, Issue 6, p.04020037, 2020.
[21] N. F. Kershner, M. J. Traum, W. A. Abdel-Fadeel, W. A. Aissa, H. S. Abdel-Mohsen, S. A. Algabli, “Building Engineers’ Global Competency Via Lab-Kit-Based Virtual Exchange,” *American Society for Engineering Education (ASEE) Annual Conference and Exposition*, Charlotte, NC, USA, June 21-24, 2026.
[22] M. J. Traum, M. Fitzgerald, W. A. Aissa, A. Ali Reda, “Building an International Energy Engineering Education Virtual Exchange Program Between the U.S. and Egypt by Leveraging EELM™ Pedagogy and @HOLM™ Laboratory Kits,” E-Podium Presentation, *Sigma Xi Annual Meeting & Student Research Conference*, Virtual Online, November 5, 2021.
[23] L. P Christofferson, “I Carved Until I Set Him Free,” *Meridian Magazine*, Nov. 15, 2022. URL: https://latterdaysaintmag.com/i-carved-until-i-set-him-free/
[24] F. Mérida, C. Rinaldi, L. Gallego, A. S. Kraus, H. Joo, E. L. Meier, “Work-in-Progress: Optimization and Consolidation of a Chemical Engineering Lab-on-a-Kit,” *American Society for Engineering Education (ASEE) Annual Conference and Exposition*, Baltimore, MD, USA, June 25-28, 2023.