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Enhancing Undergraduate Civil Engineering Mechanics of Fluids Laboratory Experiences using Sensors and Computing Tools

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Fluid mechanics laboratories traditionally use manual hydraulic instrumentation such as piezometers, venturi meters to make pressure and flow measurements and illustrate conservation of mass, energy and momentum. While these types of instruments continue to be used in the industry, there are also new sets of microprocessor-controlled instruments that are increasingly being utilized to make real time flow and energy measurements in real world systems. In addition to focusing on illustrating fundamental concepts related to flow, energy conservation, major and minor losses in pipes and open channels, it is also important to expose students to modern instrumentation methods that they will likely encounter in their practicing careers. Micro-processor based tools also help extend data collection outside traditional laboratory class times allowing students to work with high volume, high frequency (velocity) data. In addition, these processors can be programmed to collect data at different accuracies/precision thus enabling students to understand the veracity of measurements and associated uncertainties. Students also get a first-hand experience of various sensors and concepts related to physical computing (hardware/software integration) that is necessary in modern data collection endeavors.

A sequence of micro-processor based sensors and web-based dashboards were introduced into the junior level mechanics of fluids laboratory making use of Arduinos, ESP8266s and Raspberry Pi environments. In particular, the Hall effect sensor for flow measurement, ultrasonic and laser based sensors for depth and hydraulic head measurements, temperature and salinity sensors were integrated to collect data in tandem with conventional hydraulic instruments and conservation principles. Students were exposed to the setup of the sensors and the associated software required to run the sensors. This allowed students to understand the role of indirect measurements (example voltage differences) and the role of calibration in obtaining hydraulic data. The ESP8266 allowed for integration of data with the cloud using ThingSpeak framework to demonstrate wireless sensing capabilities. The precision of measurements were controlled via programming and students were asked to evaluate which instrumentation provided greater precision in an effort to dispel the myth that automatic data acquisition does not necessarily imply accurate data collection. Informal and formal evaluation on the incorporation of micro-processor based sensors indicated students appreciated these additions to the laboratory as it provided them with exposure to modern data collection practices. In addition, the incorporation of these sensors partially overcame modifications to the civil engineering curriculum which resulted in removal of a course on introductory circuits. The use of Sensors and Online Dashboards in the lab also enabled downstreaming of the computational thinking concepts that students are being exposed to as part of a newly implemented common first year experience in the college of engineering.

Keywords: instrumentation, Python, automation, wired/wireless sensors, fluid mechanics laboratory

Introduction:

Civil engineering is largely concerned with ensuring the society functions at an optimal level and in harmony with the environment. Civil infrastructure provides a means for the society to function, Brownjohn, (2007) and include a diverse array of systems that not only include buildings and roads, but also dense array of water conveyance infrastructure that moves fresh water to people and takes away used water away from homes. The drinking water infrastructure alone is made up of 2.2. million miles of pipeline (ASCE, 2021) much of which is rapidly deteriorating and in poor conditions. The American Society of Civil Engineers (ASCE) gives as a grade of C^- to our nation's water infrastructure. Other water infrastructure such as levees are in much worse condition receiving an overall grade of D. In a similar vein, the wastewater treatment and conveyance infrastructure received a grade of D+ with a projected annual infrastructure investment gap of $81 Billion. Structural Health Monitoring (SHM) is based on the broad idea that structural and environmental characteristics be monitored regularly to ensure infrastructure assets are repaired and rehabilitated in a timely manner to avoid further deterioration and failure (Housner et al., 1997). While SHM has been actively researched since 1970s, the transition to practical field applications has largely been slow (Cawley, 2018). However, advancements in sensor technologies, Smartphones and computational advancements, such as cloud computing have helped intey the adoption of SHM approaches in real-world applications. It is now clear that advanced sensors and computational tools will be used more frequently in the future in all aspects of civil engineering (Aburazzi et al., 2020; Salehi et al., 2021; Bado and Casas, 2021) transforming the way engineers monitor and analyze civil engineering systems

While sensors and physical computing have already started to play an important role in civil engineering and are expected to increase in utility in years to come, undergraduate students in most programs have limited exposure, if any, to modern-day computing tools and sensors. The recent changes in Fundamentals-of-Engineering (FE) examination, particularly the removal of circuits and computational methods sections coupled with legislative pressures to keep the number for credit hours to graduate as low as possible has often led to the removal of basic engineering science courses such as circuits, thermodynamics and numerical methods from undergraduate curricula (Morse et al., 2015) which creates a situation where civil engineers might have difficulties adopting modern technologies in 'real-world' engineering analysis and design or treat these modern tools as essentially 'black-boxes' and use them without fully understanding their utility and limitations.

The civil engineers of 21st century are confronted with many grand challenges of the future. They must design creative solutions necessary to sustain growing populations, foster equality and justice while combating the deleterious effects of climate change, pollution and landscape degradation (NAE, 2017). Transdisciplinary thinking and modern sensing and computational tools have a key role to play in addressing these engineering grand challenges (Madni, 2019; Bhattarai, et al., 2021). Future engineering is likely to be more cross-cutting with greater interfacing of physical and cybernetic systems (Malykhina et al., 2019) and with a greater emphasis on circular economies (Singh et al., 2021). Clearly, the void left by the curricular changes in civil engineering curricula due to a de-emphasis of basic engineering science (circuits, computing technologies, thermodyanmics) must be compensated elsewhere to allow undergraduate students to pick up necessary skills related to modern-day sensors and modern computational tools to ensure they can be successful in the changing landscape of engineering.

The present work builds on the hypothesis that laboratory courses provide an ideal platform to introduce civil engineering students to modern computation and sensor technologies. This hypothesis is based on the following:

- Laboratory courses are intrinsically experiential in nature and therefore provide a conducive environment for exploration of new ideas.
- Laboratory courses are designed to reinforce fundamental concepts and theories that students have already been exposed to in associated core courses. Therefore, the addition of new materials does not create a significant cognitive overload or impediments to learning.
- Laboratories offer an excellent place to compare the traditional and modern instrumentation, look at trade-offs and discuss better ways to design sampling campaigns and structural health monitoring programs. Therefore, they provide an ideal platform to discuss the role of modern day sensing and informatics and issues related to the inter-linkages between frequency, accuracy and precision of measurements.

Given the growing need for cross-disciplinary engineering training, and ensuring engineering students have requisite skillsets necessary for the practice of engineering, the college recently adopted a common core curriculum for first year students. The common core engineering curriculum emphasizes three aspects – 1) Computational Thinking and Data Science; 2) Bio-Inspired Design and 3) Socio-Technical Reflections. Introductory courses related to these topics have been developed and are required of all first-year engineering students regardless of their intended major. The development of these introductory courses were based on a variety of factors including, trends identified by professional engineering societies, evaluation of job advertisements, discussions with industry groups, exit interviews of students as well as review of pedagogic literature (e.g., Talmi et al., 2018; McGunagle and Ziska, 2020; Lavi et al., 2021). College policies also require that the content of these courses be incorporated into other lower- and upper-division classes in all disciplines and undergraduate degree programs. The use of computational methods and sensing in civil engineering laboratories also help achieve the objectives of up-streaming the ideas of common core curriculum that is required by the college.

Using the Mechanics of Fluids Laboratory as the test-bed, the study seeks to understand how modern day computational methods and sensors can be used enhance undergraduate student laboratory experiences. The changes made to the curriculum to infuse modern day computing and sensors and the feedback from the students on these changes are discussed in this study. The paper concludes with some broad conclusions that can be drawn about infusing computing and sensors into undergraduate civil engineering laboratories and offers suggestions for further improvement.

Methodology

The Mechanics of Fluids Laboratory is a required, junior level course for all civil and environmental engineering undergraduates within the department of civil, environmental and construction engineering. It is a traditional civil engineering laboratory that has 10 experiments covering basic fluid properties, principles of fluid statics, application of conservation of mass (Continuity equation) and energy (Bernoulli's equation) principles to pipe flows, and conservation of momentum principles to study the impact of jets and flows in open channels. The laboratory experiments aim to reinforce the concepts presented in the Mechanics of Fluids course that students take one or two semesters prior to enrolling in the laboratory. The laboratory uses four basic apparatus – a) Hydrostatic Bench; b) Volumetric Bench; c) Pumps in Series and Parallel Apparatus and d) An open channel flume to conduct the required experiments (see Figure 1).

Figure 1: Experimental setup of fluid mechanics laboratories

Students are required to make a series of hydraulic measurements in the laboratory using manometers to measure pressure heads; volumetric flow measurements (volume per time) and gravimetric measurements as necessary (e.g., density calculations). In addition, students are exposed to many traditional hydraulic devices such as hydrometer, venturimeter, orifice plate, rotameter. They develop and make use of calibration curves to indirectly estimate flowrates both in pipes and open-channels. In addition, students are routinely required to make height measurements in various laboratories (e.g., when applying Stokes Law for viscosity measurements; measuring the height of the water in fluid statics and open channel flow laboratories). As, the density of water depends upon temperature, students are required to make routinely measure water temperature as well. The knowledge obtained in this course aims to help students in their upper-division courses such as Water Systems Design which covers the analysis and design issues related to storage and conveyance of municipal water, stormwater and wastewater systems. Given the increased emphasis on using poor-quality water resources in recent years (Karim et al., 2020), the estimation of total dissolved solids (TDS) using densities of fresh and brackish water was also added to the set of experiments in the year 2019.

A suite of advanced computation methods and micro-processor based sensors were added to the curriculum to expose students to modern computational and sensing methods in the year 2021and based on limited, informal testing of a few sensors (flowrate, temperature) in year 2019 (2020 classes were online due to the Covid pandemic). These additions were largely guided by the following factors:

1) Increase the scope of the laboratory using modern computational methods and allowing students to explore conditions that are not possible to replicate within the laboratory;

2) Provide socio-technical context to the laboratory experiments and help students contextualize the purpose of laboratory methods in 'real-world design' settings;

3) Introduce students to modern sensors and help them evaluate their pros and cons in civil engineering practice.

Illustrative examples of the changes made to the laboratories are discussed next, followed by student assessment of these changes.

Using Cloud-Based Interactive Dasboards to Enhance Laboratory Methods

Civil engineering in the 21st century is moving towards increasing smart technologies in civil engineering domains. These technologies range from sensors and crowd sourcing to the IoT (internet of things) (Berglund et al, 2020; Dolla et al, 2022) Interactive dashboards are now becoming commonplace in engineering practice (Gaspar, 2017; Storey and Treude, 2019). These dashboards are generally cloud-based and allow 24 x 7 access to engineers to analyze and mine data (Ferreira, et al, 2013; Suryada, et al, 2014). Modern computational languages, for example, Python and R, can be used to develop both front-end (client) and back-end (server) architectures (Dahouei, 2017; Li. 2020). Using a cloud-based virtual machine several interactive dashboards were setup to further expand the scope of the material covered.

Density measurement is the first experiment students perform in the Mechanics of Fluids Laboratory. As the mass of a fluid cannot be established without knowing its volume, density is a fundamental measure in fluid mechanics. The ambient temperature in the Mechanics of Fluids Laboratory typically ranges from 18°C – 22°C and the lack of a constant temperature chamber precludes the measurement of density of water over a wide range of temperatures. Numerical experimentation and interactive dashboards were used to expand the scope of this laboratory.

In the first dashboard (see Figure 2), students explore how density varies with temperature. The dashboard provides information on the anomalous expansion of water between 0º C – 4º C and also depicts how the density decreases from 4º C on. Students interactively explore the changes in density with temperature and the nonlinear nature of this change. They are asked to reflect on whether the measurement of mass or volume is more important for accurate density estimation. The dashboard is also used to reinforce fundamental assumptions such as the incompressibility of water or lack of change in water density due to normal pressure fluctuations.

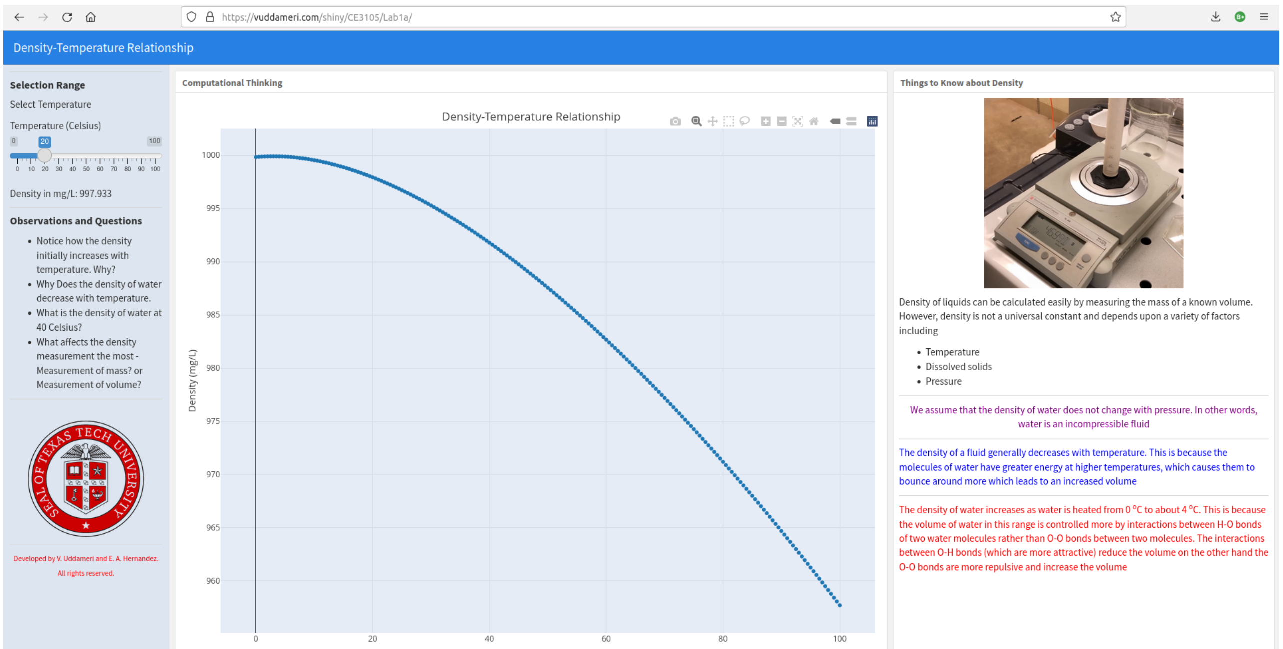

Figure 2: Interactive Dashboard for Density-Temperature Relationships (the dashboard can be accessed from: https://vuddameri.com/shiny/CE3105/Lab1a/)

The second dashboard (Figure 3) explores the salinity-temperature-density relationships. It discusses how dissolved salts and temperature both affect density measurements. To enhance computational skills, students are asked to interact with contour plots to explore the impacts of salinity and temperature on the density of water. Students reflect on whether salinity or temperature has a greater influence on water density and why? The dashboard also introduces the students to think of feedback loops between salinity, temperature and density and how temperature can impact both density and salinity via evaporation.

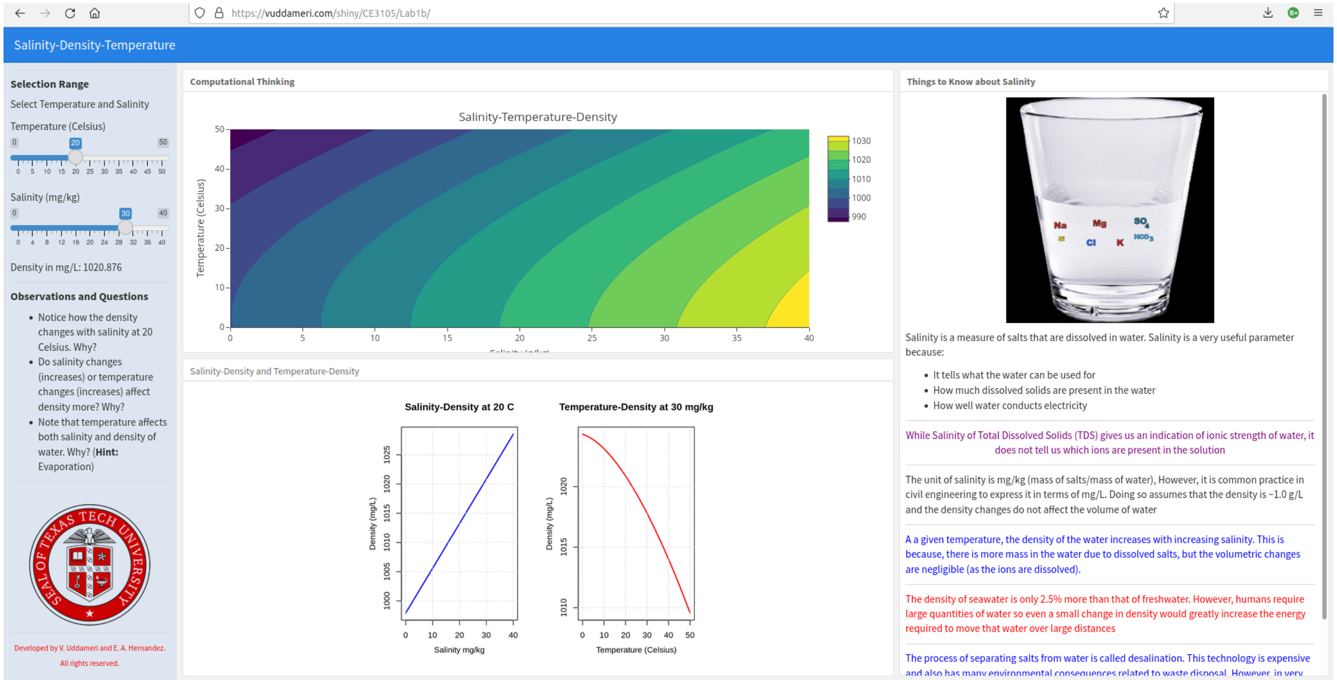

Figure 3: Interactive Dashboard for Salinity-Temperature-Density Relationships (the dasboard can be accessed from: https://vuddameri.com/shiny/CE3105/Lab1b/)

The interactive web dashboards were developed using R Markdown Language (Xie et al., 2018). The computing platforms at the university were limited to Windows-based virtual machines. However, a Linux-based RStudio server was necessary to host the dashboards. Therefore the dashboards were hosted on a private cloud computing provider (Linode.com). The Nginx server (Nginx, 2022) was used as a reverse proxy to transfer secured HTTPS requests to the underlying Rstudio server (Rstudio, 2022). A 2GB RAM and 10 GB SSD hardware configuration using Linux Ubuntu version 21.04 was adequate to host all dashboards required for the class. Currently, the rate for provisioning such systems is $10/month.

Adding Microprocessor-Based Sensors for Monitoring

In addition to expanding the scope of the laboratories and enhancing student enagagement using interactive dashboards, several microprocessor-based sensors were also added to augment data collection for several experiments. Additional sensors added to the laboratories included – 1) DS18B20, temperature sensors; 2) Interface Gravity analog Total Dissolved Solids sensor; 3) Hall-Effect Flow Sensor; 4) HC-SR04 ultrasonic depth sensor and 5) BMP180 Atmospheric Pressure Sensor.

Arduino microprocessor board was used to control the sensors and acquire necessary data. Data were initially read via serial port into a laptop in initial experiments. The Pyfirmata protocol and Pyserial library were made used of in subsequent laboratories along with the Matplotlib library and custom Python scripts to visualize the data from the sensors in near real time. In addition to Arduino, the ESP8266 microprocessor board was used in conjunction with micropython and DHT110 and DHT220 temperature, humidity sensors and BMP180 Atmospheric Pressure Sensor to allow students explore different microprocessors available in the market.

The measurement of fluid flows is another important fundamental laboratory in Mechanics of Fluids Laboratory course. This laboratory focuses on different approaches to flow measurements. In addition to direct measurement of change of volume over time ($Q = \Delta V/\Delta t$) the laboratory exposes students to several indirect hydraulic approaches listed in Table 1.

Table 1: Flow Measurement Approaches in Measurement of Fluids Laboratory

Instrument	**Principle of Flow Measurement**	**Remarks**
Graduated Cylinder + Timer	Flowrate Definition	Direct measurement method. Difficult when flowrates are high.
Venturimeter	Bernoulli's Principle (energy conservation) + Continuity Principle (mass conservation).	Relate flow to pressure differential brought forth by gradual change of area within the pipe. No loss of energy.
Orifice Plate	Bernoulli's Principle (energy conservation) with head loss term + Continuity Principle (mass conservation).	Flow is related to pressure differential brought forth by head loss caused by abrupt change in flow using a orifice plate. **Needs a loss coefficient term.** That must be known a-priori or obtained via calibration.
Rotameter	Balancing upward hydraulic (drag) and downward gravitational forces.	Flow related to rotameter height. Entails calibration with known flowrates.

The flow measurement appratus comes equipped with these instruments. A sequence of manometers are connected at various locations of the pipe and corresponding to inlet and outlet locations of the venturimeter and Orifice plate. These manometers provide are read by the students to obtain pressure head differentials. Rotometer heights are also read directly from the apparatus (shown in Figure 4).

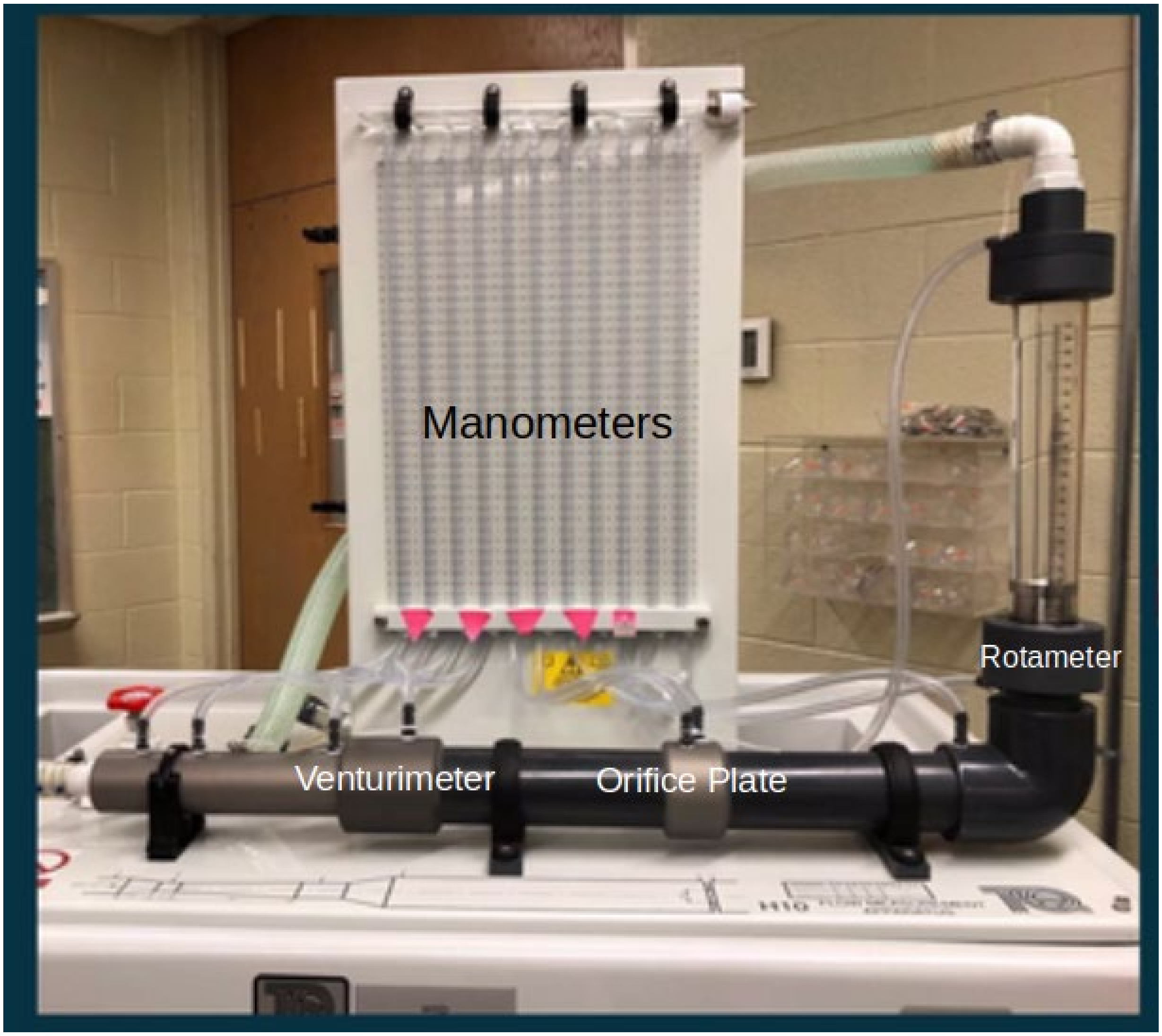

Figure 4: Traditional Flow Measurement Apparatus with Various Hydraulic Measurement Methods

A new flowrate measurement sensor based on the principles of hall-effect was also added to the lab. This sensor was coupled with an Arduino microprocessor and calibrated before the class to provide flow measurements every second (see Figure 5). The addition of the sensor helped expand the scope of the laboratory in two ways – 1) The students were exposed to another flow measurement method, that is widely used in the water industry. 2) Students were able to see the pros and cons of obtaining high resolution temporal data of flows which was not otherwise possible with point measurements that the traditional instrumentation of the hydraulic bench offered.

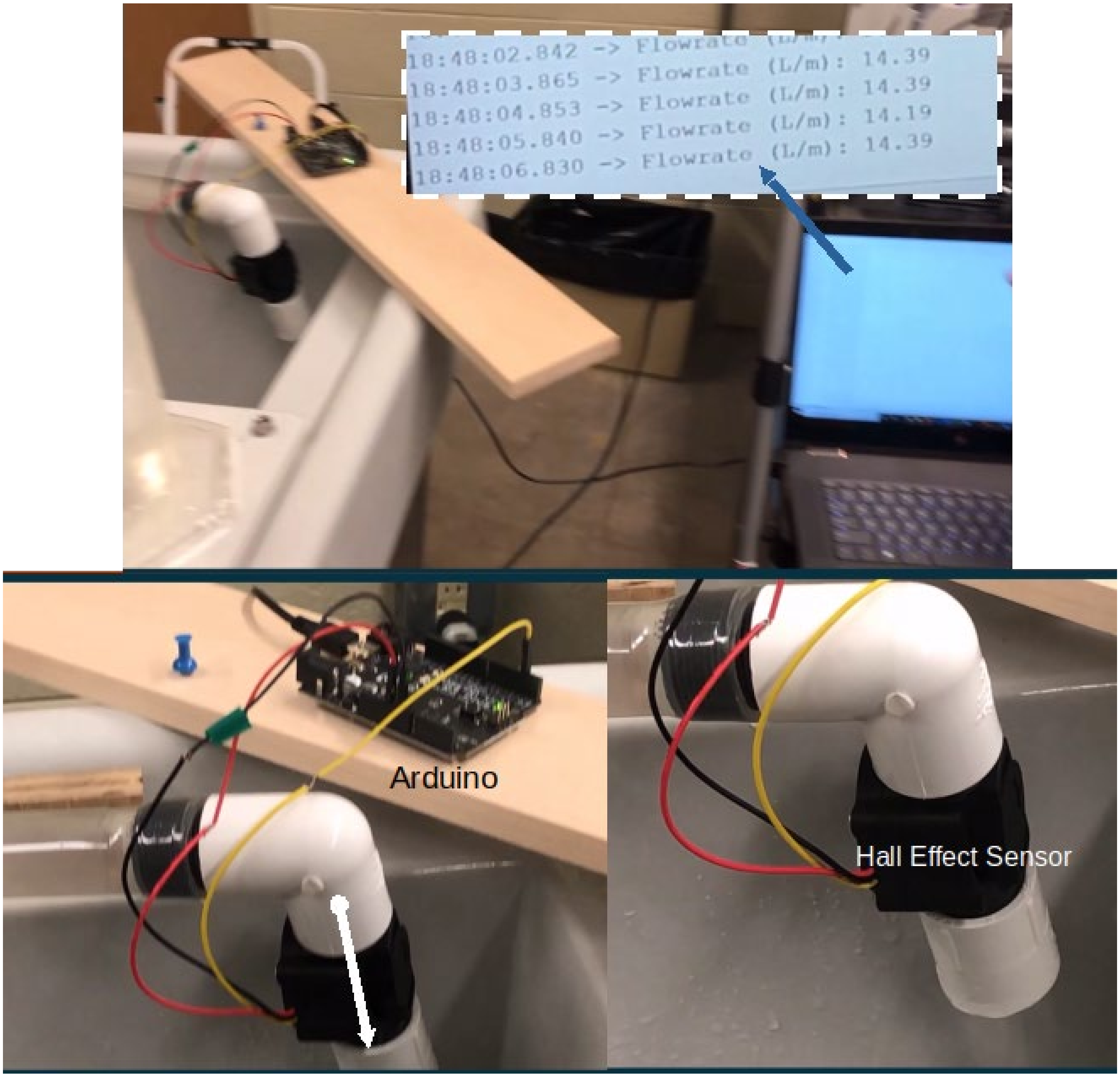

Figure 5: Addition of Hall-Effect Flow Sensor and Microprocessor based Control and Data Acquisition

As shown in Figure 5, the wiring of the sensors to the microprocessor and the software controlling data acquisition were kept transparent to allow students to understand how sensors are connected and controlled. Students were also provided additional information behind the principles of the working of the Hall-Effect sensors (i.e., the voltage potential generation in an electromagnetic field and how flowrate changes affect this process within the sensor). This illustration is representative of other sensors being added to the laboratory.

Student Feedback and Assessment

Interactive Dashboards

Students were asked informally in the next laboratory class about their experiences with the dashboard. An overwhelming majority (>90% in a sample size of 60) indicated that the dashboard was a useful way to learn more about information presented in the lab. They also felt that the material presented in the single page dashboard was easy to follow and was not distracting. The interactive widgets were easy to use and the dynamic updating of the charts and data helped them grasp the material better and was engaging.

To more rigorously evaluate the utility of dashboards and student engagement. The weekly laboratory quiz was modified to include questions both from the material covered in the lab as well as that presented on the Dashboard. Table 2 provides the questions on the online quiz and identifies whether the information was presented in the laboratory or online via interactive dashboards. The quiz questions were randomized during the testing and administered to 60 students who enrolled in the Spring 2022 Mechanics of Fluids Laboratory class.

Table 2: Quiz Questions for the Fluid Properties Lab. (Note: LAB indicates the material was presented in the laboratory and DB refers to information presented on the interactive dashboards).

Information Presented in	Quiz Question
LAB	The density of a fluid is slightly higher at the poles than at the equator under similar conditions
LAB	The specific gravity of a fluid can be ascertained using:
LAB	Specific Weight is a function acceleration due to gravity
LAB	1 lb of Glycerin has the same density as 1 lb of water
LAB	Which diameter ball will fall the fastest in salt water
LAB	The hydrometer has values greater than 1.0 at the top of the scale
LAB	The density of Moonshine is 0.99 g/cc its specific gravity is approximately ________
LAB	The specific gravity of Glycerin is same on the moon as it is on mars
LAB	Density increases as you add more fluid to a container
DB	The relationship between density and temperature is due to increased energy in the molecules
DB	Density is most affected by changes in salinity or temperature?
DB	Which measurement for density is most sensitive?
DB	Between 0 and 4 degrees celsius, the volume of water is controlled by the ________ bond.
DB	Mass affects changes in the density more than volume.
DB	At a given temperature, the density of water decreases with increasing salinity
DB	Density at a given temperature and pressure is constant for a fluid
DB	Desalination is expensive and has environmental consequences such as ______.
DB	The density of water increases as the temperature increases from 0 to 4 degrees celsius.
DB	Salinity is a measure of the amount of sodium in water.
DB	The density of a liquid generally ________ with increasing temperature.

Of the 20 quiz questions 11 were based on interactive dashboards and 9 were based on materials presented face-to-face laboratory periods. A two-sample t-test was used to evaluate if there were differences between students comprehension (as tested by the administered quiz) of the material presented in class and interactively. The null hypothesis and alternative hypotheses were stated as follows:

H_0: There is no difference in performance of the students on the materials presented in class and using interactive dashboards was tested against a two-tailed hypothesis

H_A: There is a difference in student performance between the materials presented in-class and interactive dashboards

A two-tailed t-test was used to assess the differences using the average score of each student for questions in each group. The average score for each group was computed as - total points obtained by the student on Group DB (Group LAB)/total number of questions in Group DB (Group LAB)). The results from the study indicated that the null hypothesis of no differences could not be rejected at a significance level of 0.05 (N = 60). The quantitative assessment coupled with the informal feedback from the students indicates that expanding the scope of the laboratories using interactive dashboards can be a viable approach to allow students to explore the concepts presented in the lab to conditions that are otherwise not possible to conduct physical experiments. This preliminary analysis provided the necessary impetus to conduct other forms of interventions. In particular, the use of interactive Jupyter Notebooks to automate laboratory calculations is being explored along with having the students submit lab reports as markdown files served using GitHub/Google Colab platforms.

Use of Microprocessor Based Sensors

Both inclass surveys and focused interactions with students in each laboratory group were used to obtain feedback related to the adoption of sensors. The initial set of assessment was carried out after the students were provided a short lecture on the various flow measurement methods which included the Hall effect sensor.

Figure 6 depicts the students' perceptions with regards to the use of sensors for flow measurements. Over one-half of the students (~55%) did not initially feel that the electronic sensors were better than traditional hydraulic based flow measurement methods while 45% felt that the sensors would be better. The summary statistics of student perceptions are listed in Table 4. Students were then asked to freely discuss why they felt the sensors were better or not in a focus group format. Table 3 captures the various comments made by the students identifying the pros and cons related to sensor usage.

Table 3: Reasons Presented by Students as to why they Prefer or do not Prefer Electronic Sensors

Pros for Using Sensors	**Cons for Using Sensors**
More accurate and precise	Not sure how it works
No human error	Unsure of the calibration
Technology is better	Not sure how many times it was dropped
More precise	Probably costs more money.
Works at a lower (atomic and molecular level) electromagnetic properties	Don't trust electronics in general

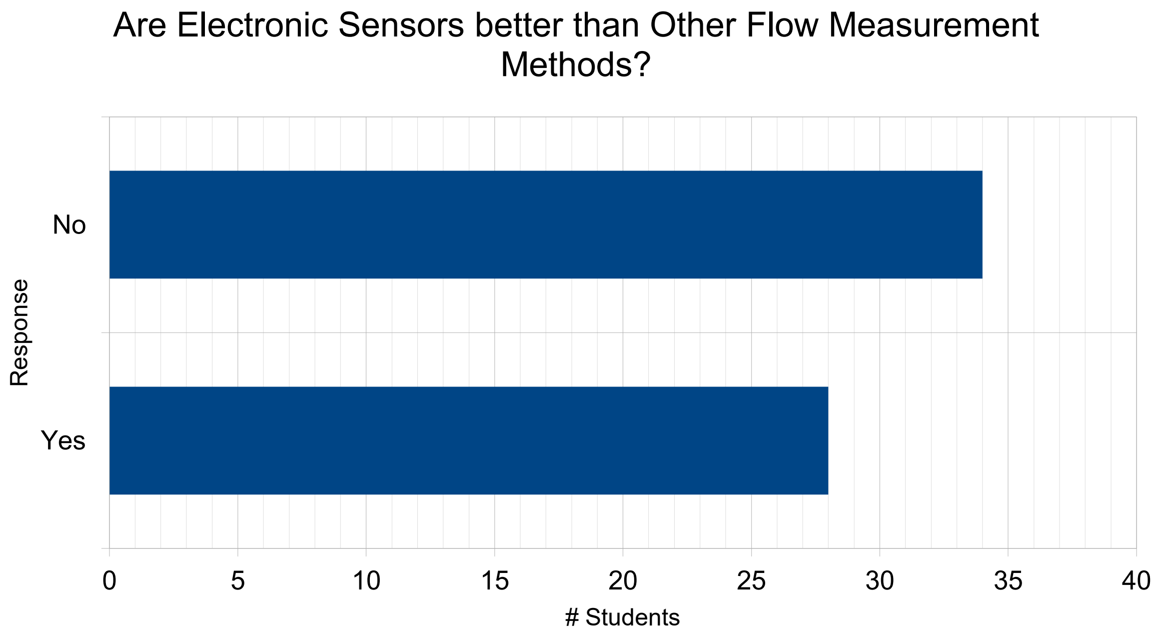

Figure 6: Student Perceptions Related to Use of Electronic Sensor for Flow Measurement

It is important to recognize that the students had a better understanding of the traditional principles (conservation of mass, energy and momentum and headloss) behind different hydraulic instrumentation (venturimeter, orifice plate and rotameter) as they were covered the Mechanics of Fluids (theory) class that the students had already taken while the principle of Hall-effect was presented in the laboratory. This lack of familiarity with the principles behind the sensor and its calibration were noted to be the major deterrents to adoption of electronic sensors by the students who were surveyed.

Lack of familiarity with the sensors and issues related to their calibration, and lack of understanding of their internal workings were stated as the primary factors by students who did not feel comfortable with their usage. Therefore, students who had responded No to the earlier question (Figure 6) were asked if they felt comfortable with using sensors, if they were allowed to build one on their own for use. Clearly, doing so, would give them a greater understanding behind how the sensor worked and also assuage their fears related to prior calibration. As the question was only intended to those who did not want to use a flow sensor in the first place, the sample size here was a total of 34 students over 4 different sections of the laboratory.

As shown in Figure 7, an overwhelming majority of students (~75%) did not feel comfortable building their sensors, even though they were told they would get assistance with the process. As such, they demonstrated a continued skepticism towards the usage of sensors. The overwhelming reticence towards sensor building and deployment also highlights that the removal of electronic circuits class from the civil engineering curriculum likely reduces the students comfort with electronic circuits and sensing technologies.

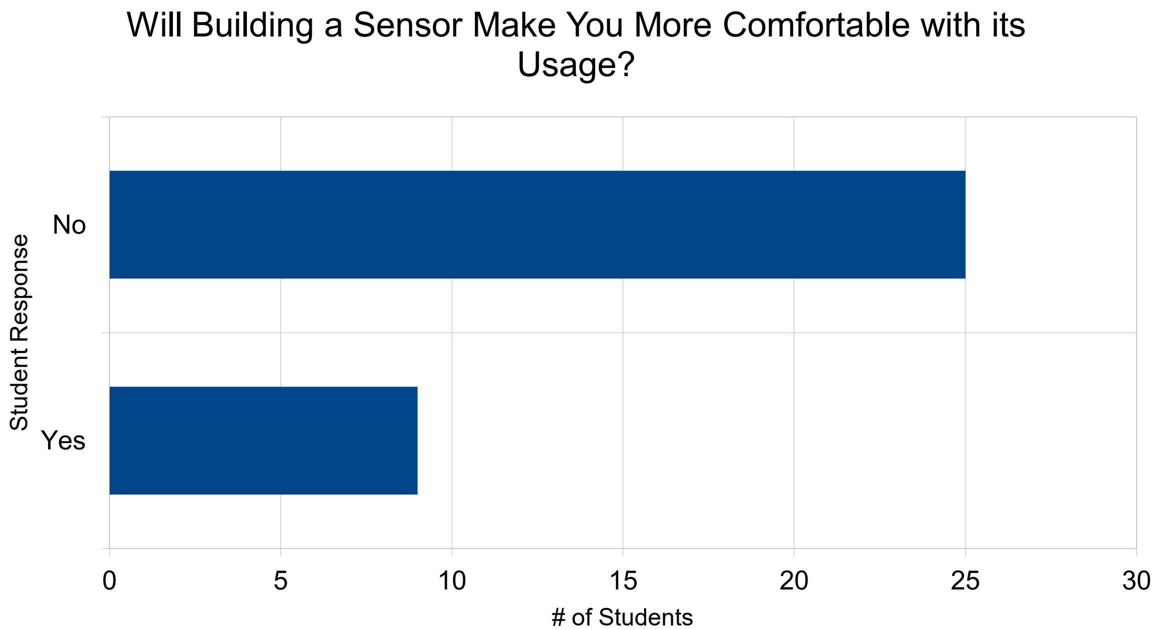

Figure 7: Students Willingness to Build Sensors in order to Improve their Comfort Level with the Technology

Summary statistics of the perceptions students had regarding the use of sensors is shown in Table 4. Of special note, in all cases, the variance was less than 1 indicating that students liked using sensors regardless of their concerns related to calibration

Table 4: Summary Statistics of student perceptions with regards to sensor use

	Mean (%)	Std. Dev(%)
Are Electronic Sensors Better than Other Flow Measurements	56.67	5.66
Building a Sensor Makes you More Comfortable with Usage	73.53	11.31
Student Interest in Hall Effect Sensor for Fluid Flow	15	8.42

Students were also asked which fluid flow instrumentation would be of interest to them. Approximately 85% of the students selected conventional measurement methods – i.e., Venturimeter, Orifice Plate and Rotameter (see Figure 8) while only 15% were interested in learning more about electronic sensors.

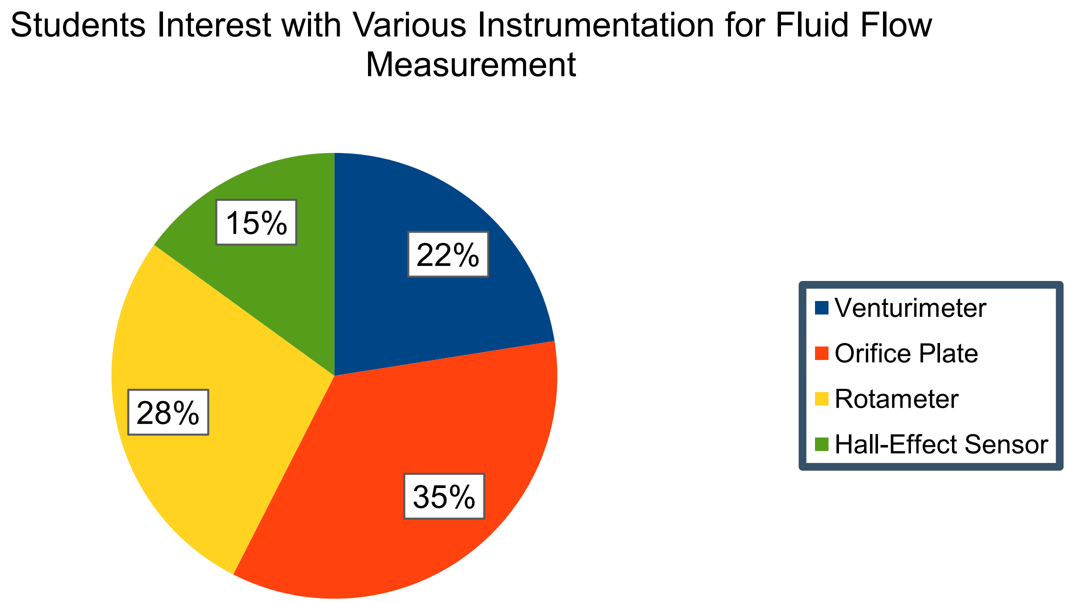

Figure 8: Students Interest with Various Fluid Flow Instrumentation (Sample Size 40).

Students were also asked about their experiences with the sensors after the completion of the laboratory and how the use of the sensor compared with the use of other instrumentation. An overwhelming majority of the students (>90%) of the students in the laboratory indicated that they were comfortable with the measurements provided the sensor. The ability to check the results of the sensor with direct flow measurements (i.e., calibration checks) were noted to be the most important consideration. While students were curious about the functioning of the sensor and appreciated getting a peek into the setup of the sensor, they did not feel comfortable with being able to deploy one on their own. The programming interface was notably the hardest part to comprehend.

The ease of the utility of the sensor in obtaining readings was not a major factor for most students. A majority of students felt the use of conservation of mass and energy principles utilized by Venturimeter and Orifice-Plate made these instruments more rigorous than other methods. The students ordered the accuracy of the instruments as Venturimeter > Orifice Plate > Rotameter > Hall-Effect Sensor because, venturimeter was directly based on fundamental principles of mass and energy conservation and did not need any additional information (e.g., orifice loss coefficient). The need for calibration was noted as the major limitation with rotameter and Hall-effect sensor.

The low cost of the sensor (~$15 for the sensor; $25 for the Arduino) came as a surprise for many students. Based on this cost factor many students felt the deployment of the sensor was reasonable, but most of them felt they should have traditional instrumentation alongside. While all students understood the ability of the sensor to collect data at a high frequency, some expressed concerns with regards to the noted fluctuations in the measurements made by the sensor. They had questions related to how such high frequency measurements can be properly used for analysis and design which led to useful discussions on data fidelity and time-averaged flow measurements which otherwise would not have been possible in the laboratory as other measurements only provided point measurements and observed variability could largely be attributable to differences between human operators.

Conclusions

The overall goal of the study were two fold – 1) Expand the scope of some laboratories using interactive dashboards and 2) Expand the scope of the laboratory using electronic sensors. The paper presents two interventions that were made to a junior-level Mechanics of Fluids Laboratory class. The first intervention was the development of interactive dashboards to help students understand how temperature and salinity affects the density of a fluid. Students were required to measure density at a given temperature and salinity. Two dashboards were created using R Markup language and deployed on a cloud server to allow students interactive numerical experimentation. To test the utility of this intervention, the weekly laboratory quiz contained questions on materials covered in the face-to-face laboratory session and exclusively on the dashboards. There was no statistical difference between the performance of the students on materials presented in different formats. In addition, students were asked informally to describe their experiences with the dashboard use. The students felt the single-page dashboards were easy to maneuver and interact and the material presented was not hard to comprehend.

An electronic flow sensor (based on the principle of Hall Effect) was added to the fluid flow measurement laboratory. A majority of the students were skeptical about the usage of sensors prior to conducting the experiment. The lack of knowledge related to the sensor and issues pertaining to sensor calibration were noted to be the two main factors for their reticence. However, students did not feel comfortable configuring sensors due to limited to no background in electric circuits. While the comfort level of students increased with the use of the flow sensor, especially as they were able to check its calibration. The programming aspect of sensor deployment was noted to be the most difficult for students to comprehend. While students understood the utility of the sensors in collecting high frequency data, they also felt the need to complement it with traditional measurement methods. The noted variability in the sensor measurements provided opportunities to discuss the role of sampling frequency and time-averaged values that was otherwise not possible before.

The study indicates that the students exhibited useful engineering analytical skills such as being skeptical about calibrated instruments, the need for redundancy of measurements and measurement methods and asked relevant questions related to utilizing high frequency data. However, their comfort level with electronic sensors was extremely low due to lack of prior exposure. The integration of sensors alongside traditional instrumentation is useful to build confidence with using sensors by civil engineering students and helping them become more comfortable with modern data collection approaches. Based on the findings from this study, additional interventions and scaffolding tools are being planned to help students become more comfortable with sensor and physical computing technologies. The study also provides useful feedback to refine first-year courses on computational thinking and data analysis in order to make them more suitable for up-streaming purposes. The findings also indicate that the elimination of engineering circuits hinders students comfort with sensing technologies. Laboratory courses do provide a useful pathway to foster computational thinking and introduce sensing technologies to overcome the elimination of basic engineering electives in modern civil engineering program. The interventions presented here have low cost overhead and can therefore easily be introduced into existing laboratory courses.

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