Students Using Sensors: Multi-Disciplinary Interactive Demonstrations for First-Year Design Courses

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Abstract

The research presented is a work in progress on the development of interactive classroom demonstrations created for use in Engineering Design & Society, a first-year introductory engineering design course with an emphasis of using the human-centered design process to address societal problems. Coursework covers basic programming, solid modeling, rapid prototyping, data acquisition, and sensors. These demonstrations are designed to illustrate the use of sensors across engineering disciplines, educate students categorized as undecided engineering majors about the many branches and applications of the engineering field, and highlight the value of a working knowledge of electrical and computer science components regardless of the chosen discipline.

Each demonstration is composed of a Vernier analog or digital sensor, Vernier Arduino Interface Shield, Arduino, removable breadboard with supporting circuitry, and a model of an environment where the sensor would be applied, typically constructed with 3D printed parts. Students are able to build their own supporting circuitry, implement it in the model environment, and control real time inputs and operating conditions through physical stimulus and manipulating the Arduino code.

Current constructed demonstrations are as follows:

a.) An automated conveyor belt coupled with the Vernier Photogate Sensor with an emphasis on industrial engineering and manufacturing.
b.) An automated titration apparatus using a Vernier Ph sensor that illustrates applications of environmental and chemical engineering.
c.) A model bridge strut equipped with the Vernier Dual Force sensor in selected crossbeams that allows the student to observe static tensile and compressive forces. This demonstration mostly concentrates on civil engineering, with supplementary mechanical engineering principles.

This presented body of work includes supporting schematics of all model demonstrations, including detailed descriptions of their functionality and operation, for other universities interested in developing their own representative models for student education or recruitment. In the future, models of all major engineering subdisciplines will be developed, with current plans for Aerospace and CS/Electrical engineering focused demonstrations. The intention behind these self-contained demonstrations is to provide comprehensive methods of educating undecided engineering majors about future career paths and promoting interdisciplinary critical thought through hands-on interaction.

Introduction

In the interest of student retention in engineering colleges, numerous programs have adjusted their first year engineering courses to include subjects that immediately define the role of the modern professional engineer [1] [2]. This has resulted in the earlier introduction of engineering design principles, in contrast to the more traditional method of teaching design after the student has completed a barrage of general sciences such as calculus, chemistry, and physics. While designing without a strong scientific background rarely leads to a successful outcome, failing to educate the student on these courses' intended applications can lead to a lack of motivation and disillusionment with engineering as a whole [2].

The method of incorporating design principles into freshman and general engineering coursework varies greatly between institutions, with programs varying from yearlong general engineering coursework to summer transition programs for high achieving incoming freshmen. At the University of Florida, an introductory course titled "Engineering Design and Society" is used as a general introduction to the college of engineering, while also addressing social challenges and the values of problem solving from a multidisciplinary approach, by using the human centered design process. A team project based course, students are presented and encouraged to explore prototyping skills such as solid modeling, basic programming skills, electronics, sensors, data acquisition, power tools, and 3D printing [3].

It was clear that whatever an introductory engineering program's structure, its success and overall impact was dependent on the successful integration of multidisciplinary information and principles. This is for the intended purposes of providing first year students with the knowledge to make an informed decision about their major, as well as a general appreciation and cooperation for all branches of engineering. While Engineering Design and Society already has an emphasis on multidisciplinary design approaches, a series of supplemental hands-on demonstrations were designed to target the student's individual interests with a themed demonstration for each branch of engineering. These activities are generally 10 to 20 minutes in length, while incorporating real-world applications, selected explanations of discipline-specific engineering concepts, data collection, sensor integration using Vernier and Arduino systems, and examples of manufacturing methods utilized in the rest of the course. The resulting classroom demonstrations are easily reproduced at low cost, and can be characterized as widely adaptable enrichment material for the implementation in a variety of introductory engineering course formats.

Background

The ability to immediately address emerging problems in society has been critical in maintaining engineering's relevancy as a profession. In response, the fields of science and technology have been advancing at a dynamic pace to which STEM education often struggles to maintain. Modern engineering education must transition from adapting curriculum to fit current advancements, to anticipating future changes in the roles engineers play in society and adjusting programs accordingly. The National Academy of Engineering addressed this issue in "The Engineer of 2020," citing the need for strong analytical and communication skills, as well as leadership, ingenuity, lifelong learning and the ability to be responsive to input from a broad range of disciplines [4].

Furthermore, considering recent industry feedback and the rise of globalization within the workplace, it is growing more apparent that employers also value creative solutions, critical thinking, and problem solving skills in their new hires [2]. According to the United State's Accreditation Board for Engineering and Technology (ABET), design is recognized as central to all types of engineering and aids in developing a student's ability to evaluate and design a need-fulfilling system, process or component [7]. By exposing a first year student to design and manufacturing principles, along with the importance of interdisciplinary cooperation, the intended effect is that the student will address future coursework, internships, and full time positions with improved social skills, teamwork, social conscience, and creative innovation [2].

A primary and well-documented method of introducing design principles into the classroom is through interactive, hands on activities. Hands on approaches encourage a student to "play" and experiment with alternative solutions and develop thought processes independent of computer simulation [5] [6]. This helps to develop instinct, addresses the frustration students often experience in visualizing 3D design solutions from drawings, and introduces the limitations of conceptual computer modeling. Engaging in interactive, experiential learning activities, if designed appropriately, can also encourage teamwork, as well as those highly sought after leadership and communication skills. In addition, students repeatedly respond positively to experiential learning experiences in interviews, focus groups, and survey responses[1] [5] [7].

In response to considerations for the globalization of the engineering profession, equipping new engineers with the ability to view and incorporate solutions from multiple fields is becoming a well-recognized necessity. To quote the Engineer of 2020 initiative, "We recognize and understand that we must understand and capitalize on the treasure that is the diversity of American higher education" [4]. Incorporating design principles into general engineering curriculums not only aids students in making a well informed choice of major, but has the added benefits of exposing students to new perspectives both from the differing interests and skill levels of their peers, and from the societal issues addressed in course delivered design challenges.

Available Facilities and Resources

Currently, University of Florida's general engineering course is taught in a traditional classroom that has been outfitted with modular student workspaces, tool chests, and desktop 3D printers. While the printers are monitored by student assistants and shared collectively by the class, workspaces and tools are allocated in five groups of four students, spaced out along the classroom's perimeter [7].

Figure 1. Engineering Design and Society Classroom Setup and Student Workstations [4]

Equipment allotted in each workstation includes an inventoried list of hammers, wrenches, screwdrivers, a saw and miter box, cordless Dremel and assorted accessories, power drill and assorted accessories, sanding blocks, ratchet set, wire strippers, set of pliers, soldering equipment, tap and die kit, calipers, measuring tape, level, and some common sizes of fasteners (nuts, bolts, screws, and washers). A clamping vise is also attached to the tool chest's wood topped work surface [7].

Figure 2. Workstation Specific Tool Chest (left) and Shared 3D Printing Capabilities (right)

Throughout the course's duration, students regularly use the Arduino Uno Starter Kit for various assignments and an overarching design project; this kit comes equipped with an Arduino Uno board, breadboard, jumper wires, LEDs, a 9V battery, transistors, resistors, potentiometers, diodes, servo and DC motors, LCD screen, pushbuttons, H-bridge motor driver, optocouplers, and several small sensors. Coding is facilitated by Arduino software [7] [8].

Curriculum Development

As these demonstrations were primarily implemented within the course framework of Engineering Design and Society, they also align with the course goals:

> "Emphasizing the human-centered design process to address a societal challenge. Exploration of solid modeling, introductory programming, sensors, data acquisition, and 3D printing as maker tools for engineering prototyping. Teams will utilize multidisciplinary approaches, project management, written and oral communication skills in creating a societal-based design." [3]

To uphold this description, the in-class demonstrations were constructed using only recyclables and materials readily available to students within the scope of the course and its available facilities. The demonstrations also build on principles and skills discussed in class. Most notably, the sensors use the Arduino Starter Kit, which is a required purchase for the class and is the electronic backbone of the course's overarching design project. As the course's textbook requirement, each student will individually own their kit after the course's end, thus promoting explorative prototyping beyond the semester's end. Through Arduino's extensive online platform, students are also introduced to a vast community of makers and inventors, with a host of open source projects they can complete at their interest and disposal. The only components not used within the course are Vernier sensors and an Arduino adapter shield. Vernier sensors are commonly used in high school science courses. In this case, student ease of use and familiarity was prioritized over strict adherence to course material guidelines.

Further complying with the scope of the course, each demonstration had to exhibit a specific branch of engineering, highlight its cooperation with other branches of engineering, contain a real-world application with clear societal impact, and reinforce the importance of sensor integration across all engineering systems, while providing clear instruction and introducing discipline-specific concepts. The instructional guides accompanying each demonstration mimic the format of lab assignments the students will encounter in upper level courses. Likewise, demonstration topics and applications were selected due to their similarity to upper level course assignments as well as familiarity to the student. Many of the demonstrations feature concepts that are specific to multiple engineering disciplines. These secondary disciplines are discussed alongside the principle theme of the demonstration.

Current Demonstrations

1. Primary Focus: Industrial Engineering

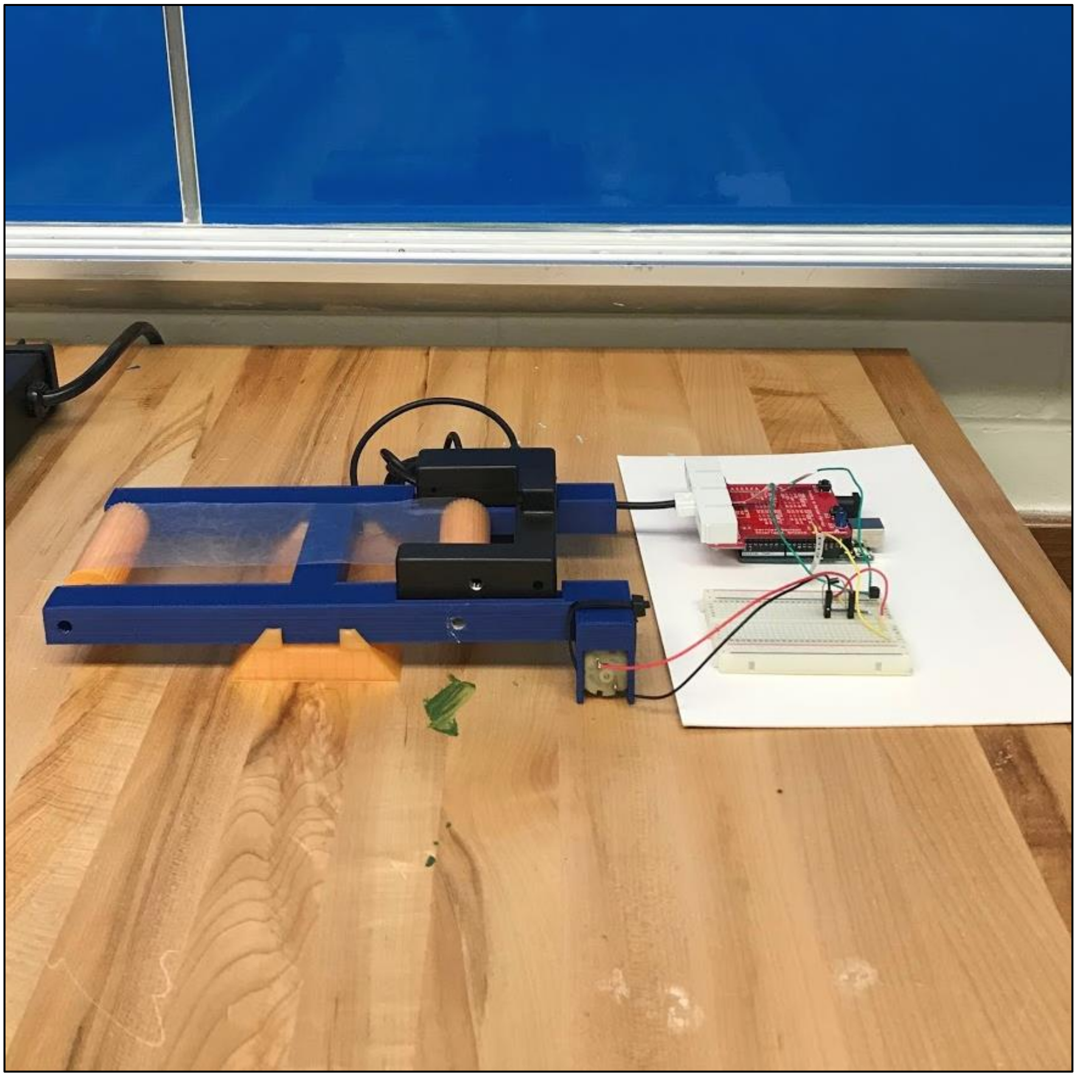

Figure 3. Industrial Engineering Demonstration: Motorized Conveyor Belt, Photogate Sensor, and Supporting Circuitry.

This demonstration highlights industrial engineering in a manufacturing environment. Mechanical engineering is included as a secondary focus, as product design overlaps closely with manufacturing and factory planning. The project application is as follows: after undergoing a mechanized process, a product is placed on a conveyor belt to be transported to the next, human driven, manufacturing process. The students are directed to implement a Vernier Photogate sensor to stop the conveyor belt and signal a pause in production until the product has been removed by the human operator. The intended effect is that the human operator is not overwhelmed by the amount of incoming product. This device is similar to a scaled down conveyor belt one would find at the grocery store. Figure 4 is a schematic detailing how the

Photogate sensor is inserted into the first analog port of the red Vernier shield, and is subsequently connected to the DC motor powering the conveyor belt. Almost all structural components of the conveyor belt were 3D printed, with the exception of the belt, which was made out of a recycled plastic bag, and a rubber band used as a timing belt to transfer mechanical power from the DC motor to the conveyor belt rollers.

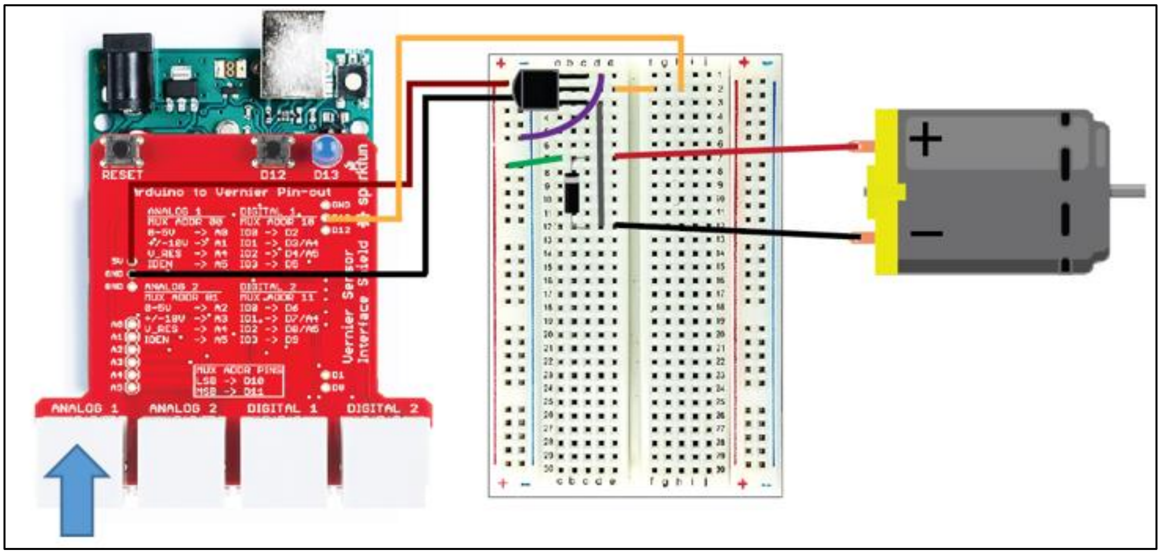

Figure 4. Student Instructional Graphic for System Wiring where Blue Arrow Denotes Photogate Sensor Port

2. Primary Focus: Chemical Engineering

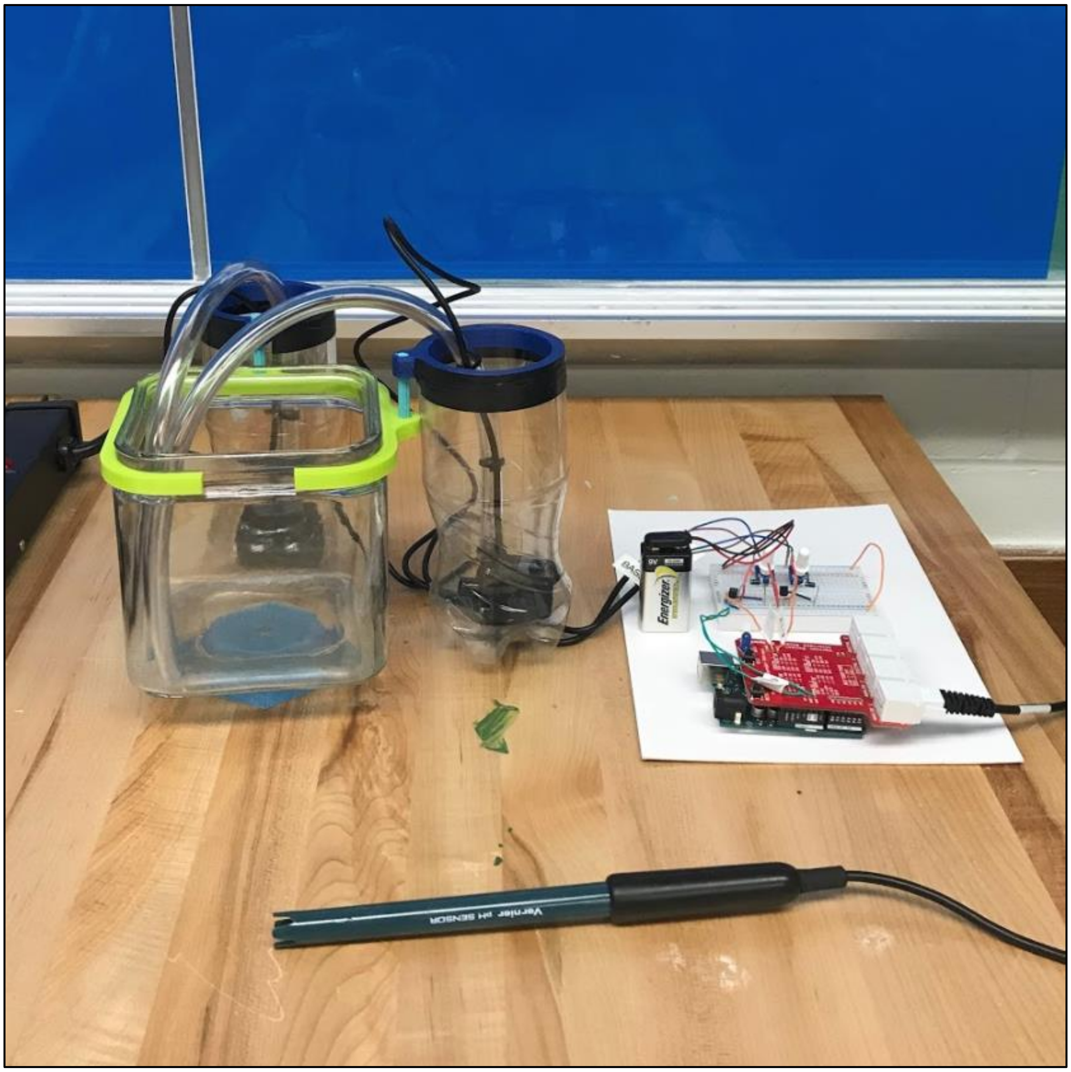

Figure 5. Chemical Engineering Demonstration: Dual Reservoir and Pump Setup, Main Reservoir, pH Sensor, and Supporting Circuitry.

Concentrating on chemical engineering, this demonstration uses a pH sensor and two aquarium pumps with potentiometers to explore concepts related to environmental and civil engineering in the utilities sector. The student is presented with a hypothetical situation in which a reservoir of treated wastewater requires treatment before it can be released into the environment, in order to minimize environmental impact, such as inducing abnormal algae blooms. Through completing the demonstration, students build an automated titration system that automatically adjusts the wastewater's pH levels to neutral by pumping in the correct amount of acidic and basic treatment solutions, housed in adjacent reservoirs. Since titration is a common subject for high school lab demonstrations, it lends an air of familiarity to an otherwise brand new application. Alternative applications for using sensor feedback to monitor chemical properties such as food processing, pharmaceuticals, chemical manufacturing plants, and environmental field tests are discussed as well. In line with the environmental themes of this project, all fluid containers were sourced from recycled materials and outfitted with custom 3D printed collars. This project has the most intensive use of electronic components, as it features two high voltage components (the aquarium pumps), requires additional power through a 9V battery. An alternate version of this demonstration was also developed, and uses potentiometers to regulate fluid flow.

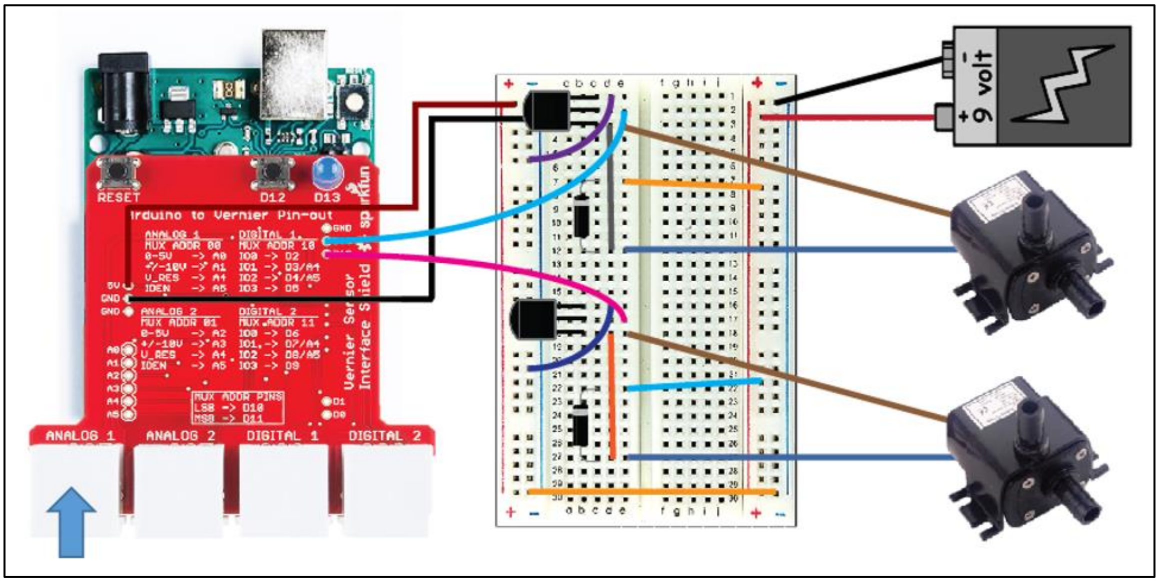

Figure 6. Student Instructional Graphic for System Wiring, where Blue Arrow Denotes pH Sensor Port

3. Primary Focus: Civil Engineering

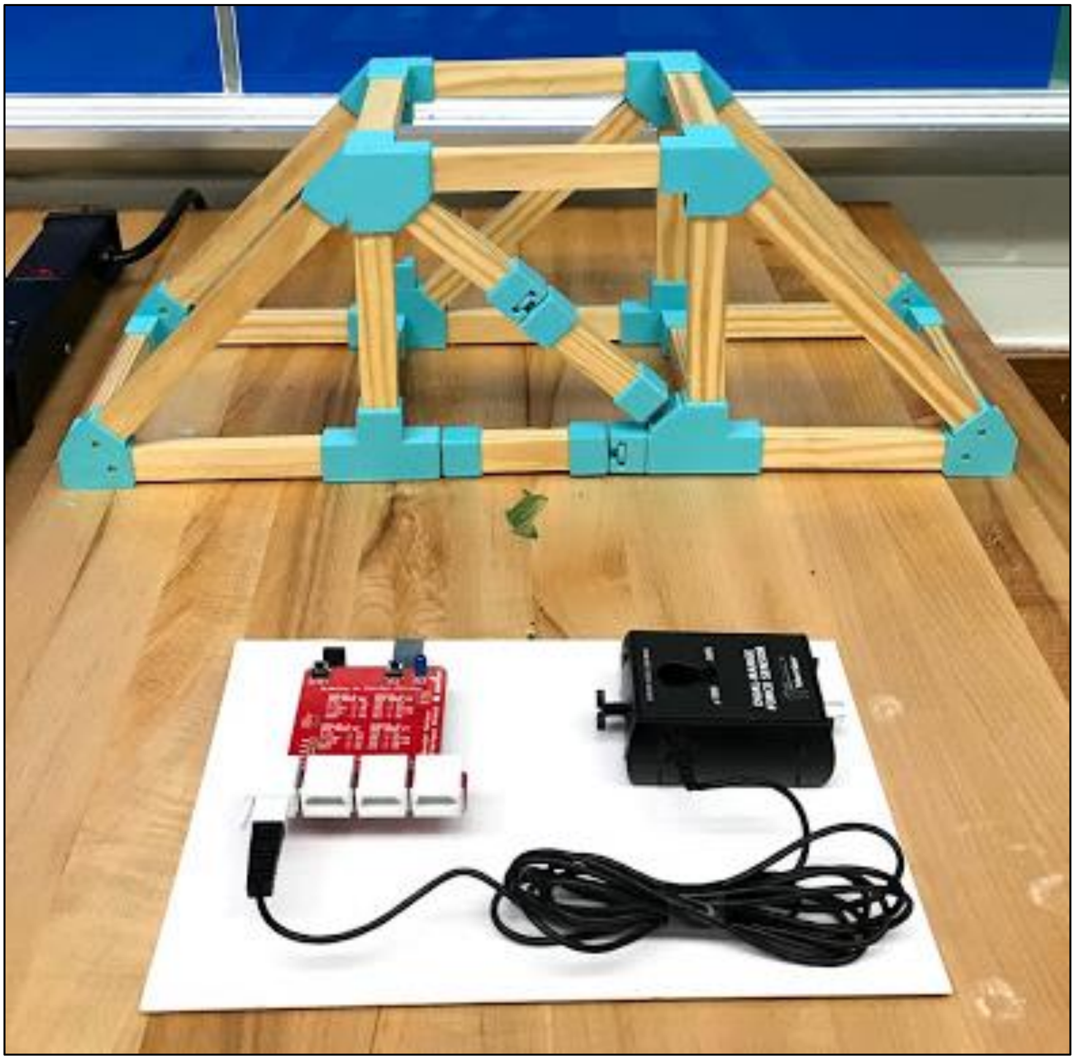

Figure 7. Civil Engineering Demonstration: Model Truss, Three Removable Beam Sections, Dual Range Force Sensor, and Supporting Circuitry.

Like the industrial engineering demonstration, the demonstration for civil engineering also had a secondary focus on mechanical engineering, as it introduced beam loading and couple forces, concepts covered under statics and mechanics of materials courses.

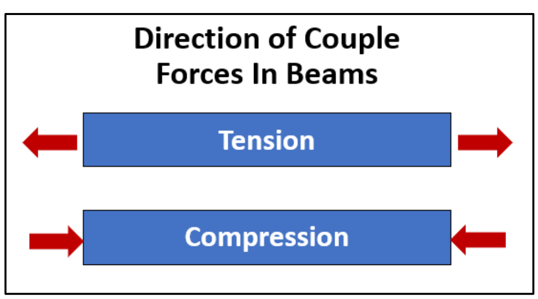

Figure 8. Student Instructional Graphic Explaining Beam Theory

The chosen project application focuses on systems of imbedded sensors in bridges responsible for determining whether certain environmental factors will cause unsafe conditions for drivers. As such, this demonstration focuses more on data acquisition than wiring. Using a wooden truss fitted with 3D printed fixed joints, students insert the Vernier Dual Force sensor into one of three removable beam sections, and subject the truss to vertical loads in four different testing areas, while monitoring the difference in force measured by the sensor using a serial output monitor included in the Arduino coding suite. The three different removable beam sections allows for three variations in how the demonstration is presented. Depending on whether there is a positive or negative force difference, students are able to determine if a load induced a compressive or tensile couple force in the beam that they are testing, and actively observe how the components of a truss distribute force throughout a structure.

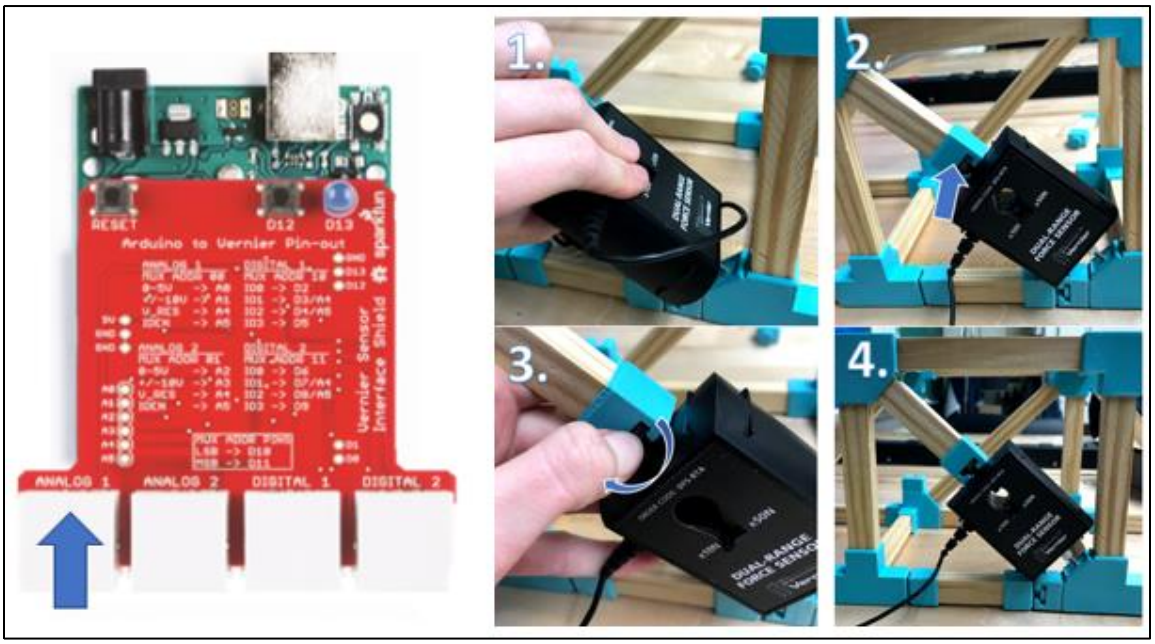

Figure 9. Student Instructional Graphic for System Wiring where Blue Arrow Denotes Dual Force Sensor Port (left) and Student Instructional Graphic on How to Install the Dual Range Force Sensor into the Truss.

This demonstration presented an additional design challenge during development, due to the level of precision needed to fix translational movement of the sensor when installed into the truss frame. After multiple design iterations and taking into consideration the ring stand mounting capabilities the dual force sensor was already equipped with, 3D printed fixtures that were imbedded with traditional fasteners successfully eliminated any translational movement the sensor may exhibit under different beam loadings, allowing for the successful measurement of compressive and tensile forces. Similarly, the removable beam sections were developed to mimic the sensor’s mounting capabilities.

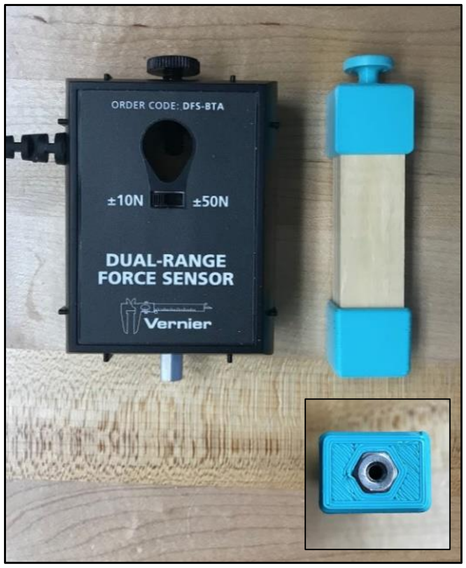

Figure 10. Side by Side Comparison of the Dual Force Sensor and Removable Beam Section's Mounting Capabilities with Supplementary Bottom Section View.

Results

1. Design Outcome

In most cases, designing demonstrations with materials restricted to Engineering Design and Society was not impactful in the presentation's overall performance. However, the civil engineering demonstration placed particular strain on the removable beam sections, which were made from pine with 3D printed end caps. Installing and uninstalling the beam sections temporarily places the end caps in a state of shear, which undermines the structural integrity of 3D printed layers, inducing fracture.

Figure 11. Shear Fracture in Removable Beam Section End Cap

To improve the durability of the removable beam section, the end cap design was imbedded with a ¾ in. nail. This significantly improved the flexibility and lifetime of the beam section. Multiples of the removable beam section were made as a precaution in the event of another fracture.

The expected time for the student to complete each demonstration was reevaluated near the end of the design process to guarantee that the hands on activities could be completed within an appropriate period of class time, around 10-20 minutes. This evaluation altered the procedures of some demonstrations, resulting in the reallocation of certain concepts into a variation of the original activity. The procedure for the Civil Engineering activity was reduced from using three different removable beam sections to using one, providing the opportunity to present multiple versions of the demonstration if desired. Likewise, the first iteration of the Chemical Engineering activity used potentiometers as a secondary method of controlling fluid flow. While the final procedure does not include the potentiometer circuit build, it is included as an additional enrichment activity in the event of student interest.

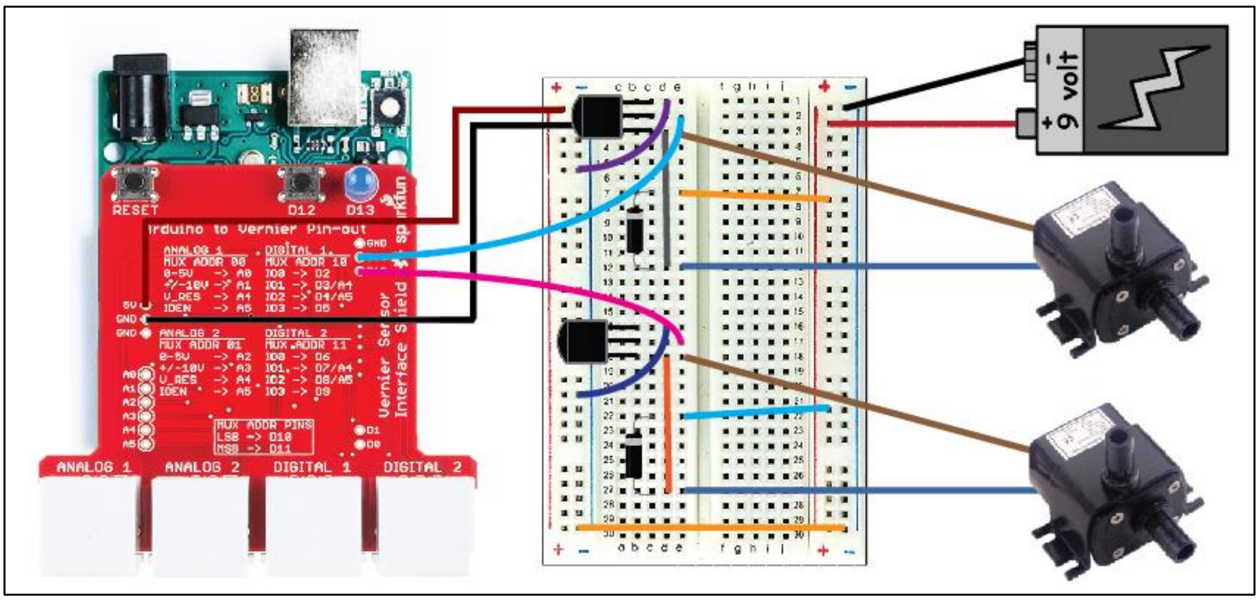

Figure 12. Student Instructional Graphic for Alternative System Wiring, where Blue Arrow Denotes pH Sensor Port

2. Pilot Launch and Data Collection Process

The next stage of development is implementing the curriculum within the first year design course, Engineering Design & Society. As students are usually introduced to the Arduino Uno Starter Kit around one month into the semester, the demonstrations will be featured in a class period six weeks or later into the semester, allowing time for students to gain familiarity with the microcontroller and included accessories through completing course assigned builds. During the chosen class period, students will individually build the supportive circuitry for each demonstration. Upon completing the build, they will integrate their circuitry and complete the rest of the activity. Observations will be gathered throughout the build process to evaluate student engagement and opinions, as well as identify points of confusion to further improve each demonstration. Lastly, an online survey will be distributed to all participants, to be completed within 24 hours of the in class activity. The proposed survey structure is as follows:

1. Student Demographics:
    - Gender
    - Ethnicity
    - Year of study
    - Major

2. Quantitative Questions:

    - On a scale of 1 to 10 rate your knowledge of the engineering discipline before completing this exercise.
    - On a scale of 1 to 10 rate your knowledge of the engineering discipline after completing this exercise.
    - On a scale of 1 to 10 how much did you enjoy this exercise?

    - For each exercise indicate the extent to which you agree/disagree
        i. Strongly Disagree
        ii. Disagree
        iii. Neutral
        iv. Agree
        v. Strongly Agree

    - The background information clearly outlined the real-world application
    - The instructions were clear and easy to follow
    - The exercises were challenging and fun
    - It is important to learn about other engineering disciplines even if you are not interested in majoring in them
    - The “Hands On” approach is an effective way to learn new things.

3. Qualitative Free Response Questions:
    - Have you had any previous experience with circuits, microelectronics, or sensor integration?
    - What did you like and dislike about the exercise?
    - Would you suggest any improvements to the exercise?
    - What is your opinion on incorporating more interactive demonstrations into engineering courses?
    - Which branch of engineering (not presented in the in class demonstrations) would you like to learn more about in the future?

Conclusion

This introductory program of three demonstrations primarily focused on Civil, Industrial, and Chemical engineering educates first year and undecided engineering students about available career paths in an interactive manner, while reinforcing universal engineering values of cooperation, multidisciplinary design approaches, sensor integration, and data collection. Due to the small, tabletop scale of these demonstrations, they are easily adaptable to introductory engineering course guidelines, and can be built from easily sourced, often repurposed materials. All of these demonstrations utilize 3D printing technology as a way to highlight the value of solid modeling and rapid prototyping. The level of dynamic interaction accomplished with a small scale demonstration is very promising, and can provide a more personal level of general engineering education.

Future work

Implementing these demonstrations into the coursework of Engineering Design and Society is set to continue, and two additional demonstrations are currently being designed. One demonstration will focus on Aerospace Engineering by utilizing a Vernier Gas Pressure Sensor in a small-scale wind tunnel to observe the trailing pressure differences in aerodynamic and non-aerodynamic shapes. The next will feature Computer Science and Engineering through the use of a Vernier Motion Detector in smart home and private security applications. Additional topics of interest will be chosen from student feedback data collected in the pilot introduction of these demonstrations.

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