Experiences with Integrating Project-Based Learning into an Instrumentation Course for EET Students

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Abstract

This paper presents experiences with and advantages to integrating project-based learning into an instrumentation course for electronics engineering technology students. In support of project-based learning, the final three weeks of a 14-week semester are dedicated to student-initiated projects. These projects focus on integration of hardware and software, sensor and actuator selection, continuous process improvement via test and measurement, project management, teamwork, and oral and written communication. The stated course objectives support attainment of all five ABET-ETAC Criterion 3 student outcomes and contribute to satisfying some of the Criterion 5 and Program Criteria requirements. Two sample student projects along with the impact of project-based learning on student outcomes attainment are included herein.

Introduction

The ability to conduct and design experiments is rated as one of the most desirable technical skills of engineering and engineering technology graduates. Specifically, employers want engineering technology graduates with a working knowledge of data acquisition, analysis, and interpretation; an ability to formulate a range of alternative problem solutions; and hardware and software integration capabilities specific to their profession [1]. Accordingly, project-based learning (PBL) [2] was integrated into a sophomore/junior level instrumentation course for EET students. PBL empowered students [3,4] to self-direct their educational experience by designing experimental systems for given specifications. It is an instructional method that integrates structured, new knowledge gained in this course and other courses with the new self-taught knowledge via solving real-world problems. A PBL-based pedagogical approach [5,6] facilitates students' critical thinking and problem-solving skills while accomplishing the course-specific objectives. In addition, PBL pedagogy contributes to epistemological development [7] of students.

The three-credit instrumentation course meets for two one-hour lectures and one three-hour lab per week. The first three weeks of the 14-week semester are primarily devoted to LabVIEW programming. During the next eight weeks, the concepts and hardware/software integration of sensors and transducers, interface electronics, data acquisition, and instrument control are covered. The final three weeks of the semester are dedicated to student-initiated and student-led project implementation. The end-of-semester course projects provide an opportunity for students to integrate their theoretical, hardware, and software knowledge by developing complete instrumentation systems. Development of soft skills such as teamwork, proposal and report writing, oral presentation, and project management basics is a key part of the project experience.

Direct and indirect assessments of the established student outcomes for the project experience were conducted to evaluate the pedagogical effectiveness of the PBL approach.

End-of-semester projects, a key component of the PBL methodology, provide opportunities to students for developing the project idea, preparing the project proposal, specifying all of the necessary sensors and actuators, implementing the project including necessary shop work, preparing a final report, and orally presenting their work including demonstrating successful operation of the project.

The following sections present a summary of the course-level assessment approach, pre-project course-embedded laboratory experience, PBL structure and management, two sample student project experiences, an assessment summary, and a brief conclusion.

Course Objectives, Outcomes, and Assessment

The three objectives of this instrumentation course (ENGTECH 241) are for students to be able to 1) identify and select sensors and actuators for instrumentation system design, including analysis and design of input/output interface electronics; 2) design and implement instrumentation systems integrating hardware and software, including test and measurement-based process improvement; and 3) gain an understanding of the importance of teamwork, and oral and written communication. All five of the ABET-ETAC Criterion 3 student outcomes [8], listed in Table 1, are supported by the stated objectives of this course. The mapping between the three course objectives and Criterion 3 student outcomes is shown in Table 2.

Table 1. ABET-ETAC Criterion 3 student outcomes [8].

1	An ability to apply knowledge, techniques, skills and modern tools of mathematics, science, engineering, and technology to solve broadly-defined engineering problems appropriate to the discipline
2	An ability to design systems, components, or processes meeting specified needs for broadly-defined engineering problems appropriate to the discipline
3	An ability to apply written, oral, and graphical communication in broadly-defined technical and non-technical environments; and an ability to identify and use appropriate technical literature
4	An ability to conduct standard tests, measurements, and experiments and to analyze and interpret the results to improve processes
5	An ability to function effectively as a member as well as a leader on technical teams

Table 2. Mapping of course objectives to Criterion 3 student outcomes.

Course Objectives At the end of the course, students will be able to…	Supported Student Outcomes (per ABET-ETAC Criterion 3)
identify and select sensors and actuators for instrumentation system design, including analysis and design of input/output interface electronics	1, 2
design and implement instrumentation systems integrating hardware and software, including test and measurement-based process improvement	1, 2, 4
gain an understanding of the importance of teamwork, and oral and written communication	3, 5

Students are assessed for course objectives and associated Criterion 3 student outcomes using various direct and indirect assessment tools. Additionally, course-embedded performance index-based direct assessment of student outcomes [9,10] provides valuable input to the overall course assessment and continuous improvement process. Results from various direct and indirect assessment instruments are archived and processed to generate action items used as input to the course- and program-level continuous improvement process.

Pre-Project Weekly Course Laboratory Experiences

Pre-project laboratory experiences during the first 11 weeks of the semester are grouped into three categories: 1) software development only, 2) digital and analog I/O integrating sensors and actuators, and 3) on/off control application. As mentioned earlier, the final three weeks of the course are dedicated to student-initiated project implementation. The instrumentation and data acquisition specific software used is LabVIEW, and available hardware include the NI-myDAQ [11] data acquisition device with breakout board, and GPIB controller board.

Project-Based Learning Structure and Management

Early in the semester, students start developing potential end-of-semester project topics with feedback and guidance from the instructor, leading to a pre-proposal with two project ideas for each team of three students. The required preproposal is due by the ninth week of the fourteen-week semester. Upon discussion, modification, and approval of the pre-proposal, each team is required to submit a formal proposal for the approved project topic by the tenth week of the semester. The required proposal is quite detailed as it includes project implementation ideas supported by major outcomes and design specifications, sensors and actuators selection, hardware/software integration plan, I/O interface drawings, relevant circuit schematics, parts list with vendor and pricing information, and a three-week project completion schedule including a Gantt chart. Students are also given access to a well-equipped departmental shop for fabrication and metal/wood work, including SolidWorks-supported 3-D printers. Each team of three students is allocated a nominal budget of $100 for purchasing project-specific parts not typically available in the laboratory. Project deliverables include a functioning system hardware prototype along with supporting documentation (pre-proposal, proposal, mid-point design review summary, and final report) and a formal end-of-semester presentation. Prototype hardware, student presentations, and final reports are archived for use as part of the display materials for future accreditation visits. Project management skillset developed in this course contribute to student success in the semester-long capstone design course offered the following academic year. Two of the projects completed during the fall-2019 semester as part of the instrumentation course, Robot Umpire and Hot Tea Machine, are presented next.

Sample Student Project: Robot Umpire

The goal of this project was to create a baseball pitching aid that would allow pitchers to play a game by themselves to improve their abilities. The Robot Umpire would register if the pitcher threw a ball or a strike and keep track of strikes to the batter, balls to the batter, outs in the inning, total strikes thrown, total pitches thrown, the pitcher's strike percentage, the pitcher's walks in the inning, the number of innings played, and the batters on base in the inning. The strikes to the batter, balls to the batter, and outs in the inning were to be displayed on the LabVIEW Front Panel as well as on the frame of the Robot Umpire unit. The ball will return to the pitcher via a PVC pipe attached to the net that will funnel the ball to a conveyor belt that is blocked by a pulley system. When the pulley is triggered, the ball will fall to the conveyor belt and return to the pitcher. To read strikes and balls from the pitcher, photoelectric sensors [12] were attached to the frame, shown in Fig. 1, in such a way that they would create a grid system in the strike zone where the ball could not go through the strike zone without triggering the sensors. The relevant pictorial views of the system are shown in Fig. 2.

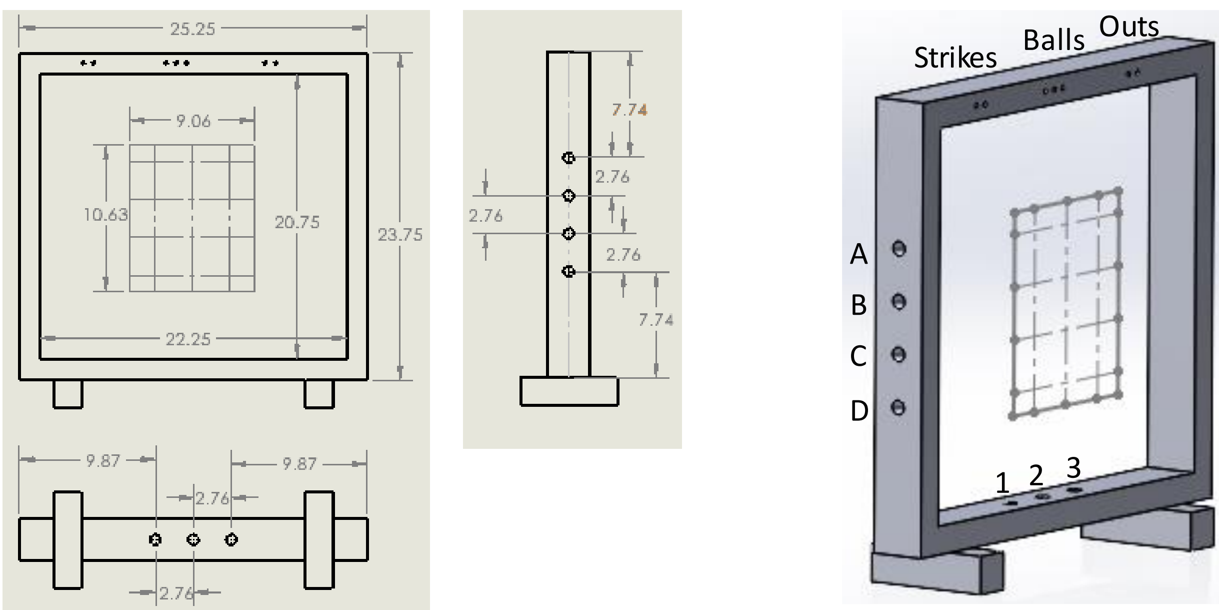
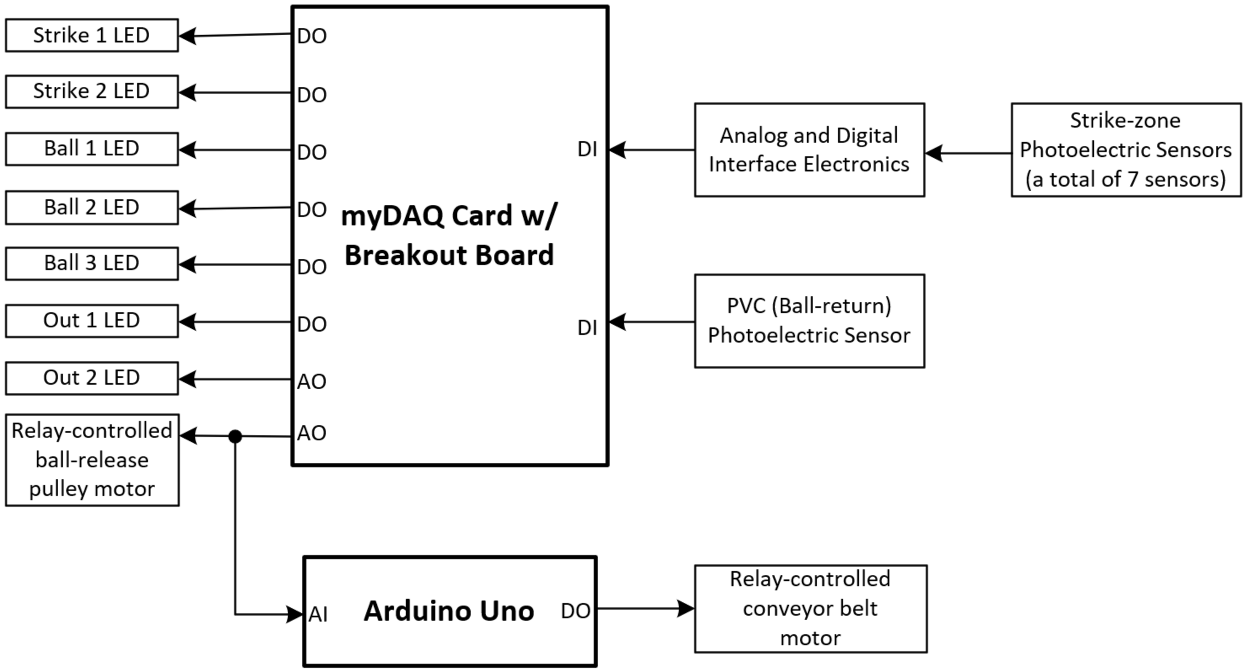


Fig. 1. Robot Umpire frame and the strike-zone sensor grid (dimensions in inches).

Fig. 2. Pictorial views of the Robot Umpire system.

For the pitch to be a strike, it has to trigger at least one of the photoelectric sensors on the left side of the frame (A, B, C, or D) and trigger at least one of the photoelectric sensors on the bottom of the frame (1, 2, or 3) at the same time. If the ball did not trigger a sensor on the left and a sensor on the bottom at the same time, the ball would funnel into the PVC pipe in the back of the net where there is another photoelectric sensor that counts the total number of pitches. If that sensor was activated without the strike sensors being triggered, the pitch would be counted as a ball. The sensor in the PVC pipe also is used as a trigger for the pulley system that blocks the PVC pipe. Upon triggering, the pulley system will pull the device blocking the pipe out and the ball will fall to the conveyor belt, which is also turned on with the signal from the sensor in the PVC pipe. Additionally, the code keeps track of the strikes to the batter, balls to the batter, and outs in the inning and displays them on the frame with LEDs, as shown in Figs. 1 and 2.

The system I/O interface diagram and analog interface configuration for the strike-zone photoelectric sensors are shown in Figs. 3 and 4, respectively. The signals from all seven strike-zone photoelectric sensors (A, B, C, D, 1, 2, 3) are processed per the analog interface configuration of Fig. 4. The processed outputs are then digitally combined to create a single strike-zone input signal $[(A+B+C+D)\bullet(1+2+3)]$ for the myDAQ card. The PVC ball-return photoelectric sensor output, however, is directly connected to a separate digital input. There is a total of seven LEDs at the top of the Robot Umpire frame for displaying strikes to the batter, balls to the batter, and outs in the inning. An output from the myDAQ card controls the on/off status of the ball-release pulley as well as the conveyor belt motor for ball return. However, after using up all ten I/O channels of the myDAQ card, an Arduino UNO was added to implement the conveyor belt control logic and associated delay functions.



Fig, 3. I/O interface diagram for the Robot Umpire.

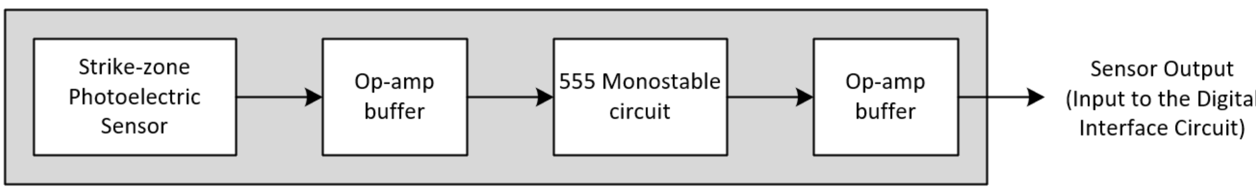


Fig. 4. Analog interface configuration for the strike-zone photoelectric sensors.

The front panel of the LabVIEW program, shown in Fig. 5, displays the total pitches thrown by the pitcher, the total number of strikes thrown by the pitcher, the pitcher's strike percentage, the number of walks in the inning, number of innings played, and the runners on base in the inning. The two waveform charts included in the front panel show strike pulse at the top and PVC sensor pulse at the bottom. As a ball is thrown, observing these two pulses confirm the successful operation of the Robot Umpire system, including the strike zone sensors as well as the ball return sensor.

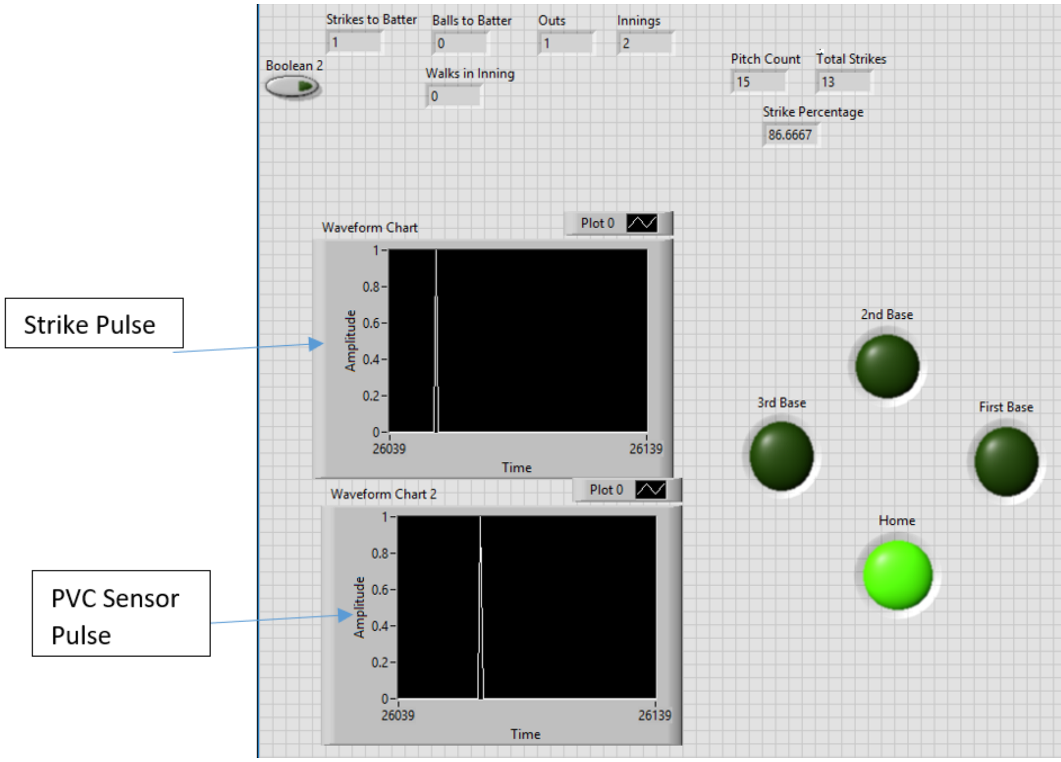


Fig. 5. LabVIEW front panel for the Robot Umpire system.

The LabVIEW program for this project extensively uses *case structure, sequence structure, local variable*, and *shift register* functions. If the pitch sends a signal to the digital input, the code adds a strike and lights up the first strike LED. If the pitch signal is not sensed but the PVC sensor sends a signal, the code adds a pitch to the pitch count as well as a ball and turns on the first ball LED. If the pitcher throws three strikes during an at-bat, the code resets both strike and ball LEDs and turns on an out LED. If the pitcher reaches three outs, all LEDs on the frame reset and the code adds an inning to the inning number. If the pitcher throws four balls during an at-bat, both strike and ball LEDs are reset, and the code displays runner on base. The code displays runners on base up to three; once the pitcher has walked batters around to home, all base indicators are occupied and begin flashing to tell the pitcher to throw strikes. After the pitch is processed, the sensor in the PVC pipe sends a signal to the pulley motor and the Arduino board. The pulley motor is turned on for 50 ms whereas the Arduino turns on the conveyor belt after a delay of 650 ms (to allow the pulley to release the ball onto the belt). The conveyor runs for 15 s, time needed to roll the ball back to the pitcher. As the conveyor turns on, the pulley system is pushed back into position to be ready for the next pitch.

Sample Student Project: Hot Tea Machine

The goal of this project was to design a machine that, with the push of a remote, makes a hot cup of tea of the user's choosing. Apart from pushing a remote button, the user must load a tea bag of their choice to the servomotor's wing and fill the separate water container from time to time. All other tea-making process functions are automated via the LabVIEW software and DAQ board-interfaced hardware. A hardware I/O interface diagram for the hot tea machine is shown in Fig.

6, consisting of four digital inputs, one analog input, and three digital outputs. A pictorial view of the system is shown in Fig. 7, consisting of the following student-selected sensors and actuators as part of this project: 315 MHz RF transmitter/receiver pair, SPDT snap switch, optical liquid level sensor, RTD temperature sensor, hot water circulation pump, portable immersion liquid heater, and dc servomotor. It is to be noted that majority of these sensors and actuators were used by the students for the first time in this project.

The tea-making process starts with placing a mug (sensed via a snap switch) followed by the tea request signal transmission via the 315 MHz, 4-button key fob. The corresponding 315 MHz toggle-type receiver provides the tea selection (green tea or back tea) signals to the myDAQ board via two digital inputs. Next, the single-point infrared emitter/detector liquid level sensor [13] detects an empty mug, accordingly the control logic activates the 12 VDC/2.1 GPM circulation pump to fill the mug with water. The pump is deactivated once the liquid level sensor signals that the desired water level is reached. The 120 VAC/300 W immersion liquid heater is then turned on to heat up the mug water to the user selectable temperature (typically 80^{o} C). Once the desired water temperature is reached (sensed using a 100 Ω Platinum RTD), power to the heater is turned off. This is followed by the LabVIEW control logic outputting a “high” signal to an Arduino UNO digital pin, activating the Arduino code for tea bag up/down motion implemented using a dc servomotor. Arduino code for the servomotor automates the tea-dipping process by dipping the tea bag four times and then draping the tea string over the edge of the mug.

Successful operation of the water pump was a challenge to be solved. At a rated voltage of 12 VDC, the pump would pump out the water with too much force, splashing water outside of the mug and into the work area. To fix this, applied voltage was reduced to 5 VDC. Additional features implemented to achieve a reliable pumping setup included priming the pump’s tubing, vertical positioning of the water storage container, and vertical positioning of the tubing within the mug to avoid overflow issue.

The LabVIEW front panel for the hot tea machine is shown in Fig. 8. The front panel features LEDs to help the user understand where the system is in the process. The system status LEDs include user tea selection (green or black), mug presence/absence, and mug water level status. The user can also enter the desired water temperature for tea (typically 80^{o} C), and observe the increasing water temperature numerically as well as graphically. The LabVIEW code is based on functions such as *for loop*, *case structure*, *formula node*, and *local variable*. Water temperature calculation was based on the analog voltage received from an RTD-based voltage divider circuit. Digital inputs included RF receiver outputs, snap switch circuit output for cup presence/absence, and mug water level sensor output. Various digital output signals were generated within the code for controlling the pump, water heater, and the Arduino/servomotor tea bag motion control system.

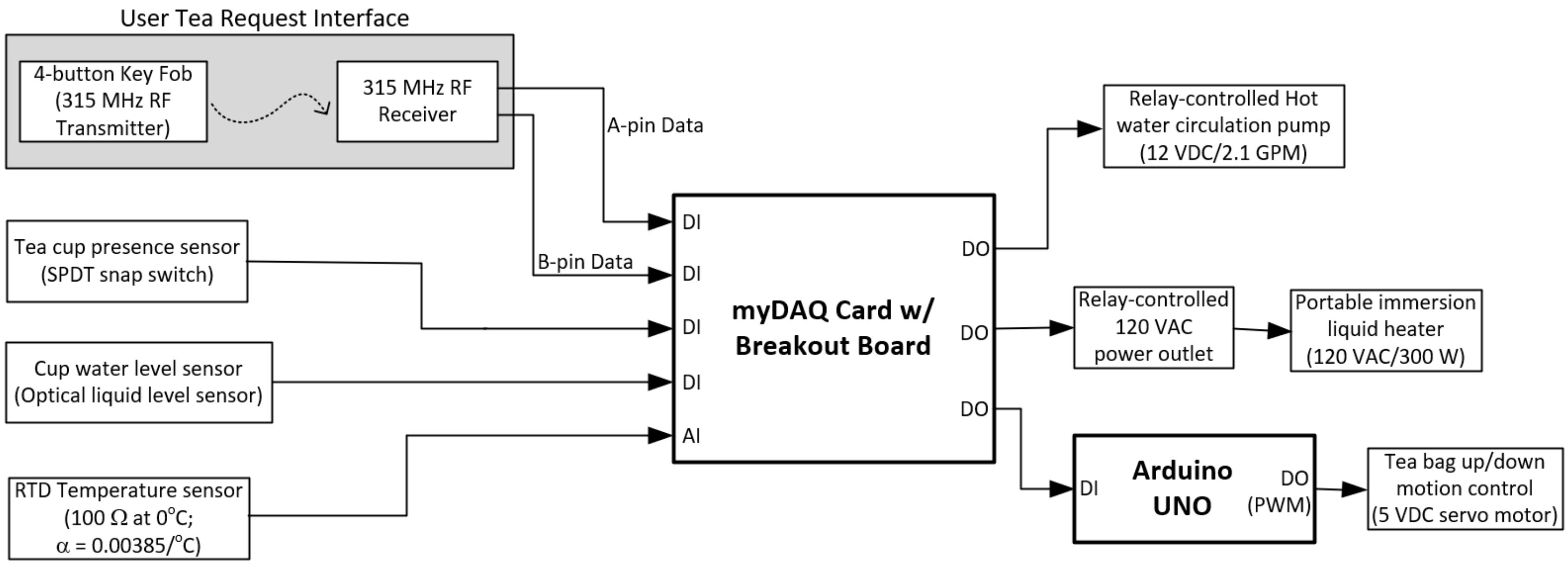


Fig. 6. I/O interface diagram for the hot tea machine.

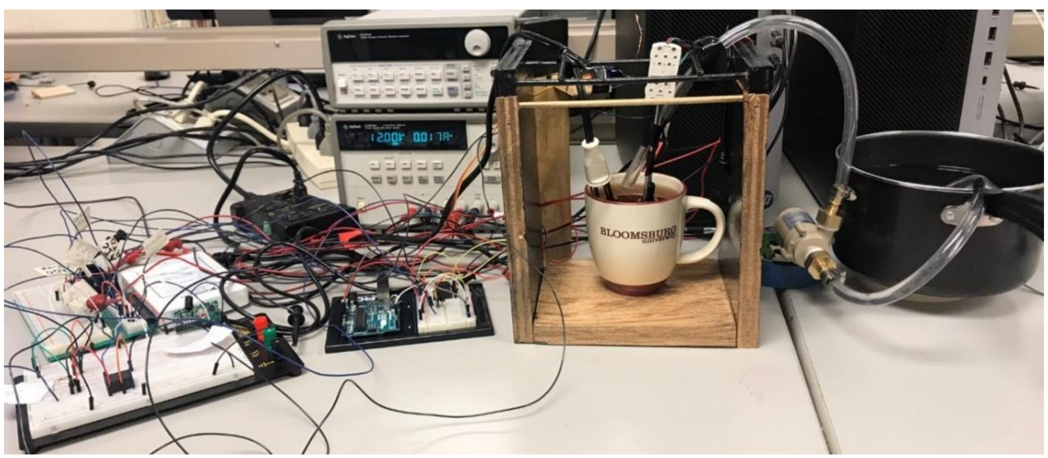


Fig. 7. A pictorial view of the hot tea machine.

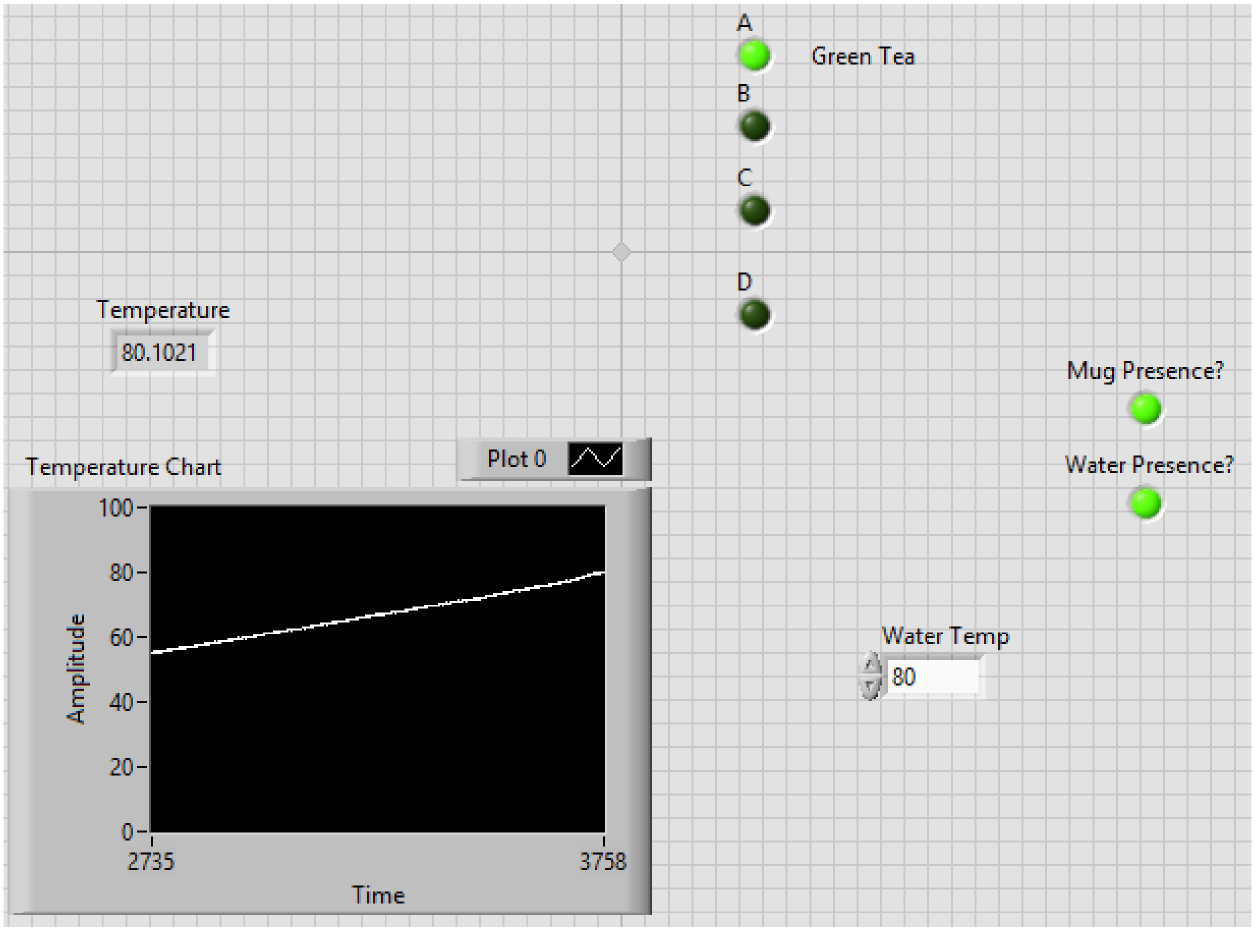


Fig. 8. LabVIEW front panel for the hot tea machine.

Course Assessment

Direct assessment of student outcomes for the project experience was conducted using several instruments, including the project proposal, project evaluation rubric, final report rubric, and project presentation rubric. These assessment data were evaluated to generate action items to be implemented during the next offering of the course project experience. This feedback process is part of the EET program's continuous improvement process that directly improves student learning. Example action items generated based on fall 2019 instrumentation systems project experience are discuss advanced timing features of LabVIEW, provide more guidance on hardware development, emphasize the importance of effective work distribution among team members, include a weekly progress report requirement, and require a timed practice presentation before the formal presentation. These action items will be implemented during the fall 2021 offering of the course.

In addition to direct assessment, ABET-ETAC Criterion 3 student outcomes [8] for the end-of-semester project experience were assessed indirectly via student survey. Results of the indirect assessment for fall 2019 offering are shown in Table 3.

Table 3. Indirect assessment data for Criterion 3 student outcomes.

Criteron 3 Student Outcome		**Level of Attainment?**									
		Pre-ENGTECH 241 (N = 9)					**Post-ENGTECH 241 (N = 9)**				
		E	**G**	**S**	**U**	**(E+G) [%]**	**E**	**G**	**S**	**U**	**(E+G) [%]**
1	An ability to apply knowledge, techniques, skills and modern tools of mathematics, science, engineering, and technology to solve broadly-defined engineering problems appropriate to the discipline	0	2	5	2	**22**	4	5	0	0	**100**
2	An ability to design systems, components, or processes meeting specified needs for broadly-defined engineering problems appropriate to the discipline	0	0	5	4	**0**	2	7	0	0	**100**
3	An ability to apply written, oral, and graphical communication in broadly-defined technical and non-technical environments; and an ability to identify and use appropriate technical literature	2	2	2	3	**44**	2	4	3	0	**67**
4	An ability to conduct standard tests, measurements, and experiments and to analyze and interpret the results to improve processes	0	4	5	0	**44**	7	2	0	0	**100**
5	An ability to function effectively as a member as well as a leader on technical teams	0	6	1	2	**67**	5	2	1	1	**78**

(**E**: Excellent, **G**: Good, **S**: Satisfactory, **U**: Unsatisfactory)

It can clearly be observed that from the students' perspectives this course contributed significantly in improved attainment of student outcomes 1, 2, 3, and 4. Attainment improvement for outcome 5, however, was marginal. Overall, emphasis needs to be placed in improving students' soft skills in the areas of written/oral communication and teamwork. Apart from supporting Criterion 3 student outcomes, the PBL-based course offering also contributes to meeting the Criterion 5 (Curriculum [8]) and applicable Program Criteria [8] requirements such as project management, public safety, professional and ethical responsibilities, and quality and continuous improvement.

Student Comments

The process of developing, implementing, and testing a project from scratch for the first time was a valuable experience for most students. The majority of students were pleased with the project management structure, though a few suggested that the project duration be extended to four weeks (instead of the currently allocated three weeks), to help them transition into the semester-long capstone design course offered the following academic year. Qualitative feedback from students is presented below through their comments:

- ✓ This course pushed us to learn from our mistakes
- ✓ Able to develop systems with a few basic sensors and actuators
- ✓ Gained enough knowledge with various components in different applications to consider myself an EET student
- ✓ Most enjoyable class (the first design-oriented course experience)
- ✓ Hardware and software integration was challenging at times, but thoroughly enjoyed
- ➢ Focus more on hardware
- ➢ Give more examples of similar problems
- ➢ Include advanced LabVIEW features in lab experiments

Conclusion

Experience with integrating project-based learning into an instrumentation course was presented. A few students struggled in defining the structure of their teamwork at the beginning of the three-week project period. It was also observed that students did not have prior experience through coursework in designing, debugging, and testing a system with multiple functional blocks, which contributed to their difficulty in breaking the design into functional modules and designing and testing them separately before putting them together. Improving student competence in this area will be a goal for the next offering of the course. Overall, the experience has been very rewarding and challenging for the students as well as the instructor. Assessment-generated action items will be implemented for the next offering of the course, and additional assessment data will be collected from future offerings as part of the program's continuous improvement plan.

References

1. J. D. Lang et al., "Industry expectations of new engineers: A survey to assist curriculum designers," *Journal of Engineering Education*, pp. 43-51, Jan 1999.
2. W. Stone and H. Jack, "Project-based learning integrating engineering technology and engineering," *Proc. ASEE Annual Conf.*, 2017.
3. G. Figgess and R. Vogt, "Building career-ready students through multidisciplinary project-based learning opportunities – A case study," *Proc. ASEE Annual Conf*., 2017.
4. J. Song and D. Dow, "Project-based learning for electrical engineering lower-level courses," *Proc. ASEE Annual Conf.*, 2016.
5. R. Ulseth et al., "A new model of project based learning in engineering education," *Proc. ASEE Annual Conf*., 2011.
6. A. Shekar, "Project based learning in engineering design education: Sharing best practices," *Proc. ASEE Annual Conf.*, 2014.
7. R. Liu and J. Zhu, "Personal epistemology: The impact of project-based learning," *Proc. ASEE Annual Conf.*, 2018.
8. "ABET-ETAC criteria," 2021. Accessed: Nov. 1. 2021. [Online]. Available: https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-technology-programs-2019-2020/.
9. J. L. Colwell et al., "Tools for using course-embedded assessment to validate program outcomes and course objectives," *Proc. ASEE Annual Conf*., 2004.

10. S. R. Kolla and D. Border, "ATMAE to ABET accreditation: An assessment transition in an electronics and computer engineering technology program," *Proc. ASEE Annual Conf.*, 2016.
11. National Instruments, "NI-myDAQ device specifications," July 21, 2019. Accessed: Nov. 1, 2021. [Online]. Available: https://www.ni.com/pdf/manuals/373061g.pdf.
12. AutomationDirect, "SS series photoelectric sensors," n.d. Accessed: Nov. 1, 2021. [Online]. Available: https://cdn.automationdirect.com/static/specs/pe18mmss.pdf.
13. Cynergy3 Components, "Optical liquid level sensor," 2012. Accessed: Nov. 1, 2021. [Online]. Available: https://www.cynergy3.com/sites/default/files/product-data-sheets/OLS5.pdf.

Biography

BISWAJIT RAY received his BE, MTech, and PhD degrees in Electrical Engineering from University of Calcutta (India), Indian Institute of Technology-Kanpur (India), and University of Toledo (Ohio), respectively. He is currently the director and a professor of the ABET ETAC-accredited Electronics Engineering Technology program at Bloomsburg University of Pennsylvania. Previously, he taught at University of Puerto Rico-Mayaguez and designed high-reliability aerospace electronics at EMS Technologies in Norcross, GA. Dr. Ray is active in power electronics consulting work for various industrial and governmental agencies.