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Integration of Active Learning Framework in an Instrumentation Course to involve Junior Level Engineering Students in Multidisciplinary Research Projects

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Abstract

The ENGE 380 (Instrumentation) course offered to the engineering students at the junior level at the University of Maryland Eastern Shore (UMES) provides the basic foundation for the interdisciplinary domain of sensors, instrumentation, and data acquisition that permeates almost all scientific and engineering endeavors. Project efforts integral to the course offer an opportunity to the primary author to expose interested students to the experiential learning and research efforts ongoing at the campus under his leadership that are aligned with sustainability-related initiatives of the National Institute of Food and Agriculture (NIFA), earth and space science mission objectives of NASA, and the broad educational experiences for students in a land grant minority-serving campus. To provide hands-on learning experiences the students are introduced to a popular microprocessor board with add-on sensors & actuators kit to complement the course lectures. Students receive guidance with the basics of the microprocessor board and its peripherals for analog and digital inputs and outputs. As an integral component of the project, the students are encouraged to participate in extramurally funded project efforts collaborating with doctoral students in the Food Science and Technology (FDST) graduate program in the areas of mechatronics for smart farming and digital agriculture. This paper will provide an overview of the ENGE 380 course and the project efforts integrated with the fall 2021 offering of the course. In particular, the paper will highlight the instrumentation and data acquisition efforts undertaken by interested students to investigate the charging patterns of solar and wind turbine setup that powers a 3 axis farming robot installed in a tunnel house over a 10 ft. by 20 ft. raised bed, as well as an autonomous precision ground robot under development in the campus for collecting photo-synthetically active radiation (PAR) data at selected way-points under the crop canopy. ABET learning outcomes and assessment efforts that are in alignment with the course will also be presented.

1.0 Introduction

Most engineering programs have integrated an instrumentation-related course as part of their curriculum [6]. Instrumentation is an expansive field that is relevant for all data-driven scientific and engineering projects that involve measurements, monitoring, and feedback control. Depending on the instructor and curricular emphases the course content varies. Instrumentation (ENGE 380) course is a required course for all engineering majors for the ABET-accredited “General Engineering” program at UMES which provides specialization options to the students in the traditional areas of electrical, mechanical, aerospace, and computer engineering. The course is offered to engineering juniors and draws upon pre-requisite knowledge of computer programming, electrical, and mechanical engineering fundamentals of a spirally bound curriculum [7] with a broad emphasis. Interested readers can visit the URL Instrumentation Course Syllabus Fall 2021 to peruse the course outline. The course provides an overview of sensors and instrumentation and the critical role it plays in characterizing physical phenomena and process monitoring as well as feedback control. Fundamentals of electricity (DC and AC) and electronics as well as engineering mechanics and thermal sciences are revisited in the context of specific sensing devices, their design, error analysis, and calibration. Class discussions are also held related to computational tools for data recording, display, signal, and control using Arduino Sketch, EXCEL, MATLAB, and LABVIEW software environments. Historically the course has been developed as a 3-hour lecture course and is followed by an Instrumentation Control Lab (ENGE 383). In the broader context of the course, demonstrations are provided by the aviation faculty in the department (engineering program is integral to the Department of Engineering and Aviation Sciences at UMES) related to aviation instrumentation and airplane instrumentation panel, graduate students in the Food Science and Technology (FDST) program provide an overview of instrumentation aspects of ongoing multidisciplinary research efforts in smart farming and precision agriculture[9] led by the primary author, and the UMES laboratory manager to cover basics of voltmeters, ammeters (including the clamp ammeters), oscilloscopes, Vernier calipers, etc. Experiential and active learning components are integrated with the course using popular microprocessor-based sensors and actuator kits and simulation tools. The course objectives have some overlaps with all of the 7 outcomes listed by ABET in the Criteria 3 of the new accreditation guidelines [8] but put more emphasis on the last three.

2.0 Course Assessment

The fall 2021 offering of the Instrumentation (ENGE 380) course was presented in a hybrid format. Most of the classes, exams, as well as project presentations were conducted in person but other than the first and last two weeks one of the three one-hour class periods was held online using “Blackboard Collaborate Ultra”. Two of the three quizzes offered during the semester were implemented online using the ‘lockdown browser’ and ‘respondus monitor’. It has been generally observed that when all classes were held online during the peak period of the pandemic the integrity of the assessment process was compromised. In fall 2021 as we transitioned to in-person learning, adjustments were made to enhance the integrity of the assessment process. Although homework was assigned every week, the 10% of the grade aggregated for the homework was based on a few unannounced quizzes on selected days when the homework was due. The hands-on project component was structured to include a dimension of learning seldom captured by exams. Although the class participation (10%) and project components (15%) of the grade were relatively small compared to the 2-class exams (20 % each) and the final (25%), the exams included questions related to the project implementation to augment the emphasis on active learning [9]. The assessment of the project assignment provided extra credit options to encourage students to participate in experiential learning and research efforts ongoing at the campus under the leadership of the primary author as outlined in the following section.

3.0 Project Assignment for fall 2021 Instrumentation (ENGE 380) course

The project assignment was provided to the students in the first week of classes in early September. Students could work in teams and provide a plan and update on September 30 and turn in the final report by December 6th. The class periods for the last week of classes were reserved for project presentation and demonstration. For ready reference, the project assignment can be perused at the URL Instrumentation ENGE 380 Project Assignment (Fall 2021). The rubric used for assessing the presentations is available at the URL Rubric for Project Assessment Instrumentation course (ENGE 380) for interested readers. The required components of the projects included:-

(i) Working with an Arduino UNO microprocessor board kit with a few sensors and actuators (Figure 1).
(ii) AC and DC Circuit simulation using PHET simulation software and verifying hand calculations with virtual voltmeters and ammeters in the simulation environment https://phet.colorado.edu/en/simulation/legacy/circuit-construction-kit-ac-virtual-lab
(iii) Familiarizing themselves with the sensors and instrumentation on board some of the NASA satellites deployed to collect earth science data (NASA/JPL Earth Now https://climate.nasa.gov/earth-now/#/) and providing a written summary as part of the project report.

Besides the required components the course students were also encouraged to participate (with extra credit incentive) in ongoing experiential learning and research projects under the leadership of the primary author aligned to the sustainability initiatives supported by NIFA and Maryland Space Grant (NASA) that parallel the land grant mission objectives and educational goals of the university.

In the next few paragraphs, the required components of the project assignment are elaborated with examples of student work in fall 2021. Some of the extra credit efforts undertaken by a few of the course students are also highlighted.

Figure 1: Grove Starter Kit for Arduino

(i)Although the students were allowed to work in teams of 2 if they chose to, all students were provided with a kit and were required to familiarize themselves with all components of the kit, interface the sensors and actuators and get familiar with the Arduino microprocessor board and the digital and analog input-output pins and Arduino IDE. Once they were familiar with all aspects of the kit they were required to come up with a plan of integrating as many of the sensors and actuators in the kit and if appropriate acquire additional sensors and actuators (not more than $15 / team) with the permission of the instructor to develop a novel demonstration project that illustrated the knowledge they acquired during the exercise, as well as their creativity in coming up with innovative ideas and executing them. The Grove shield that was integral to the kit allowed students to connect all components to the microprocessor board with four-wire connectors that came with the kit, without any need for soldering. In keeping with the notion of a spirally bound curriculum students had to use and reinforce their knowledge of computer programming, digital logic, basic circuits, and engineering mechanics that they acquired in courses in freshman and sophomore years to execute the Arduino related component of the project. For brevity only a couple of examples of Arduino projects developed by the students are provided below (Figures 2 and 3):

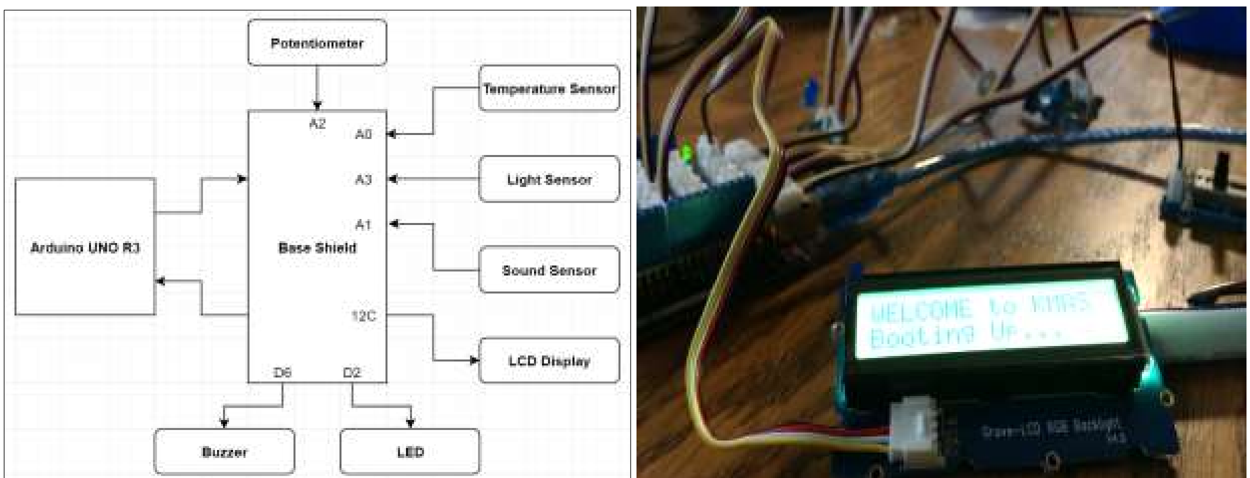


Figure 2 : Monitoring and Alarm System with 4 Sensor Inputs, Buzzer & LED outputs, and LCD Display

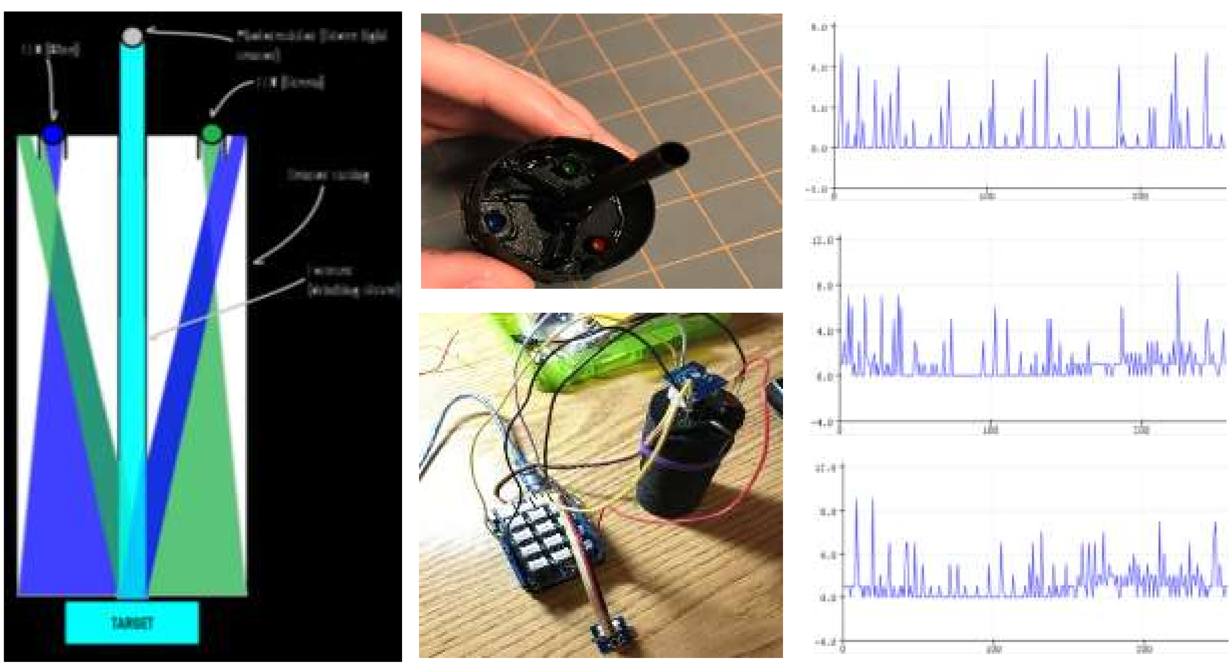


Figure 3 : Rudimentary Reflective Spectrophotometer using red, blue, green LED and light sensor

In Figure 2 a student project is illustrated. In this project, 4-analog sensor inputs from a potentiometer, temperature sensor, light sensor, and sound sensor that are provided with the kit are wired to the Arduino microprocessor board using pins A0, A1, A2, and A3. When the levels of sensor inputs or combinations reached predetermined levels, LED light and sound buzzer wired to digital ports D2 and D6 are activated through appropriate coding. Also, an LCD screen element provided with the kit was interfaced using an I2C port to the Arduino and was programmed to display appropriate text related to the status of the alarm system and sensor levels.

Figure 3 describes a student project for the course that attempted to develop a rudimentary reflective spectrophotometer. A toilet paper roll and straws were used to develop the casing and the guides for the red, green, and blue LEDs that were turned on to be reflected off of target surfaces and detected by a photoresistor (light sensor). A button switch was also used to activate the set-up using a digital input. The LEDs, light sensor, and button switch were all part of the kit. The sample data profiles shown(Figure 3) were reflected signals captured by the light sensor for a

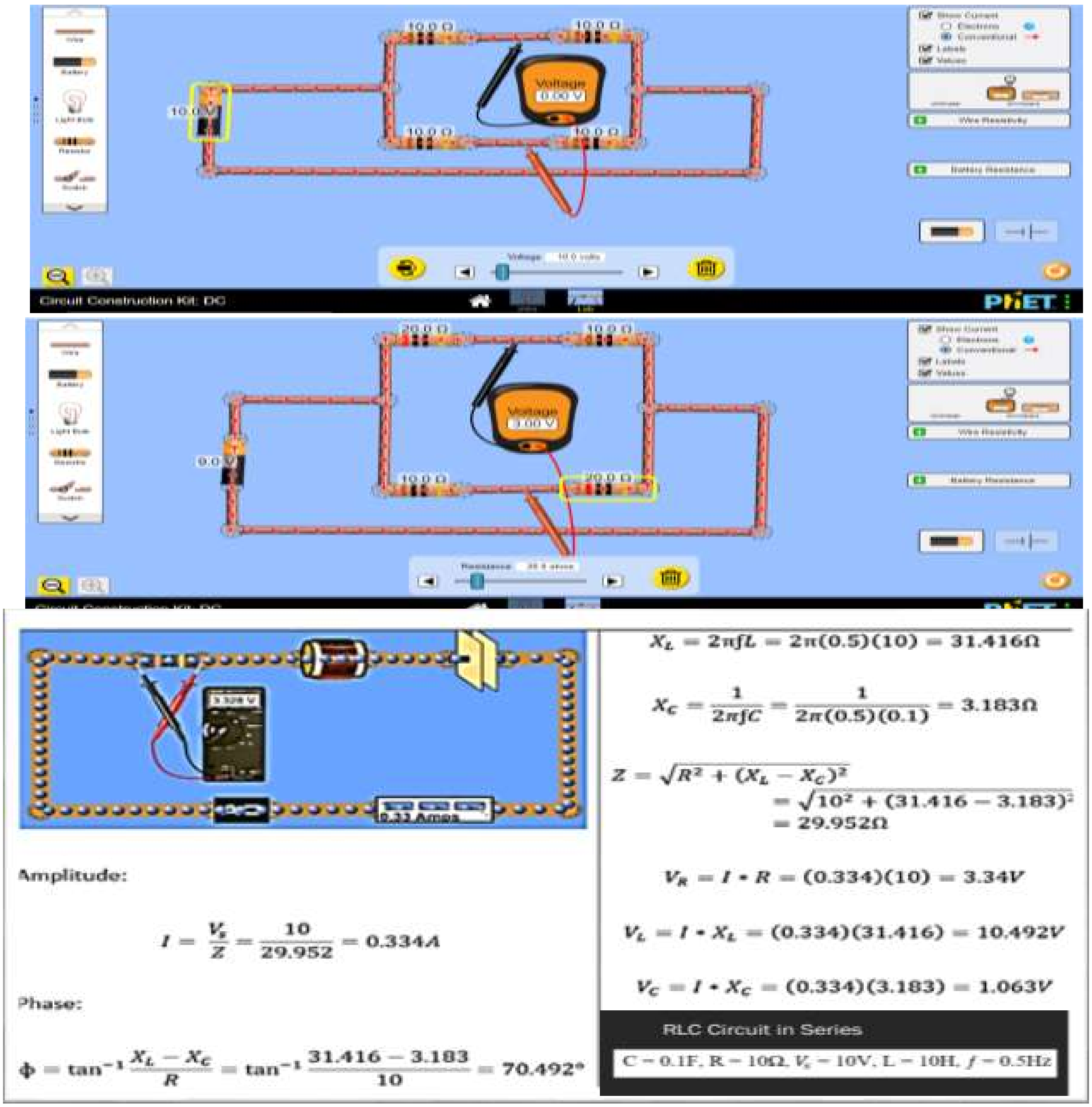


Figure 4 : Examples of PHET circuit simulations (balanced bridge, half bridge, and AC RLC seriies circuits)

post-it note, printer paper, and red foam piece used as targets and displayed on the serial monitor by the Arduino. From a scientific point of view, the setup has several shortcomings but provided a unique learning experience for the participants.

(ii) Although basic circuits and the associated lab is a pre-requisite for the course, in keeping with the overlaps of content in a spirally bound curriculum, reinforcement of some of the electric circuits fundamentals was found to be beneficial for the students. Project assignments involving DC circuits (resistors in series and parallel, as well as Wheatstone Bridge circuit simulations) and AC RLC series and parallel circuit simulations using the PHET platform and the virtual voltmeters and ammeters integral to the environment helped clarify some of the misconceptions and allowed students to verify hand calculations with the appropriately inserted ammeter and voltmeter readings by way of active learning and experimentations. In Figure 4 samples of student work for balanced bridge and half-bridge DC circuits and a series RLC circuit AC circuit simulation and the corresponding calculations submitted as part of the project, assignment is shown. It may be noted from the figure, that the color-coding of the resistors matches the resistance values of 10 Ω (brown, black, black, and gold) for all bridge resistors for the "balanced bridge" circuit as indicated by the voltmeter reading of '0' Volts. The 20Ω resistor color code (red, black, black, and gold) for two of the "half-bridge" resistors and the corresponding voltage reading of '3' Volts is also readily observed. Students could readily verify these values using hand calculations using DC series and parallel resistor circuits. The hand calculations for AC circuits with resistor, capacitor, and inductor in series also match with the simulation results observed using appropriately inserted virtual voltmeters and ammeters (Figure 4). In the interest of brevity examples of other DC and AC circuit simulations are not included here.

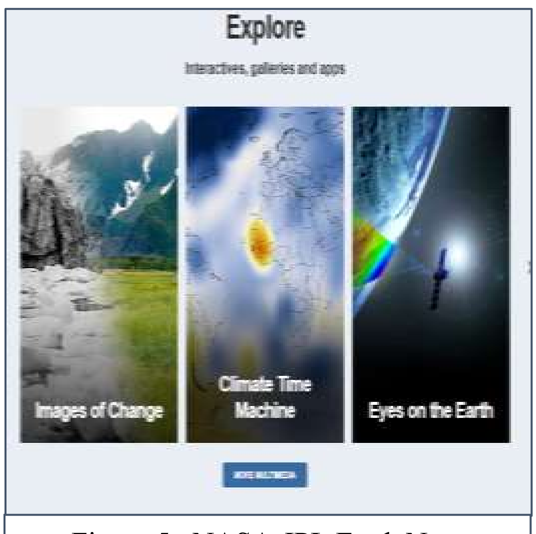


Figure 5 : NASA-JPL Earth Now

(iii)UMES campus is less than 40 miles from NASA Goddard Space Flight Center's Wallops Flight Facility. NASA scientists and engineers particularly with the Instrumentation and Science branch engage with UMES engineering and aviation science students as part of their outreach efforts. The NASA/JPL Earth Now App not only provides an excellent overview of NASA's efforts in collecting earth science data from instruments deployed on various satellites but also a window into some of the summer internship opportunities related to earth and space sciences. As part of the project assignment, the students were required to explore the NASA Earth now App and Website and observe the "vital signs" related to climate science displayed on the spherical model of the earth. Each project team was assigned to acquire as much knowledge and understanding of three selected earth-observing satellites and the onboard instrumentation including passive and active sensors for data gathering.

Besides the required components of the project as delineated and illustrated above, the primary author also encouraged registered students in the course to participate in extramurally funded project activities supported by NIFA and Maryland Space Grant Consortium(NASA) in the broad areas of smart farming and robotics. As outlined in the project assignment students could choose to participate in any of the listed activities to earn extra credit for the project and the overall course. Not all the students chose to undertake the extra credit options but a few of them who did and had significant contributions are included as co-authors along with a graduate student in the food science and technology (FDST) doctoral program who worked closely with them. The FDST

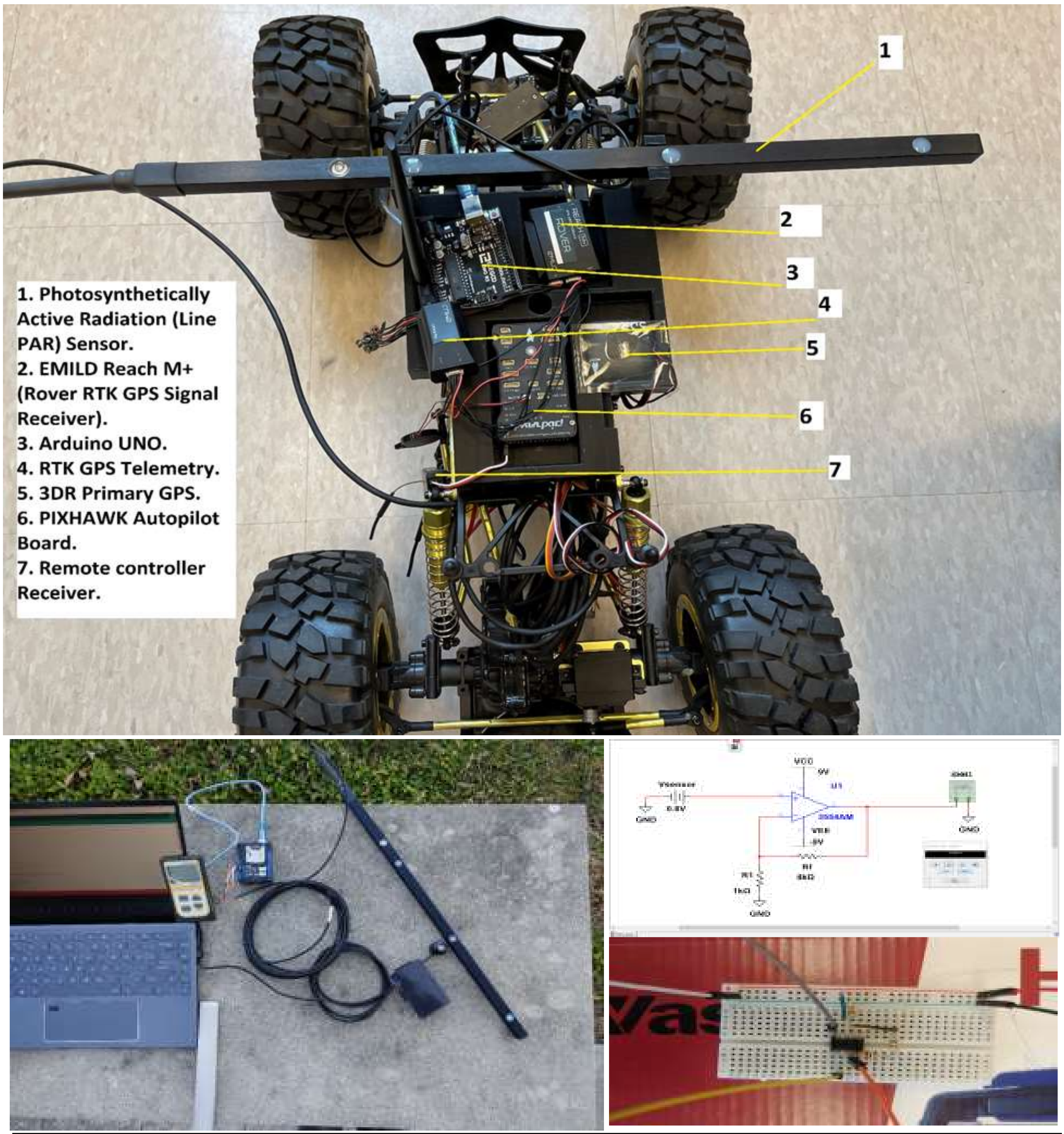


Figure 6: Unmanned Ground Vehicle(UGV) Assembly Plans for Navigation and PAR Data collection

graduate student is currently involved in developing an unmanned ground vehicle (UGV) that is to navigate under crop canopy to collect Photosynthetically Active Radiation (PAR) data (Figure 6). The UGV will use the Pixhawk Auto Pilot board (https://px4.io/autopilots/) for autonomous navigation to specified waypoints accurately utilizing Real-Time-Kinetic(RTK) GPS(https://store.emlid.com/product/reachm-plus/). The UGV frame is borrowed from Exceed RC Rock Crawler $1/8^{th}$ scale 4 Wheel Drive (https://www.nitrorcx.com/rc-electric-rock-crawler.html). The PAR data will be logged with corresponding GPS location data on an SD card data logger interfaced with the Arduino UNO microprocessor onboard the UGV. One of the undergraduate students in the course was entrusted to assist the FDST graduate student with calibrating a Quantum APOGEE Photosynthetically Active Radiation(PAR) Line with 3 sensor elements (https://www.apogeeinstruments.com/sq-313-ss-sun-calibration-original-line-quantum-with-3-sensors/). The scope of the undergraduate project was to consult the online manufacturer's manual (https://www.apogeeinstruments.com/content/SQ-100-300-manual.pdf) and interface the analog sensor output which ranged from 0-800mv to an analog input port (10 bit) of Arduino UNO and use the appropriate calibration to convert the signal to appropriate PPFD

Figure 7 : The FarmBot, Solar and Wind Power Data Acquisition and Analysis Project

(Photosynthetic Photon Flux Density) units of μmol/m^2.s. During the calibration, the student team also compared the output of the line sensor as displayed on the serial monitor output of the Arduino to a pre-calibrated handheld PAR sensor that was provided to them.

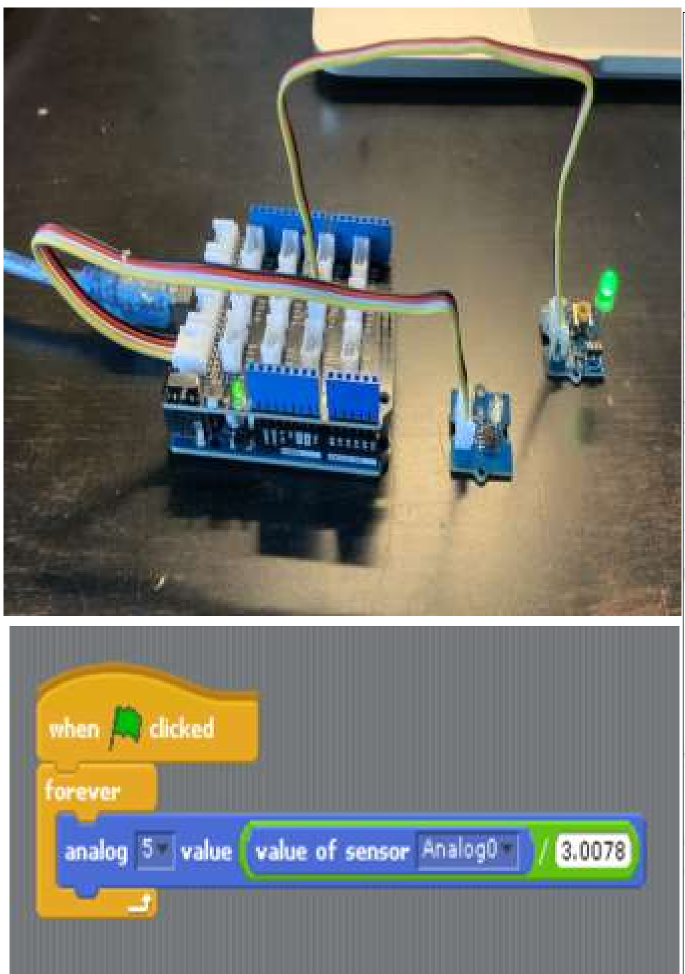
The student team also put together a non-inverting operational amplifier circuit (that was covered in the course lectures) to magnify the 0-800 mv sensor output to a range of 0-4V with an amplification factor of 5 with an appropriate circuit as shown in Figure 6 to improve sensitivity and accuracy. The logistics of mounting the amplifier circuit on the UGV is complicated and may not be used in the final setup, however, the exercise provided a relevant learning experience and advanced the overall project goals.

The smart agriculture project team utilizes a FarmBot (3-axis farming robot capable of seeding, weeding, irrigation, soil moisture measurement, time-lapse photography, and other related tasks autonomously) set up in an outdoor tunnel house and an indoor one that uses LED grow lights. The outdoor set-up is powered by a small wind turbine (~400 Watt) and solar panels (~400 Watts). The FDST graduate student utilizes the platform for small-scale field experiments for his dissertation work and it also provides an educational and experiential learning platform at the nexus of food, energy, and the environment [10]. The study of the charging pattern of the storage battery vis-à-vis solar radiation and wind pattern is of interest to the FarmBot project team.

Interested undergraduates in the ENGE 380 were given the option of working with the FDST graduate student to assist with instrumentation and diagnostics efforts for the FarmBot as well as to set up a system to record wind and solar charging patterns and relate the data to local wind and solar radiation data. Figure 7 shows the FarmBot set up in a tunnel house and the solar and wind power setup and all of the instrumentation that was used by the student team in fall 2021 associated with the FarmBot project. Two students from the ENGE 380 course in the fall of 2021 assisted the FDST graduate student with the preliminary instrumentation efforts for the FarmBot-related renewable energy data analysis project as their extra credit option to enhance their project and overall course grade. The student team was assigned to collect the charging pattern data for the storage battery and correlate the information with the data records at the local weather data repository at the URL https://www.wunderground.com/dashboard/pws/KMDPRINC15/table/2021-09-16/2021-09-16/daily. During the course of their engagement with the project, the students used the Fluke Digital Ammeter and Logger to measure and log the amount of current flowing into the storage battery from the solar panels and wind turbine. They also measured the current utilized by the FarmBot and an exhaust fan in the tunnel house that was wired to the battery through an inverter system with a digital clamp meter. A battery tester was also used to ascertain the health of the battery. When the wind and solar radiation were low and the batteries were drained during trials with the exhaust fan or FarmBot, a battery charger was used to charge the battery and a battery meter gauge was wired up to indicate and record the percentage charge level. A 'Kill-A-Watt' electricity usage monitor was used to note the total amount of power consumed by all connected equipment individually as well as together. During the course of their work, the students also got to use an analog DC power supply to diagnose a faulty/burnt inverter and a digital 12 Volts DC power supply to test a faulty water pump that is used by the FarmBot to autonomously irrigate the 10 by 20 ft raised bed planted with peanuts for fall 2021.

It should be stated here that some of the issues of accurately recording charging pattern data and correlating them with the local wind and solar data are yet to be fully resolved and some students will continue to look into accomplishing the original goals of the project in spring 2022 and beyond. However, the students readily acknowledged that involvement with the overall effort provided them with valuable hands-on experience in using various instrumentation, meters, and gauges.

As outlined in the project assignment all students in the ENGE 380 course were to demonstrate the use of S4A (http://s4a.cat/ Scratch for Arduino) along with the other Arduino-related component of the project. Downloading of S4A firmware and installation on the microprocessor board and sample coding were demonstrated in the class. However, some students had Covid-related issues and anxieties and felt they had limited time to work on this. Scratch is an educational program developed in the MIT multi-media lab (https://scratch.mit.edu/). S4A is based on Scratch and allows simple icon-based programming of the Arduino open-source hardware platform and provides blocks similar to Scratch for managing sensors and actuators connected to Arduino. Some of the student teams however did manage to do some preliminary work on S4A. A sample student project using an LED light and a light sensor included in the kit provided to the students is shown




```
int lightSensor = A0;
int LED = 6;
int lightValue = 0;
int LEDvalue = 0;
void setup() {
  // put your setup code here, to run once:
pinMode(lightSensor, INPUT);
pinMode(LED, OUTPUT);
Serial.begin(9600);
}

void loop() {
  // put your main code here, to run repeatedly:
  lightValue = analogRead(lightSensor);
  LEDvalue = (lightValue/3.0078);
  Serial.println("Light Sensor Value:");
  Serial.println(lightValue);
  Serial.println("LED Light Value:");
  Serial.println(LEDvalue);
  analogWrite(LED, LEDvalue);
  Serial.println();
  delay(1000);
```

Figure 8 : Arduino with LED and Light Sensor and the Sketch Code and equivalent S4A code

in Figure 8. The light sensor senses the ambient light level and writes a proportional analog value to an analog output port (in Arduino this is a PWM port that allows a digital pin on the Arduino to be configured as an analog output using the PINMODE set up). The 'Firmware' for S4A sets up the Arduino pins appropriately and the documentation has to be read carefully to understand the settings so that the Scratch codes developed in S4A execute appropriately.

4.0 Conclusion

Learning can be categorized into developing skills in three broad domains - cognitive, affective, and psychomotor. Higher education typically focuses largely on the cognitive domain following Bloom's taxonomy – knowledge, comprehension, application, analysis, synthesis, and evaluation [11]. ABET outcomes for engineering education integrates developing student abilities in both the affective and cognitive domain. While lecture-based instruction is essential from the point of view of delivering content knowledge that is considered appropriate in an engineering curriculum, blending active, cooperative, and problem-based learning with course lectures reinforces the development of higher-order skills of application, analysis, and synthesis. In lecture-based instruction the teacher is active and students are passively listening and trying to take notes and comprehend the material being taught. In the context of the Instrumentation course (ENGE 380) which the students take after basic circuits and associated laboratory, it has been generally observed by the primary author that there are some fundamental conceptual problems among many students. Laboratory courses are often touted as a vehicle for active learning, however, discussions with students have revealed that structured laboratory exercises in the basic circuits lab had shortcomings in helping them develop circuit analysis skills and appropriate use of ammeters, and voltmeters, oscilloscopes, and, other laboratory instruments. Some students in the ENGE 380 course have indicated that the class and project-based active learning exercises with PHET AC and DC circuit simulations followed by hand calculations to verify results displayed by virtual scopes and meters, helped remove some of the gaps in their knowledge effectively.

Sensor technologies and data acquisition related to instrumentation and measurements for monitoring and control have exploded in recent years, and it is virtually impossible to provide an expansive overview through lectures. However, hands-on active and team-based cooperative learning with the Arduino kit not only allowed the students to understand the basics of data-acquisition fundamentals, sensor calibration processes, analog, and digital input-output basics but also reinforced some of their programming skills in C++ that were introduced to them in a sophomore-level programming class. Discussion with students revealed that programming logic came more easily to them when they processed the structure of the code for the output they wanted to observe in the physical domain. The higher-order synthesizing skills of the students were also brought to bear with the open-ended creative project with the Arduino kit. The ABET learning outcomes related to teamwork, analyzing and interpreting data, and self-directed acquisition of new knowledge was facilitated by the problem-based learning exercises and project assignments.

Lastly, the extra credit options allowed the undergraduate students to get involved with ongoing extramurally funded experiential learning and research projects and provided them some flavor, albeit limited, of the relevance of the course material in the broader context. Also, in a limited way, the extra credit-driven involvement of the undergraduate students advanced the goals of the ongoing funded projects led by the primary author and provided support to the graduate student engaged in the efforts delineated. The activities also provided a window into the broad overlaps of NASA's earth and space science undertaking, sustainability efforts of NIFA, the land grant mission of the campus, and their common educational objectives and workforce development goals.

5.0 Acknowledgment

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Bibliography

1. Loker, D. R., & Strom, S. A. (2019, June), *Innovative Laboratory Projects for a Measurements and Instrumentation Course* Paper presented at 2019 ASEE Annual Conference & Exposition, Tampa, Florida. 10.18260/1-2—32967
2. Habibi, C. (2019, June), *Integrating Internet of Things (IoT) in the Measurements and Instrumentation Course* Paper presented at 2019 ASEE Annual Conference & Exposition, Tampa, Florida. 10.18260/1-2--32987
3. Smith, J. A. (2014, June), *Inductive Learning Tool Improves Instrumentation Course* Paper presented at 2014 ASEE Annual Conference & Exposition, Indianapolis, Indiana. 10.18260/1-2—20631
4. Craig, R. R. J., & McConnell, E. (1999, June), *Virtual Instruments Revitalize An Undergraduate Measurements And Instrumentation Course* Paper presented at 1999 Annual Conference, Charlotte, North Carolina. https://peer.asee.org/8045
5. Dannelley, D., & Bryner, E. (2020, June), *Fundamental Instrumentation Course for Undergraduate Aerospace and Mechanical Engineering* Paper presented at 2020 ASEE Virtual Annual Conference Content Access, Virtual Online. 10.18260/1-2—34696
6. Muff, D., & Heindel, T., & Sundararajan, S. (2006, June), *Demonstrating Electromagnetic Noise In An Undergraduate Measurement And Instrumentation Course* Paper presented at 2006 Annual Conference & Exposition, Chicago, Illinois. 10.18260/1-2—493
7. Lohani, Vinod & Mallikarjunan, Parameswarakumar & ML, Wolfe & Wildman, Terry & Connor, J. & Muffo, John & Lo, Jan & Knott, Tamara & Loganathan, G.V. & Goff, R. & Chang, M. & Cundiff, John & Adel, Giana & Agblevor, Foster & Gregg, M.H. & Vaughan, David & Fox, Edward & Griffin, H. & Mostaghimi, Saied. (2005). Work in progress - Spiral curriculum approach to reformulate engineering curriculum. *Proceedings - Frontiers in Education Conference*, FIE. 2005. F1D - 1. 10.1109/FIE.2005.1612007.
8. ABET, "Criteria for Accrediting Engineering Programs, 2020 – 2021" Available Online: https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2020-2021/

9. Hernández-de-Menéndez, M., Vallejo Guevara, A., Tudón Martínez, J.C. et al. Active learning in Engineering Education. A Review of Fundamentals, Best practices and Experiences.
International Journal of Interactive Design and Manufacturing 13, 909–922 (2019). https://doi.org/10.1007/s12008-019-00557-8
10. Nagchaudhuri, A., & Pandya, J. R., & Mitra, M., & Ford, T. (2020, June), Education and Research at the Nexus of Food, Energy, and Water with a 3-Axis Farming Robot Paper presented at *2020 ASEE Virtual Annual Conference* Content Access, Virtual Online. 10.18260/1-2—34492 https://peer.asee.org/34492
11. B.S. Bloom. (1984). Taxonomy of Educational Objectives. 1. Cognitive Domain. New York, Longman.