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RESEARCH

Mitigating Engineering Student Attrition by Implementing Arduino Activities Throughout Undergraduate Curricula

Dolores De Groff, Ph.D.[1]

[1] Electrical Engineering & Computer Science, Florida Atlantic University

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One of the most challenging aspects of engineering education is to engage and motivate the student audience. Studies have found that roughly 40 percent of students planning engineering majors end up switching to other subjects or failing to get any degree. Indeed, American students are turning away from science and math. There are not enough graduates in engineering to meet US workforce demands. Many students enroll in engineering undergraduate programs with the belief that the coursework would include components immediately, and build early in the undergraduate coursework, and when they do not have these hands-on fun and challenging experiences, students select alternative majors. Starting with introductory engineering courses, students should be immediately exposed to hands-on fun and challenging competitive projects. Teaching Arduino in the framework of fun competitions should capture the interest of prospective future engineers and support the engagement and retention of students. This paper is written to outline relevant pedagogical prospects.

Introduction

This research work will determine if requiring students to work on engineering projects and having competitions among themselves can be used to increase engagement of undergraduate students entering Engineering disciplines and lead to retention and measurable and lasting learning gains. This research work focuses on the development of findings on how students learn fundamentals of engineering, and successful models for the instructors teaching the course. The research also focuses on implementing Arduino projects in the Controls Lab to aid in retention and graduation of students in the major.

Described is an innovative approach to engage undergraduate engineering students by having them participate in engineering projects involving Arduino and having competitions among themselves. Initial findings show these playful and creative competitions create a context for learning that cuts across ethnic, cultural, and socio-economic boundaries. This paper describes pedagogical methods used to increase engagement of undergraduate students entering Engineering disciplines and lead to retention and measurable and lasting learning gains. Arduino was chosen for this task due to its ease of use, relatively low cost, and because simple Arduino projects are fun and easy to make. The Arduino board allows connections to be made through its pins to control things such as lights, motors, etc. The heart of any Arduino board is a microcontroller. The microcontroller can be thought of as "a little computer on a chip." The microcontroller has 28 pins and fits into a socket on the board.[1]

Arduino can easily be used with most computers such as Windows PC, Mac, Linux PC, etc. The Arduino communicates with a computer over USB. The first step would be to download the software from the official Arduino website or use the Arduino Cloud. Many schools also offer "cloud" computing; and this greatly facilitates learning. The Arduino software can be loaded into the school "cloud". Arduino projects are wonderful for beginning engineering students because there are many fun competitive projects that can be completed without students really knowing the complex details of what is going on when a sketch is uploaded to the microcontroller. Beginning students can have exposure to these hands-on fun and meaningful Arduino engineering projects. Likely, this will engage and motivate students to continue engineering studies to find out more about "what's going on under the hood."

Literature Review

From a global perspective the "...United States is falling behind other nations in the production of total STEM degrees. Of the 5 million first university degrees (e.g., undergraduate degrees) awarded globally in S&E in 2008, students in China earned about 23%, European Union students earned about 19%, and U.S. students earned about 10%".[2] And this trend of the U.S. "failing to adequately educate and nurture its domestic students and workers" has continued since even before this time period.[3] There were some gains U.S. students made in mathematics proficiency in the past years, but these gains have been erased by the pandemic. The Covid-19 pandemic and resulting disruptions to education has "led to substantial declines in the mathematics performance" of students.[3] China is now the "top producer of Science & Engineering doctoral degrees, total S&E publications, and international patents".[3] "China is a formidable competitor in technology areas critical for national security such as Artificial Intelligence, semiconductors, quantum computing, and biotechnology".[3] It should also be noted that the United States is highly dependent on foreign talent in emerging technology areas.

Quite a few engineering freshman and sophomores often decide to switch majors to a non-engineering discipline. Studies have found that roughly 40 percent of students planning engineering and science majors end up switching to other subjects or failing to get any degree.[4] One of the reasons is that there continues to be high failure rates in introductory courses, especially in mathematics. Despite the nation's growing population, the number of recipients of bachelor's degree in mathematics, engineering and the physical sciences from United States universities has remained constant.[5] Baby boomers, who hold nearly a quarter of STEM jobs requiring a bachelor's degree or higher, are currently retiring. This means young Americans will need to fill these positions. However, American students are turning away from science and math. Furthermore, it is projected STEM fields will become one of the fastest growing occupation clusters in the country.[6] Currently, there are not enough graduates to meet US workforce demands.

At Florida Atlantic University College of Engineering and Computer Science, of the 450 students recruited yearly, only approximately 300 students remain after their freshman year. According to the student feedback received from academic advising staff, many students have difficulty being successful in the mathematics and physics courses. Many students enroll in engineering undergraduate programs with the belief that the coursework would include components immediately, and build early in the undergraduate coursework, and when they do not have these hands-on fun and challenging experiences, students select alternative majors.

The required introductory engineering courses can be perceived as abstract, out of context, and difficult rather than foundational, especially for those students demonstrating deficiencies in pre-calculus, calculus, and/or physics. Math and physics are seen as impediments rather than a supportive pathway to being able to design, construct, and "tinker" in the various engineering areas of interest. Engineering content is structured to front load content for two years before students experience engaging laboratory activities that relate to their interests and prior knowledge.

Students spend approximately 50% of the hours they are awake, 7.5 hours/day, consuming and learning from various avenues of popular culture/social media. Compare this to the 3 hours/day average college class time or 3.5 hours/day for secondary schools.[7] Thus, most actual cognitive learning activities are from pop-cultural/social media rather than educational institutions. "...educational designers who wish to foster learning and understanding should incorporate learners' prior knowledge as a design principle".[8] That is, learning outcomes improve when students have a context for learning that is framed within their own experience. Also, discipline-based education research (DBER) scholars have found that effective instruction involves a range of approaches, including making lectures more interactive, having students work in groups, and incorporating authentic problems and activities.[9]

Due partly to a plethora of outside stimuli from social digital media, today's freshman engineering students may no longer be engaged or impressed by previous classical activities such as the outdated Egg Drop, Mousetrap Car, or simple soldering activity. Today's students become bored easily, turning even more to digital social media for entertainment. To grasp the attention of freshmen engineering students, instructors must consider methods that promote high engagement from the student and improve student motivation.

One such approach is the use of gamification. Almost all have prior knowledge of competitions and racing. Having the students complete a race competition combined with the project design and building of an Arduino smart car enhances the freshman engineering course by making it like a game with the winner being the one who completes the specified tasks in the fastest time.

In an article from the Harvard Education Letter in 2005 titled *The Classroom of Popular Culture* author James Paul Gee examines gamification as a learning instrument. The article explains that players customize their learning, choose the level of risk that is comfortable, improvise, innovate, explore their options, solve problems through multiple pathways, practice to improve, understand the other players' specializations, learn from these players, and use failure as a learning tool, all within a context of "pleasurable frustration".[7]

"Many in higher education have embraced gamification due to its relevance for teaching and learning because students are expected to think critically in order to solve problems, game-like simulations can be leveraged in any discipline to reinforce real world application of concepts.[10]

"In essence, the student is hooked by the idea of the game, pulled forward by curiosity to learn more or win, and ends up enjoying the experience, becoming engaged in the idea or activity and opening themselves up to the possibility of learning".[11]

Most math and engineering instruction is delivered to students in a manner analogous to a consumer of information– teach it and they will learn – also known as "stand and deliver" lecture style. While some students may benefit from this instructional style, many students encounter difficulty. Frequently students do not retain the information or are not able to apply it outside of the classroom. To develop deeper long-lasting connections, students need to apply the concepts learned repeatedly and connect contextually. Furthermore, students often do not value these challenging experiences as useful, irrespective of the deeper pathway and cognitive abilities learning these concepts may bring. Higher education plays an important role in developing intellectual and creative attributes. There is much current research that shows hands-on activities are much more beneficial than a passive approach to learning (reading and listening). For example, in the Freshman Fundamentals of Engineering course, reading about Arduino and their use in robotics is vastly different than actually building an Arduino smart robot car. Reading and being taught about STEM topics such as Arduino builds a foundation for comprehension. However, hands-on experience builds upon that and deepens the understanding of concepts.[12,13]

One vehicle to attract women, minority and otherwise disadvantaged students into Engineering is through presenting engineering as a competitive challenge as in sports. That is, teaching the Fundamentals of Engineering course (as well as other courses) in the framework of fun competitions should have the potential to increase student engagement and learning among all students. Some studies have shown that more “women shy away from competition and men embrace it”.[14] Certain studies have found that men and women respond differently to competitive environments.[14] To overcome this obstacle that some women may prefer not to compete, it is important to choose activities and projects where men and women can perform equally well. The competitions need to be made fun and without any obstacles that would put women at an unfair disadvantage. For example, an activity where strength also affected if someone would win the competition should be avoided. An example of an activity which should be avoided would be the design of concrete frisbees if the competition involved how far the frisbee could be thrown because of the advantage most men would have over women. However, the Arduino activities and Arduino Car Race are more suitable and are fair competitions for all.

Recent research work[15] also finds that STEM students who took a project-based mini course on the campus of a world-renowned university were more motivated to continue STEM courses. The researchers involved collected data by administering a short answer survey to participants at the end of the camp.[6] These results agree with data obtained by the author (Student Perception of Teaching Results, SPOT) that students enjoy hands-on activities more than more traditional approaches of perhaps just attending a lecture. This current paper describes using hands-on gamification to motivate students and support student success.

Methods and Context

Use of Arduino in Introductory Courses

As an example, an “Arduino Robot Car” project can be given to students in Freshman Fundamentals of Engineering or similar courses with the goal to engage students and improve learning. This section describes the vision of the Arduino Robot Car activity development in the framework of STEM education. An imaginative thought-provoking game environment is created where future engineers strive to design Arduino Robot Cars to achieve fastest times in an obstacle course race. This activity is suitable for beginning undergraduate engineering students and high school students taking dual enrollment.

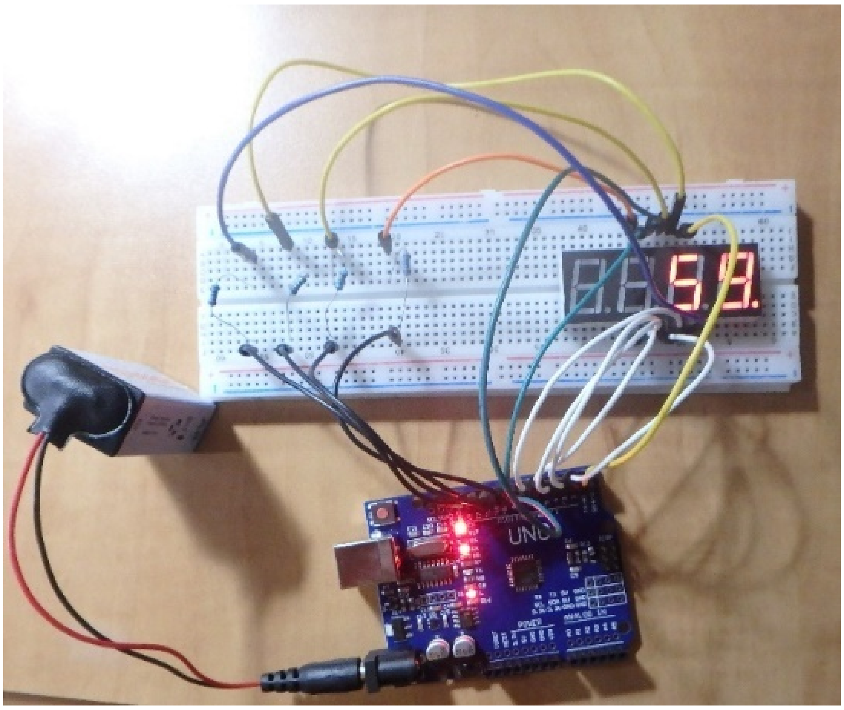

Fig. 1. Arduino Circuit for Counting Seconds

Welcome to Arduino Robot Car Race Day

Race day is the culmination of the Arduino robot car activity. In preparation for this competition, students must first become very familiar with the Arduino board and its use. Students first spend several weeks learning about the Arduino, installing software, adding libraries, and using the Arduino to accomplish some basic tasks. Students learn how to make the Arduino control LEDs, use the Arduino with digital inputs, buzzers, servos, ultrasonic sensors, temperature sensors, IR receivers, and LCD Displays. Students can construct basic circuits with the Arduino. All these activities are designed so that they will be fun for the students, thus increasing student engagement and learning. Arduinos are effectively programed using the C programming language. Students are thus exposed to C and use the language to modify already existing programs. Students will have tremendous satisfaction after making the Arduino activities work successfully. Figures 1 and 2 show the student activities of using Arduino to build a working counter and use Arduino to build a working calculator. A list of preparation labs is given in Table 1.

Once students are familiar with Arduino, students will physically build the Arduino robot car as shown in Figure 3. Then after building the car (which does take dexterity), students improve programming skills by learning how to program the Arduino to be able to control the car remotely. They then need to make the car accomplish obstacle avoidance. The Arduino robot car activity ends with a race competition using line-tracking. At the Race Day event, each student car is given a number label, and a record is kept of the time for each car to complete the race, to make the event contain aspects of a

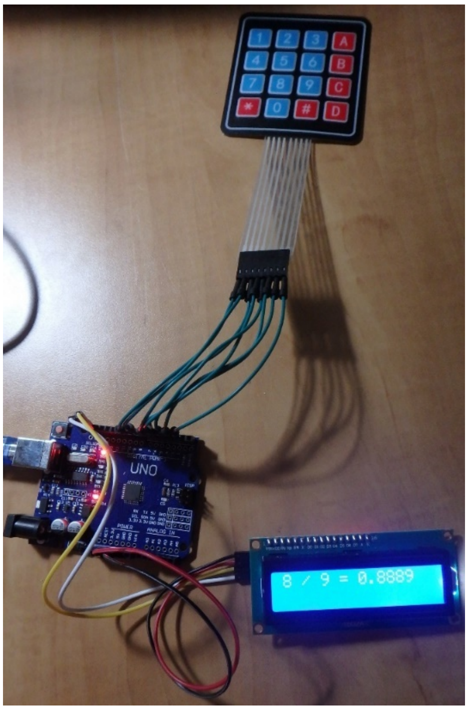

Fig. 2. Arduino Calculator

TABLE 1. ARDUINO PREPARATION LABS

LESSON 1	BLINK, LED, LEDS Stepped Up
LESSON 2	RGB LED, Passive Buzzer, Servo, Ultrasonic Sensor
LESSON 3	Digital Inputs, LCD display, 74HC595 And Segment Display
LESSON 4	Keypad, Calculator, Four-digit Seven Segment Display, Counter, Thermistor

playful competition. In an attempt to win the race, students modify program code, taking into account the car must still be able to track. Some students may choose to 3D print different wheel designs in an attempt to finish the race at the top by increasing vehicle speed.

Results

The author has taught introductory engineering courses for many semesters at Florida Atlantic University (along with many other courses). She has taught the fundamentals course with a heavy emphasis on mathematics and physics, and with no competitive projects for several years in the past. More recently, she is using the competitive engineering project method to teach introductory engineering courses. The feedback from students (survey data collected in the form of Student Perception of Teaching (SPOT) results) has been much more positive when competitive engineering projects are also introduced into the coursework, with a higher percentage of students affirming their desire for further studies in engineering. Table 2 presents student perception of teaching (SPOT) results over several semesters contrasting the older versions of the Fundamentals of Engineering course

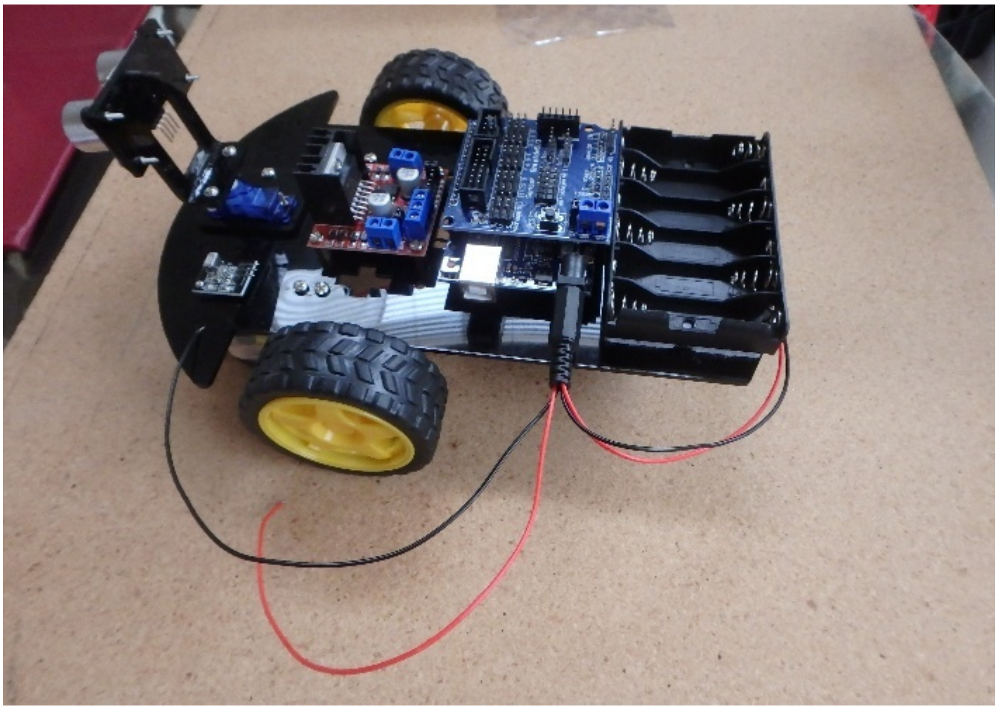

Fig. 3. Arduino Robot Car

to the newer teaching methods of hands-on project competitions. SPOTs are judged by many universities to be an extremely effective tool to evaluate the quality of instruction. For the results shown 1.0 signifies Excellent, 2.0 is very good, 3.0 is good, 4.0 is fair, and 5.0 signifies Poor. The data shows an improvement for the better in student perceptions of the course starting in Fall 2017 when students were given hands-on projects. The SPOT results continued to improve and stay below 2.0 when Arduino projects and activities were given to the students. Each SPOT for the semester shown is a survey of approximately thirty students enrolled in a lab. It should also be noted that a project such as the Arduino robot car is suitable for almost all engineering disciplines. The Arduino car involves electrical and computer engineering for wiring, mechanical engineering for building the car and designing/3D printing appropriate wheels for fast speed. Civil engineering can also be included in the project by having students build a model bridge the car will traverse. Thus, such projects should have an impact on all undergraduate engineering students and high school students taking dual enrollment and will resonate with students and have the effect of increasing student engagement. It should be noted that Florida Atlantic University has received designation as a Hispanic Serving Institution (HIS) by the United States Department of Education. Florida Atlantic University College of Engineering is one of the most ethnically diverse Colleges in America. Therefore, these SPOT results should be taken as coming from an ethnically diverse student body.

TABLE 2. SPOT RESULTS FOR FUNDAMENTALS OF ENGINEERING

FALL 2012	2.48
FALL 2013	2.33
FALL 2014	2.09
FALL 2015	2.33
FALL 2016	2.00
FALL 2017	1.45
FALL 2018	1.17
FALL 2019	1.80
FALL 2020	1.22
FALL 2022	1.60
FALL 2023	1.71

To implement this plan of engaging students through fun competitive activities and projects, the University would provide a computer lab for the course. Also, students would bring their own laptops if they desired. Arduino starter kits and Smart Robot Car kits are commercially available for different price ranges. Students can be charged a lab fee for the needed kits.

Further Discussions

Apart from the use of Arduino in Freshman engineering courses as a motivating tool to continue engineering studies, Arduinos are extremely useful in teaching the main concepts for other courses as well, one of these being Control Systems. The purpose of an Arduino is to "control things" by interfacing with sensors and actuators.

Use of Arduino in Control Systems Course

Arduino can be used to add design projects in any control systems course. It is beneficial to students to have a control lab to go with the classical control system lecture topics. As an example of one of the first control lab activities, students can be asked to control a string of LEDs (as shown in Fig. 4) by changing the corresponding code to manipulate the number of times the string blinks and the wait time between blinks. This would review Arduino concepts and coding and lead the way to more advanced topics.

Arduino can be used to implement many types of controllers. For example, Arduino can be used to implement a proportional (P) controller, a proportional-integral (PI) controller, and to implement a proportional-integral-derivative (PID) controller. A typical Arduino controller (P, PI, PID) could be used to control the brightness of an LED and is a suitable activity for any undergraduate Control Systems lab.

Referring to Fig. 5 above, it is desired to keep the LED at a certain brightness level. This desired response would be the setpoint. It is to be determined how much power the Arduino should provide to the LED to get the desired

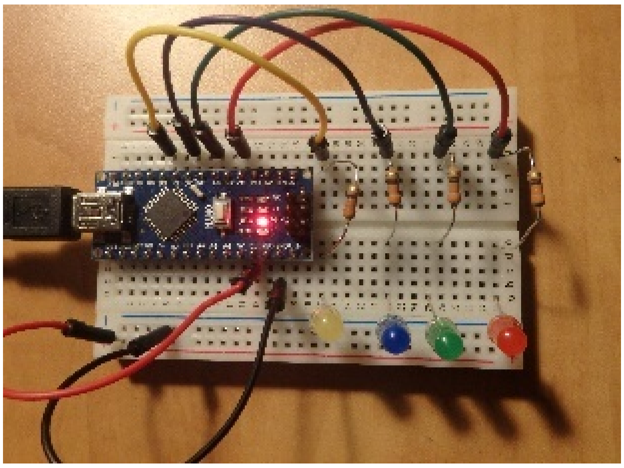

Fig. 4. Arduino Control of LED string

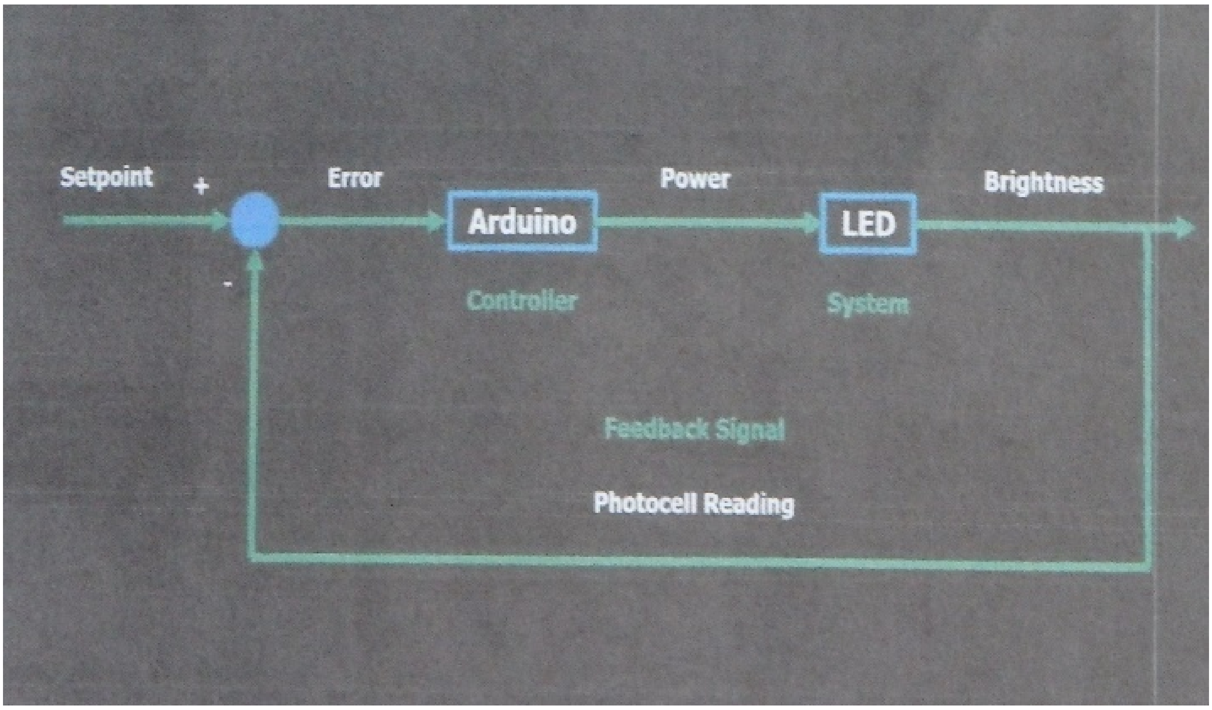

Fig. 5. Arduino Controller

brightness. The photocell is used as a sensor to feed back the current reading of brightness. This value of current brightness is subtracted from the setpoint to get an error. The error feeds back into the Arduino microcontroller to update the power sent to the LED, etc. The circuit students would construct to implement this Arduino control of an LED is very straightforward and along with the Arduino, only two resistors, the LED, and photocell need be used. The corresponding code is modified by the student to implement the controller (P, PI, PID,etc.)

Another fun and easy activity to include in a Controls Lab course is to use an Arduino to drive a stepper motor as shown in Fig. 7. By including a stepper motor activity, students would also experience open loop control where no

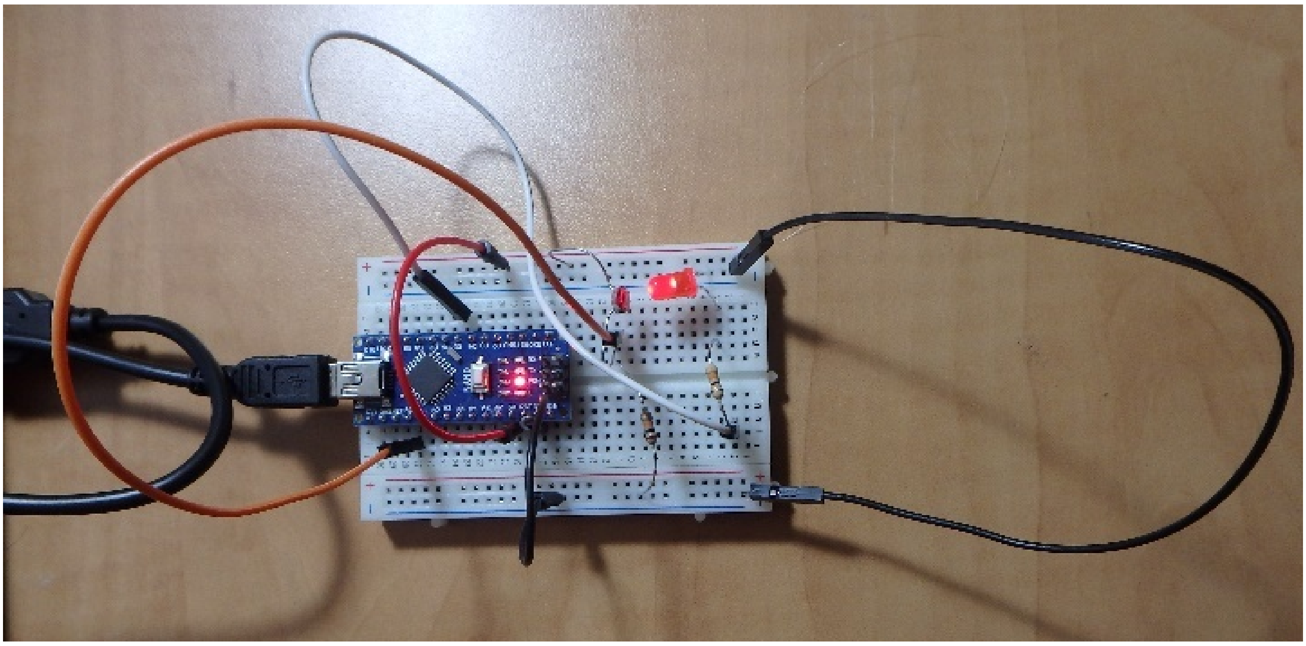

Fig. 6. Control System Using Arduino

feedback information would be needed. Thus, the use of microcontroller Arduino in Control Systems Lab can also be used as a learning tool for students to better understand classical control concepts.

Thus, a similar teaching pedagogy should be used with more advanced undergraduate students taking more advanced courses such as Control Systems Lab. That is, instructors can present engineering as a challenge like a game that should be made fun. The author has experience incorporating Arduino activities as part of the existing Control Systems Lab. Assigning an Arduino project due at the end of the semester seemed to increase student engagement and learning. Students were able to choose their own project to work on; however, it was required that students propose what they would design and get prior approval. For example, projects were required to use at least two sensors, and the proposed design should solve a social or real-life

problem. Students had the opportunity to work on a project that satisfied their interests, making the activity more fun and 'game-like' for them. This teaching method increased student participation and motivation. Table 3 lists Arduino activities that can be added to the Control System Lab. Table 4 shows a comparison of SPOT over several semesters for the Control Systems Lab course. Arduino activities were incorporated in Fall 2020. Note that Table 4 shows a perfect SPOT result for the Control Systems Lab taught in Fall 2022, signifying students perceived the course as an excellent course when Arduino was incorporated and with the end of semester project included. The survey includes approximately thirty students registered in each lab each semester.

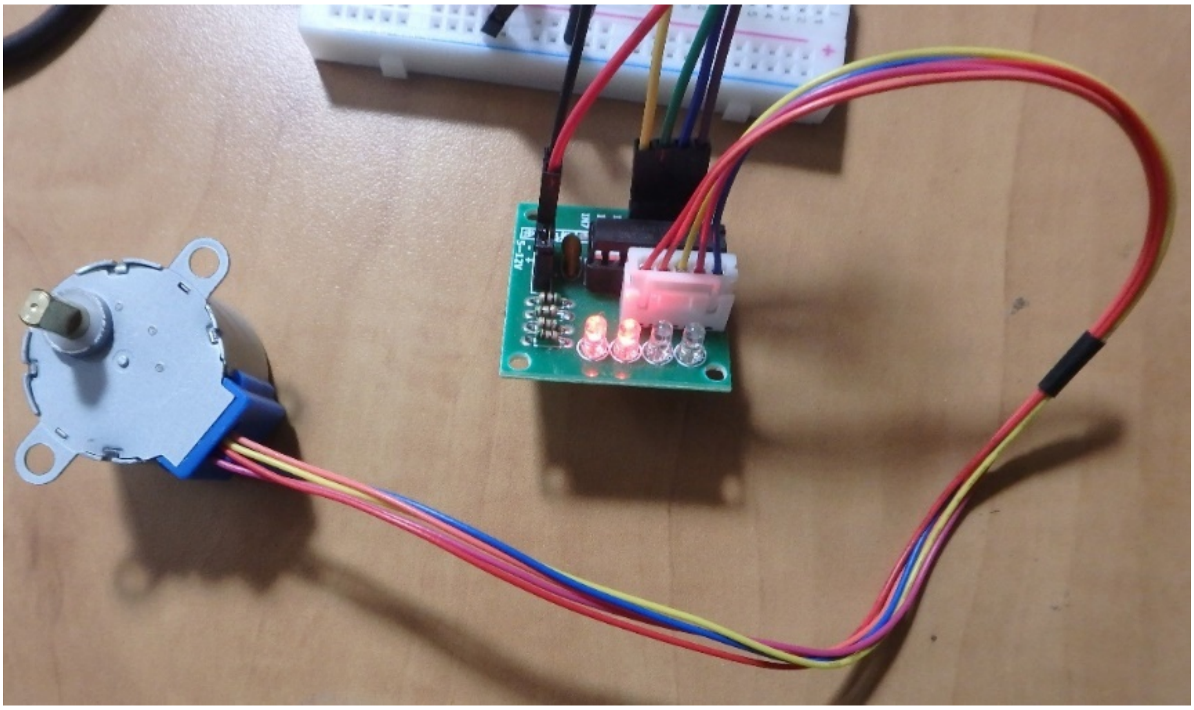

Fig. 7. Stepper Motor Control Using Arduino

TABLE 3. ARDUINO LABS FOR CONTROL SYSTEMS

LESSON 1	Introduction to Arduino and Control System using Arduino
LESSON 2	Implementing a Proportional Control System using Arduino
LESSON 3	Implementing a Proportional Integral Control System and a Stepper Speed Control using Arduino
LESSON 4	Proportional and Integral and Derivative Control System using Arduino

TABLE 4. SPOT RESULTS FOR Control Systems Lab

Spring 2018	3.11
FALL 2018	3.17
FALL 2019	3.20
FALL 2020	1.76
Spring 2021	1.46
FALL 2022	1.00

Conclusion

The present study illustrates the use of an imaginative thought-provoking competitive engineering project environment using microcontroller Arduino in introductory engineering courses as well as more advanced courses such as Control. The author has noticed improvements in engagement of students (from data collected as SPOT) which leads to retention and measurable and lasting learning gains in groups of students exposed to competitive Arduino projects with competitions at the final stage. Contextualizing engineering courses around a framework of fun competitions provides a context for the subject matter that is both well-understood by the target audience and has been empirically demonstrated to engage and motive students regardless of gender, race, or socio-economic background.

This new teaching method envisaged of including playful and creative competitions in engineering courses is designed to engage students. This method addresses high failure rates in physics and math through adding competition-based curriculum. Arduino projects can be used throughout engineering curricula. These projects fill the expectations of students seeking immediate components with fun and challenging hands-on experiences. Math and physics should be viewed as necessities rather than impediments. A competition-based curriculum (viewing the projects as competitive games) sparks interest and delivers immediate component application. It is hypothesized that such interest sparks the imagination and creates motivation for students to become successful in math and physics.

The efficacy of the methods described in this study is reflected in the classroom efforts pursued by the author. The relevant strategy of pedagogy described was adopted at the freshman level (Fundamentals of Engineering course) in the College of Engineering and Computer Science at FAU and at the junior level (Control Systems course) in the Electrical Engineering Department at FAU. The general feedback and learning experience indicated by the students (in SPOT data collected) has been encouraging. More projects and design problems for Arduino are being planned in the near future. Classroom lecture learning can be conveniently coordinated with practical design experiments using Arduino microcontroller throughout engineering curricula to capture the interest of prospective future engineers.

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