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WIP: Utilizing MATLAB in Combination with Lego Mindstorm EV3 Kits for a First-year Engineering Course

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Abstract

This Work in Progress paper will describe attempts at revitalizing a first-year engineering course. Engineering Fundamentals is a freshman course offered for both engineering technology and engineering students at Middle Tennessee State University. Traditionally, this course covers unit conversion, engineering ethics, basic math skills and their applications in various engineering disciplines, and so on without many hands-on activities. This paper discusses the revitalization of this course that combines the usage of the MATLAB with the Lego Mindstorm EV3 robotics kit. In Fall 2022, the course was redesigned to include three components: *(i)* Introduction to MATLAB programming; *(ii)* Using MATLAB to solve math and engineering problems; and (*iii)* Using MATLAB to control the Lego Mindstorm EV3 robot. Throughout the semester, mini labs were introduced to allow students to work and ask questions on different topics, such as basic coding structures, solving math problems, programming sensors, and controlling actuators. All the coding work in the course culminates in a final project where students are provided the freedom to choose a project topic. Sample course projects include robotic sumo battles between teams, projectile launchers, and programmable movement of the robots via external mediums such as a gaming controller.

This paper details how the course was redesigned, the student projects, the results from Fall 2022, and lessons learned in the process. Our ultimate goal is to improve student teaching evaluation and retention. Future work includes: *(i)* Comparing student teaching evaluations and retention rate with those in the recent years; *(ii)* Providing the students with a survey to offer their input as to not only the final project but also the entirety of the course; *(iii)* Utilizing other platforms/robotic kits suitable for freshman engineering students. We hope that this paper can help others who are interested in introducing hands-on activities and real-world applications to freshman engineering courses.

1. Introduction

First-year engineering courses can be difficult to design — they need to be effective at conveying crucial concepts, enjoyable to keep students engaged and interested, and useful to the extent that they provide students with knowledge and skills, offering more opportunities for them in the future. Middle Tennessee State University (MTSU) offers an Engineering Fundamentals course (ENGR-1100) which has been historically mathematics-focused. This is the first engineering-related course students experience at MTSU, and students faced difficult mathematics lectures that ultimately drove numerous students away from the discipline. According to MTSU's course catalog, the Engineering Fundamentals course is described as placing emphasis on problem-solving techniques and the use of mathematics in analyzing technical problems. It mentions a variety of topics that are addressed, including graphical representation of data, estimation, dimensions, units, error estimates, statistics, and teamwork. Additional non-mathematics topics such as engineering ethics and the impact of engineering solutions are also addressed during the course. Students wishing to enroll in the Engineering

Fundamentals course must have successfully passed one of the following courses: College Mathematics for Managerial, Social, and Life Sciences (MATH 1630), Pre-calculus (MATH 1730), or Calculus I (MATH 1910). These prerequisite courses are typically taken by first-year students, depending on their mathematics comprehension upon entering MTSU. Concepts taught in these prerequisite courses are crucial for students to understand any mathematics-related concepts utilized in the Engineering Fundamentals course, albeit addressed via programming.

The old format of the Engineering Fundamentals course was heavily focused on mathematical concepts, beginning with mathematical topics as basic as slope and slope-intercept form equations and continuing as far as complex mathematical topics like systems of equations and derivatives. The purely mathematical approach with a focus on engineering-related topics was heavily disliked by students. The course was taught the same way by prior instructors for years and had the issue of reaching unfamiliar topics, especially for those students weaker in mathematics. Student opinions, based on past course evaluations, mentioned the course content being too mathematical in nature, being too easy or too difficult depending upon the students' mastery of mathematics, and there were complaints about the size of the course based on the lecture style and content covered. This old format was ultimately in need of an update, leading to the course revitalization discussed in this paper. We wanted students to gain more interest in engineering and engineering technology, which could further improve student academic performance as well as enrollment. We want our students to be provided with an exciting entrance into the department while offering them the tools and experience to help them succeed. This is done through the introduction of programming via MATLAB and interfacing MATLAB software with the Lego Mindstorm EV3 robot.

The remainder of this paper is broken down into four primary parts. Section 2 reviews related works in literature. Section 3 discusses the methodology for revitalizing the course. Section 4 shows the results of our revitalization efforts in Fall 2022 and how evaluations are conducted. Section 5 concludes and discusses our future work.

2. Literature Review

A commonly held opinion amongst educators is that not all students learn the same way. The most basic form of this idea, according to [1], is that sensory involvement can impact learning, such as implementing activities that involve visual, auditory, or tactile activities as well as any potential combinations of the three.

The teaching styles of the instructor or educator can also impact the ability for students to learn. While taking into consideration traditional methods of teaching, the focus is placed upon the instructor who follows a set curriculum with topics arranged in a linear fashion to meet pre-determined goals set forth for the course by the school or university [2]. This common lecture style is referred to as a “transmission approach,” one which most educators are familiar with because it is the general norm among academics according to Osborn and Nag [2]. However, they believe that a constructivist approach is more conducive to learning, because it removes the focus from the instructor and instead places it upon the student, allowing students to form their own questions about topics, develop their own interpretations, and collaborate with their peers

[2]. Osborn and Nag claim that this approach aligns better with both Maslow's Hierarchy of Needs as well as Bloom's Taxonomy of Thinking, and though limited in their exploration of these approaches, they have seen promising preliminary successes.

When specifically discussing first-year engineering courses, it is important to consider factors beyond teaching and learning styles, such as the ability of students to build relationships with their peers. Research from Sorby, Monte, and Hein focuses on developing a common first-year engineering program at Michigan Technological University. While some of the desired changes to the schedule and curriculum lagged, such as the integration of multiple disciplines into this common first-year plan, they did introduce methods of grouping students together to allow them to familiarize themselves with their peers and build relationships [3]. An example is the concept of block scheduling, where students would register for defined set of classes, meaning they would consistently be surrounded by their peers taking the same courses. While they did also provide non-blocked schedule options for non-traditional students, the focus on building peer-to-peer relationships was more heavily emphasized on the block-scheduled courses [3]. Students could be introduced to topics in a more comfortable and familiar environment, also easing the ability to conduct group projects and develop crucial teamwork skills. The students themselves were surveyed regarding the benefits of the first-year design and were cited as mentioning that the benefits included increased computer usage, teamwork, and opportunities to work in interdisciplinary teams [3].

If we consider the implementation of these ideas in a first-year engineering course, such as the importance of teamwork, developing peer-to-peer relationships, and moving away from a transmission teaching approach and towards a constructivist approach, a commonly proposed solution is the integration of robotics kits into course assignments. This has been approached with various kits, programming platforms, and teaching methodologies. A commonly occurring kit is the Lego Mindstorm-branded robotics kit. Steadman, Jefferson, Thomas, and Hsiao from the University of South Alabama introduce a very selective approach to which incoming students may participate in a summer engineering course based on reaching a specific grade point average and ACT threshold [4]. This selection process resulted in a sample of 130 students being selected though only 24 students opted to participate. This work used a combination of the Lego Mindstorm robot with LabVIEW software during a two-week program, during which time students were immersed in team-based experiences while learning how to both develop their robots and write their own code to make the robot operate. The session concluded with an open-ended final project allowing the students freedom to select their own designs while also showing a culmination of what they learned during the entirety of the summer session [4].

This is not dissimilar to the approach taken by Mehrubeoglu from Texas A&M University who also utilized the Lego Mindstorm robotics kit for a major course project. Her focus was placed more heavily on the varying backgrounds of students, rather than having a strict selection process, developing four primary project topics of varying difficulty levels [5]. This allowed students freedom in the sense that they could select their own topic while also providing avenues for students to challenge themselves. The teams were heavily controlled by volunteer peer leaders which were those individuals with some previous experience using the Lego Mindstorm robot. They were made aware of certain issues plaguing their course, because there were

disconnects between instructor-student understanding, like a heavy focus placed on concept maps which students struggled to grasp, though the students ultimately wavered in their participation due to the fact that the project only accounted for 5% of student grades which many deemed negligible considering the condensed time frame of three weeks which they were given [5]. Consecutive attempts at using this project did reconcile these concerns by both increasing the project's weight on overall grades as well as adding an additional week to the timeline for students to complete the project.

Some other universities have offered similar first-year engineering courses utilizing different platforms. Arduino is a common choice because of the product availability and capacity for students to gain hands-on experience that would benefit them in the future when joining the workforce according to Belfadel, Rodriguez, Zabinski, and Munden [6]. The work of Jaksic, Li, Maestas, and Rothermal involves a demonstration using the Robotis Premium Bioloid kit from the Korean manufacturer Robotic, Co., Inc. The demonstration focused on a humanoid robot design having 18 degrees of freedom because of the number of included servo motors and the complexity of the humanoid robotic design [7]. This kit, while costly when compared to cheaper alternatives like a Lego Mindstorm robotics kit, also provides a more complex medium with which students can gain hands-on robotics, design, and programming experience. Note that this work by Jaksic, Li, Maestas, and Rothermal is primarily based on a demonstration set up by higher-level undergraduate and graduate students to entice new students while also testing their abilities [7].

We elect to use the Lego Mindstorm Robot instead of alternatives because our students lack the programming and circuits-related coursework at this point in their education to use alternatives like Arduino. Various sensors included in the Lego Mindstorm EV3 kit can observe phenomenon such as color, orientation and rotation, infrared and ultrasonic signals, and touch. These kits also include multiple motors and capabilities of manipulating an LCD screen and various lights. Some universities opt to utilize Lego Mindstorm robots in courses as part of workshops and competitions [8][9][10]. Some universities have fully integrated different iterations of Lego Mindstorm platforms into course design, though they tend to rely heavily on Lego's proprietary ROBOLAB software suite [11]. We rely upon MATLAB because it is user-friendly, has intuitive package management, and can be easily interfaced with the Lego Mindstorm EV3 robot. Our literature review only found a single source similar to our work utilizing both the Lego Mindstorm EV3 robot in combination with MATLAB software as a way to introduce students to programming basics [12]. In contrast, we present the fundamentals of programming prior to introducing the robots, allowing students time to grasp concepts before complicating codes with unfamiliar sensors. In addition, several future courses at MTSU utilize MATLAB heavily, and we believe that introducing the software to the students at this point could benefit them in their future study.

3. Methodology

The revitalized version of the Engineering Fundamentals course, which was first taught during the Fall 2022 semester, can be broken into three major sections: *(i)* Programming fundamentals; *(ii)* Solving mathematical problems using MATLAB, and *(iii)* Programming a Lego Mindstorm

EV3 robot with various sensors using MATLAB. The first part was necessary because Engineering Fundamentals is a first-year engineering course, and most students lack a background in programming. There is an assumed level of mathematics comprehension based on the prerequisites, and the second part let us re-address some mathematical topics in a programmatic manner. Finally, we utilize Lego Mindstorm EV3 robotics kits in the last part to provide hands-on experience to the students by asking them to build robots, write code, and interface with motors and various sensors.

Programming basics were a crucial component that needed to be taught prior to addressing any other topics, because otherwise students without the background would lack the tools to be successful in the course. The course currently uses MATLAB's built-in programming language which shares similarities with a few different programming languages including C, C++, and Python. MTSU's engineering and engineering technology students typically take a Computer Science programming course that focuses on one of the aforementioned programming languages, though it tends to be either after their first-year or concurrently with the Engineering Fundamentals course. Due to time constraint, we had to cover MATLAB programming topics at an accelerated rate at the beginning of the course to give students the necessary understanding of foundational coding concepts to be successful. Assignments during this phase of the course are geared towards introducing basic coding concepts like data types, variable declarations, logical and looping structures, text printing and formatting, and basic arithmetic operations. The remainder of the course builds upon this foundational knowledge.

The programming introduction is followed by the mathematics portion of the course. However, rather than replicating the same work students would perform in a math class, we approach mathematics with programming. Topics addressed during the mathematics phase of the course include unit conversions, linear and quadratic equations, systems of equations, and complex numbers. These concepts are not overwhelmingly challenging for students that have taken one of the prerequisite courses. The students apply the programming fundamentals from the first phase of the course to solve mathematical problems. Certain MATLAB toolboxes, comparable to libraries in other languages, were necessary to download, such as the symbolic math toolbox, though these are included free with the students' MATLAB licenses.

The final phase of the course introduces the Lego Mindstorm EV3 robotics kit which MTSU rents to students enrolled in the course to be returned at the semester’s conclusion. While Lego provides their own software to operate the robot, to practice MATLAB programming, students are asked to download MATLAB's hardware support package that allows for the interfacing of the Lego Mindstorm robot with MATLAB. Continued usage of MATLAB provides students with a consistent, comfortable environment that they will be much more familiar with at this point in the semester. This phase of the course is broken down into lectures and team projects involving the color sensors, orientation and rotation measurements with a gyroscope, infrared and ultrasonic signals, and touch sensors. The color sensors are used to determine different color wavelengths, providing the user with the name of the color detected. The gyroscope determines rotation angle and speed on a two-axis plane. Infrared and ultrasonic sensors detect the distance between the sensor and an object up to a component-dependent maximum distance which is typically around two meters. Touch sensors are used to detect contact with an object. Students

are also taught how to program and manipulate motors, LCD screens, and lights, all of which are part of the Lego Mindstorm EV3 kit.

The major project of this course begins once students have completed all assignments related to the different components in the Lego Mindstorm kit. This project is left to the students' discretion, as they worked with their groups to decide upon their own topic. Note that project topics had to be approved by the instructor to both ensure an appropriate level of difficulty and avoid too much overlap between different groups' projects. Some groups had difficulties deciding upon their own topics, at which point some ideas were offered to assist them, but by allowing students freedom of project topic, they could be as creative as possible. The primary requirement is that the project incorporate three of the major sensors or devices included with the Lego Mindstorm robot kit. Most teams utilized motors in some way, with teams tending to use these in combination with the gyroscope for steering applications and either the color sensor or ultrasonic sensor in combination with touch sensors for object detection and avoidance applications. Other possibilities included usage of the computer module to display various information to the LCD screen and playing various tones with the built-in speaker.

4. Results

Student Project: There are a total of 22 project groups, and the course projects, which represented the culmination of various topics the students learned in the semester, revealed that students both enjoyed the content and were motivated to be creative in this final work. Due to space constraint, we only present a few projects including two teams that competed in a “soccer” match by designing their Lego Mindstorm robot as a wheeled vehicle controllable with Bluetooth. However, the control schemes of the teams differed, with one team using the arrow keys on a keyboard for control while others used computer mouse movement for control. An image of the robotic soccer match is provided in the top-left of Figure 1.

Other students showed more interest in the color sensor of the robot, allowing the robot to take certain actions depending on which color was shown. One team designed their robot to be a four-legged quadruped resembling a dog, shown in the top-right of Figure 1. The dog reacted to certain colors that represented whether it was being fed, called, or told to sit. The color sensor operated most effectively when shown Lego pieces of the corresponding colors. If a specific color is not available in Lego pieces, then one could use either colored paper or smartphone screens instead. This team also altered the LCD screen to show different facial expressions for the “dog” as actions were performed through creative use of characters on the keyboard and their relative positions on the LCD screen. Another team used the color sensor to play music. Using various colored sheets of paper, students in this group assigned musical notes to specific colors; when the motors were activated, the robot proceeded in a straight line, observed a chain of colors through the vision sensor, and played a song. An example of this robot is provided in the bottom-left of Figure 1.

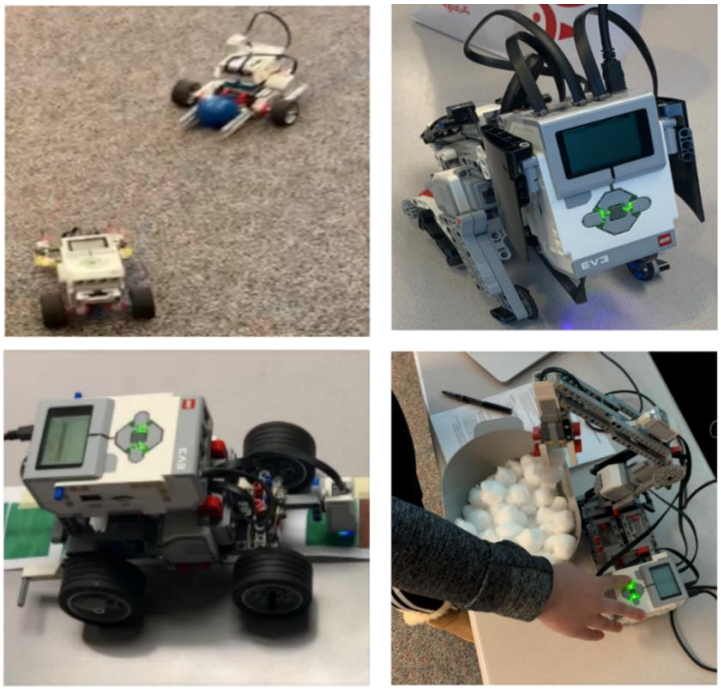

Figure 1. Examples of student projects: soccer match (top-left), color sensor dog (top-right), robot reading color to play music (bottom-left), and user-controlled crane to pick up materials (bottom-right)

Student teams also considered usage of drastically different robot designs. One team utilized a keypad movement scheme on the Lego Mindstorm computer module to control a custom crane they designed from the included parts in the Lego Mindstorm kit as shown by the bottom-right of Figure 1. This crane utilized the included motors to allow for movement in both the horizontal and vertical directions, rather than utilizing the motors in a traditional wheeled vehicle design. The crane could be lowered and raised by the student, with the crane's claw opening and closing, via keypad inputs. Demonstrations of the operation of this crane were done with lightweight objects such as cotton balls due to strength limitations of the Lego components.

Student Course Evaluation: Students completed their course evaluations using a new online system, Watermark, put into place by MTSU in the Fall 2021 semester. These evaluations, which can be customized by the instructor, include ten default questions which are used for the purposes of this work. These default questions, aimed at evaluating both course and instructor, are given numerical values based on a 5-point Likert scale. The Fall 2022 semester, which was the first semester to utilize the Lego Mindstorm EV3 robots, showed the highest response rate to date for this course, including 60 responses which represented 68.18% of the students enrolled in the course. Average scores for each question, which were between 1-5 were all 4.58 or greater with standard deviations between 0.63-0.77. It should be noted that the overall performance of the course, when compared to the averages across the Engineering Technology department, our college, and MTSU, exceeds all other averages for each question.

When the course was revitalized with a dramatic shift in content in Fall 2022, it was important to consider the students' comments from the evaluations. Positive comments from students included the following: "the projects with the Lego Mindstorm robot were very engaging"; "the class was very well done, and allowed us, the students, to learn how to use a real-world coding language and apply it to the fundamentals of engineering that we learned in the class"; and "the course was structured in a very fun and educational manner that also provided a challenge". Besides the many positive comments regarding the course revitalization, the following are a few with regards to the revitalized course content: "implement different challenging coding problems"; "make use of MATLAB on-ramp activities"; "have labs build onto each other throughout the semester"; and "using a commercial product that is not discontinued and has support available". The last comment was due to the fact that multiple commands and support packages related to Lego Mindstorm EV3 robots are either depreciated in MATLAB or no longer useful to students. In addition, certain syntax statements for the Lego robots differed from the MATLAB documentation.

5. Conclusions & Future Work

In Fall 2022, we have attempted to revitalize ENGR 1100, Engineering Fundamentals, by introducing MATLAB and Lego Mindstorm EV3 robotic kits to the students. Based on the increased levels of interest and enjoyment, quality of the student projects, the high response rate to teaching evaluation request, and high teaching evaluation scores, we think the preliminary results are positive. Nonetheless, our approach to teaching first-year engineering students still has room to grow.

Some students desired an increased challenge, while others desired more connectivity between topics and real-world applications rather than more generalized programming assignments. These ideas are all extremely useful for further developing the course to improve evaluation scores further.

We plan to further develop the course, considering both student opinion and performance as well as other faculty recommendations. The discontinuity of the Mindstorm EV3 kit by Lego and the lack of continued support in MATLAB make it necessary to consider changes to the platform. For example, we could integrate other programming languages beyond MATLAB, such as Python or other applicable languages with support packages for Lego Mindstorm robots. We could also explore the idea of purchasing different robotics kits. Ultimately, we want to provide the best possible hands-on experience for our first-year engineering students assuming their limited mathematics and computer science backgrounds when they take the course. Our desire is to entice students to gain interest in engineering without providing daunting mathematical assignments but still encouraging both thought and creativity to foster student academic growth.

Evaluation of the revitalized course is crucial to understand how effective the changes have been. Our future evaluation plan includes: *(i)* Collecting more student evaluation results and response rates and comparing them with those in the semesters prior to the course revitalization; *(ii)* Comparing freshman students retention rate and GPA before and after the course revitalization; *(iii)* Utilizing student survey to measure the success of our efforts.

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