Moving towards a Student-Centered Curriculum with Hybrid Learning: Integrating an Extracurricular Autonomous Vehicles Project into the Electrical Engineering Program

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***Abstract*—The School of Engineering offers project-based courses and opportunities for conducting undergraduate research to enhance the active and experiential learning aspects of the engineering curriculum and effectively integrate theory and practice. While this rigorous approach has produced a legacy of highly qualified and competitive engineering graduates, it has done so at the cost of creating a high-pressure environment for the students. Recent surveys and evaluations have indicated the need for a more inclusive environment—both educationally and culturally—at the School of Engineering. This study reports on an initiative to move towards a more student-centered curriculum by integrating a comprehensive extracurricular autonomous vehicles (AV) project into the electrical engineering (EE) program through the required freshman engineering design course, Vertically Integrated Projects (VIP) program, and additional advanced elective courses. There are three main goals for this initiative: 1. Serve as an equalizer for a more inclusive environment through providing early exposure to technical skills, theoretical concepts and peer-to-peer mentorship, 2. Provide an effective onboarding process that introduces educational models that foster a culture of collaboration and team work through multi-layered integration of both the core projects and the course curriculum. , and 3. Create a dynamic curriculum that consistently reflects state-of-the-art disciplinary and interdisciplinary knowledge.**

I. Introduction

Even though the existing electrical engineering (EE) curriculum has many opportunities for project based learning, those opportunities tend to be limited in scope and topic and are typically short term which is not directly conducive to providing the necessary experience for students interested in going into industry or research. Traditional mechanisms such as independent studies and research experiences for undergraduates (REU) are usually available for students that are interested in research. Whereas, students interested in industry typically seek internship opportunities and often become involved in extracurricular projects such as motor sports or intelligent ground vehicle competition (IGVC).

However, these opportunities have their challenges. REUs and summer internships can be highly competitive thus limited to a very few number of students since not all students are well prepared to have an edge in this highly competitive space. Since students joining engineering programs in higher education come from varying levels of exposure and prior experience, traditional engineering pedagogy can inadvertently amplify these disparities giving rise to experiences such as imposter syndrome which may lead to students with great potential of becoming engineers to drop out or not retain a career in engineering post graduation. This raises questions about accessibility, equity and inclusion of engineering programs which makes enhancing the undergraduate experience to prioritize improving student confidence and self-efficacy a priority [4].

The high pressure environment in undergraduate engineering programs forms another challenge preventing students from having a consistent and meaningful engagement in extracurricular projects. As a result, participation in extra curricular projects is declining; and for those who do participate, only a few are able to fully engage in the project as others have their time occupied with course work. Additionally, developing hands-on problem solving skills requires a lot of time, mentorship and consistent engagement with projects that is not easily accomplished with independent studies as those run for one semester and have a limited number of students that can partake in them, making scaling of such efforts more challenging.

The concept of a student-centered curriculum is not new to education. In fact, it is well established in early childhood education. Examples of which are Montessori and Reggio Emilia. The core principles of such approaches reside in their belief in a student-centered curriculum which has been shown to increase cognitive function, improve learning capacity, and instill self-confidence which enhances leadership skills. The Reggio Emilia approach, in particular, stands out in that it emphasizes awareness and connection of the students with their community and defines the role of the teacher as a co-learner allowing the students to carve their own paths through their educational journey encouraging risk taking, learning from failure, and most importantly understanding oneself. Such approaches have been extended to elementary education and in some cases to junior high education. However, not much of it has been seen in higher education. Such methods have proven to be effective for learning of young minds and consideration of extending them to college education can be of benefit and should be explored [7]. In this paper, we propose a hybrid approach to include an Autonomous Vehicles (AV) project into the EE curriculum that will allow for such adaptation in the long run.

The introduction of Vertically Integrated Projects (VIP) into the traditional engineering curriculum enables the integration of comprehensive long term projects, i.e. the AV project, which can act as both a pilot for future integrated projects, as well as a model for integration with the curriculum [1]. Programs like VIP have shown significant promise pertaining to diversity, student persistence, peer support, learning satisfaction, and more [6], [5], [2]. VIP can become a key mechanism for a student-centered approach to engineering education in traditional engineering programs when integrated with required and core engineering courses in the curriculum [3]. In this paper, we will discuss the scope of the AV project at large, its structure, and curricular integration. We will discuss results from a preliminary questioner that was conducted, as well as discuss future plans for a more comprehensive survey.

II. Proposed Project

The AV project is conceptually and technically multifaceted, allowing for a comprehensive design experience for students at all levels of the undergraduate and graduate education. This project is encompassing and provides students with an invaluable exposure and experience working with state-of-the-art technology and cutting edge research early on in their education. The team is split into five sub-teams, as depicted in Figure 1, that have to coordinate with each other, namely, Control, Electrical Hardware (EE HW), Drive-by-Wire (DBW), Mechanical Hardware (ME HW), and Technical (Tech). The roles and specifications of each sub-team are explained below.

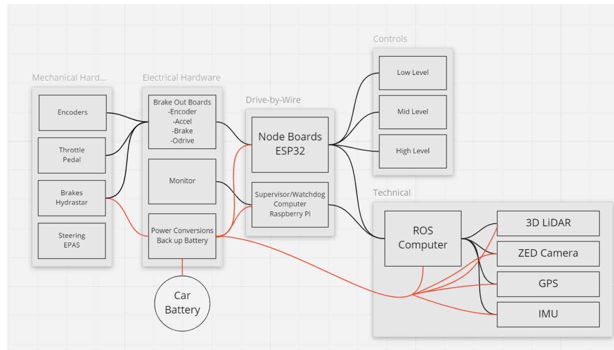

Fig. 1. Overall AV team structure.

A. Control

The controls team is split into two sections, high-level and low-level. High-level interfaces with Tech team through the Robot Operating System (ROS) stack. It receives the trajectory, pose estimate, and behavior commands from Tech team as shown in Figure 2. High-level controls then compares the desired state along the trajectory with the current state (the pose) and generates a combined linear and angular velocity command (referred to as a Twist message) to drive the system along the trajectory. The types of potential geometric control methods are pure-pursuit, Stanley controller, sliding-mode control, model-predictive control". Low-level controls interfaces with the high-level team by receiving the Twist message. They also interface with the Drive-by-Wire team (DBW) by sending motor commands via the Controller Area Network (CAN) bus. To generate these motor commands, low-level controls implements a discrete proportional-integral derivative (PID) control loop which will take the Twist message at each control step as the desired input and compare it to the current velocity state of the vehicle to generate an error signal. This error signal is then processed via a PID controller and generates a desired acceleration for the linear velocity controller, or a desired steering angle for the angular velocity controller. Each of these controller's outputs are processed by a mapping function that is determined through the characterization of the vehicle.

B. Electrical Hardware (EE HW)

The Electrical Hardware (EE HW) team develops solutions for the transmission of power and signals on the vehicle. The bulk of EE HW's work is developing printed circuit boards (PCB) for the DBW nodes to control car systems, such as steering, braking, and throttle. Members specify, design,

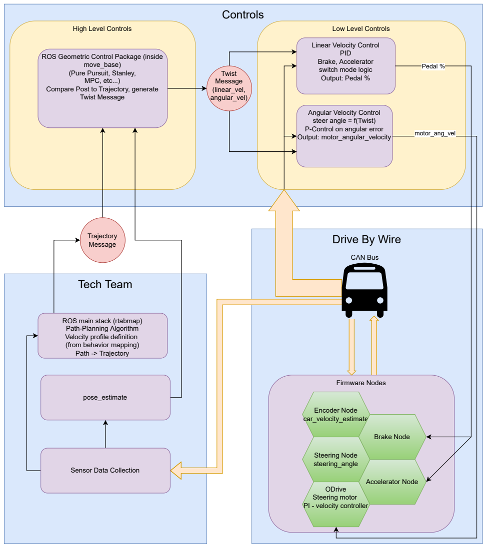

Fig. 2. Control team interfaces.

test and validate boards using Altium Designer and electrical engineering lab equipment. The main board, the DBW Node, has an ESP32, exposed GPIO, JTAG, EEPROM, and RJ-45 for interfacing to the car and other Nodes, sensors, and daughterboards (e.g. steering). EE HW also develops systems to power the custom electronics on the vehicle (GEM Polaris), using stepped-down voltage from the GEM's 48V battery. Components are tested under load to ensure reliable power delivery during operation.

C. Drive-By-Wire (DBW)

The Drive-by-Wire (DBW) sub-team interfaces with the electronics on the car and develops monitoring software. To interface with the various actuators on the car, the DBW team writes firmware that is run on the node boards designed and manufactured by the EE HW team. These nodes communicate with one another over CAN bus. The DBW team is also in charge of designing the CAN infrastructure. This entails writing the CAN messages needed to send commands, receive feedback from the actuators and sensors on the car, and monitor the status of the system. The other central focus of the DBW team is ensuring that the car is safe to operate in autonomous mode. Safety is ensured by writing a supervisor program that runs on an external computer (Raspberry Pi) that monitors the status of the nodes and determines if the car needs to make an emergency stop.

D. Mechanical Hardware (ME HW)

The Mechanical Hardware (ME HW) team supports the team with solutions for retrofitting the team's equipment onto the car. This includes sensors, enclosures for electronics, and retrofitting the steering and braking systems with controllable 3^{rd} party equipment. Examples of significant projects include a mounting bar on the top of the car for sensors, an enclosure for power conversion equipment on the back of the car, and retrofitting the whole brake system for electronic control. Members collaborate heavily with other sub-teams, especially EE HW and Technical (Tech) to prototype appropriate hardware. The ME HW team deals with rapid prototyping, 3D printing, CNC machining, laser cutters, compliant mechanisms, and hydraulic braking. They also have to account for device tolerances (e.g. field of view and temperature) and dimensioning.

E. Technical (Tech)

The Technical sub-team is responsible for collecting data from sensors mounted on the vehicle to analyze incoming obstacles and signs, detect restricting lanes, map its surrounding vicinity, and localize itself within it. The sensor data is gathered and visualized through the Robot Operating System (ROS). Individual types of data are then fed into the RTAB-map (Real-Time Appearance-Based Mapping) software to generate a global and local map of the area around the vehicle. The lane and object detection algorithm devised by the team is published to the move-base ROS package along with the two maps. With the desired goal given to the package, it attempts to navigate towards the goal by providing twist messages (navigation messages) to the base controller of the car. The Tech team provides the Control and DBW teams with the necessary data received from the sensors.

III. Integration into the Curriculum

Several courses and course structures are being used in order to integrate the AV project into the EE curriculum. By examining the EE curriculum, we identified the following required courses: freshman engineering design (3 credits spanning 1 semester), Senior Projects (6 credits spanning two semesters); and the following elective courses: Undergraduate-level VIP (1 credit each semester for up to 6 semesters), Graduate-level VIP (one credit each semester for up to 3 semesters), and other elective offerings such as control theory, machine learning, industrial robotics.

As depicted in Figure 3, the freshmen engineering design course, will be used to introduce the topic of AV giving students a meaningful hands-on experience and helping them develop intuition for complex theoretical concepts that they have not been exposed to yet. During the first half of the semester in this class, students are asked to select to be part of two of the sub-teams, namely, DBW, Tech, ME HW, EE HW, and Control. The idea is to maintain some flexibility since students typically come in with no background and are still exploring their interests. Students are then given specific mini-projects that will introduce them to the different software, hardware, and functional components that the sub-team of choice is working with. By the middle of the semester, the students are expected to have developed some technical skills that will allow them to take on a project of a slightly bigger scope. Therefore, during the second half of the semester, students are provided with a design challenge where they are supposed to work on it in teams.

After EID 101, students who choose to continue with the AV project may take VIP for up to six semester and then three additional semester if they choose to do graduate level. Every 3-credit block of a VIP set of courses vary slightly in goals. The first block, students will focus on being on-boarded, gaining experience, and specializing. Then during the second block of VIP courses, students will work on gaining a deeper understanding of theoretical concepts, additional training, and begin mentoring the new VIP students. Depending on students' interest, they may choose to take the graduate level VIP if they are interested in research or choose to work on a relevant project exploring novel industry implementations during Senior Projects. During this whole process, students are encouraged to take electives that focus on theoretical and technical concepts related to the project.

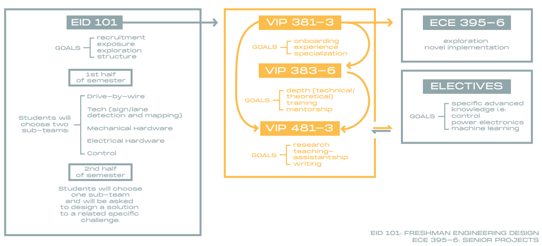

Fig. 3. Integration of the AV project into the EE curriculum.

A. Students' Response

Since this is only the second semester since we implemented this program, we are limited with the amount of data that we can collect. However, one aspect that we would like to capture is the early exposure to theoretical and technical concepts and their affect on promoting a more inclusive environment and student efficacy. We are focusing heavily on developing on-boarding material and tutorials for each sub-team that is background agnostic. We are committed to and would like to ultimately examine the hypothesis that students who have little to no technical experience going through the AV project will at some point (to be determined) catch up to those who have had prior extensive STEM related technical experiences pre-college. Furthermore, we would like to examine the impact of the aforementioned hypothesis if proves to be true. Even though this has been only the second semester, close to 50% of students selected this project (out of 6 courses) as their first choice when surveyed for the freshmen engineering course. Out of 22 students that got into the AV course in Fall 2021, we retained 12 students spanning all sub-teams most of whom had little to no experience in AV specifically and in many of the technical topics required generally. In a brief survey, that the students were given at the end of the freshmen engineering design course, students expressed that the skills they have been learning as freshmen are control, software, power supplies, circuit design, docker, python, multimeter, PCB board. When asked about why they stayed with the team, students expressed how being part of a team with mentorship from upperclassmen has benefited them. They also mentioned the potential in learning new, relevant and state-of-the-art skills through this project. The team recently competed in the Annual Intelligent Ground Vehicle Competition (IGVC), and even through the team was mostly freshmen and it was their first time competing, the team placed 4^{th} place for the Self-Drive performance and 5^{th} place for the Self-Drive Design Report. In addition, they received the Rookie of the Year award.

IV. Conclusions

Overall, integrating the AV project into the curriculum has been a great experience for students and advisors. Even though we are in the early implementation stages, we already see its impact on creating a more collaborative, inclusive, and dynamic environment in the electrical engineering school that allows students to freely pursue their interests while encouraging knowledge sharing. The AV project ties very well into the EE curriculum since it supports the creation of teams with five different focus areas, namely, control, EE HW, DBW, Tech, and ME HW. In addition to the VIP AV course, an elective, each focus supports many of the required and elective courses in EE including but not limited to: freshmen engineering design, hardware design, machine learning, data science, control theory, modern control, compilers, circuits, electronics, and other. In the future, a formalized assessment process is needed. The assessment will be able to measure students self-efficacy and its evolvement each year as they are going through the course compared to their peers who have not gone through it. Paying particular attention to students with no prior exposure to STEM related fields. We would also like to measure career-confidence after students have gone through the course and upon graduation. We also seek to integrate this program with the external community like industry and other organizations.

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