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MTI MINETA TRANSPORTATION INSTITUTE

Preparing Today's Workforce for Tomorrow's Autonomous Transportation: Bridging Electrical and Civil Engineering Disciplines

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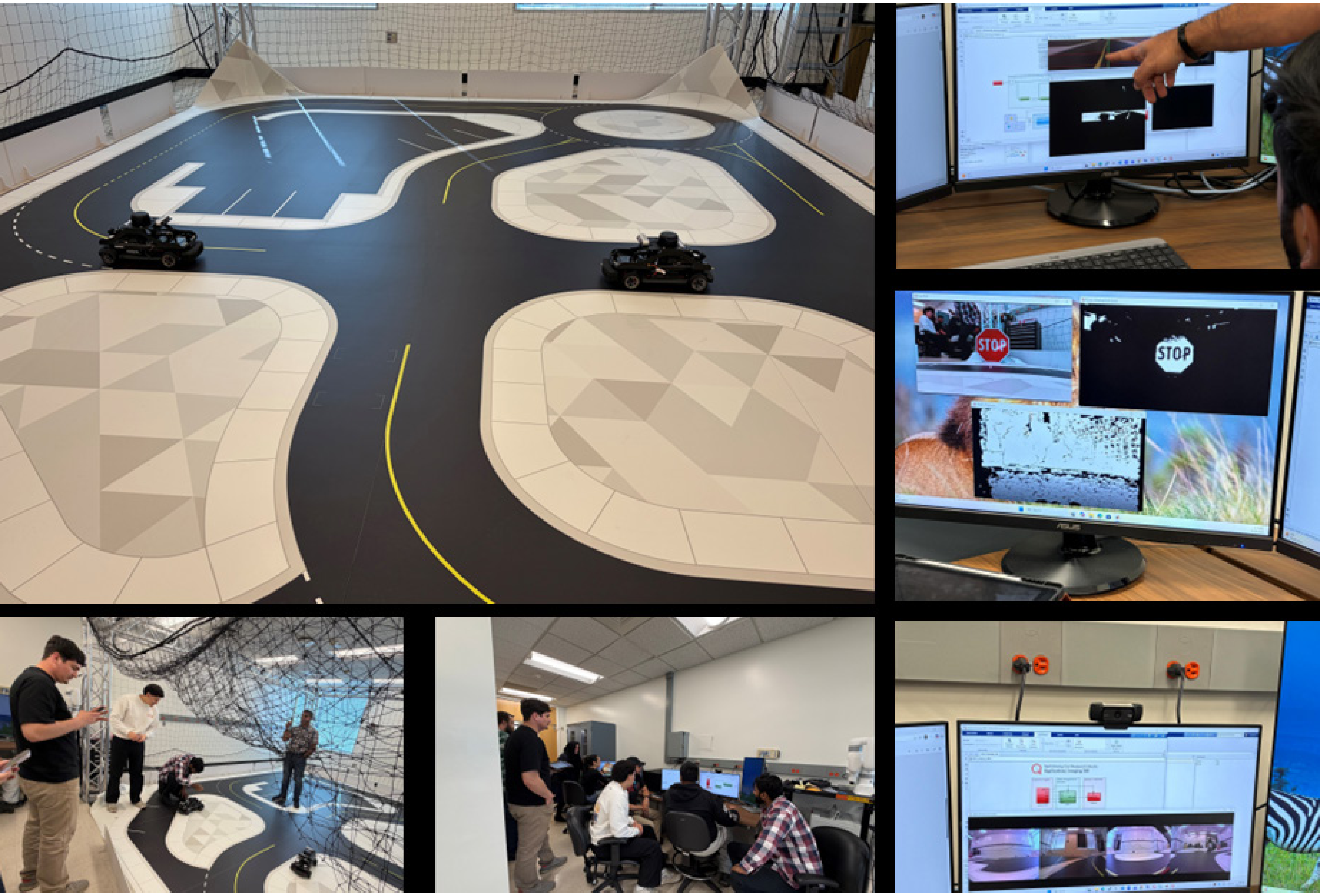

CSUTC California State University Transportation Consortium

CALIFORNIA STATE UNIVERSITY SACRAMENTO

MINETA TRANSPORTATION INSTITUTE

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16. Abstract

Autonomous vehicles (AVs) are expected to transform transportation systems and reshape workforce needs across engineering and related fields. Although existing AV workforce development efforts often emphasize electrical engineering, computer science, and mechanical engineering, transportation engineering remains underrepresented despite its importance to infrastructure, traffic operations, safety, and mobility integration. This study addresses that gap through the development, implementation, and evaluation of an interdisciplinary certificate program, Workforce for Autonomous Vehicle Engineering (WAVE), at California State University, Sacramento. The program was designed to bridge transportation engineering and electrical engineering through a two-step curriculum model consisting of theoretical educational modules and hands-on laboratory activities. Transportation engineering modules covered traffic control devices, traffic signal timing and phasing, traffic flow theory, roadway geometric design, and supplementary topics such as human factors, level of service, and intelligent transportation systems. Electrical engineering modules addressed signals and systems, sensing technologies, sensor fusion and artificial intelligence, control systems, and communication systems. The program was delivered over seven weeks to 53 civil and electrical engineering students through a customized Canvas platform and laboratory sessions using the QCar AV platform. Program effectiveness was evaluated using a three-layer framework: pre- and post-surveys, student program evaluation, and review by a panel of industry experts. Results showed substantial improvement in both student competence and confidence, strong positive student perceptions of the curriculum and laboratory experience, and strong validation from industry experts regarding the program's interdisciplinary structure and workforce relevance. The findings demonstrate that integrating transportation engineering with electrical engineering through theory-based and experiential learning provides an effective model for preparing students for emerging careers in the AV workforce.

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Executive Summary

Autonomous vehicles (AVs) are rapidly advancing and are expected to influence mobility, safety, equity, sustainability, land use, and overall quality of life. At the same time, AV deployment will significantly affect the workforce by creating new employment opportunities while disrupting traditional roles in transportation and automotive sectors. Preparing students for this transition requires educational programs that reflect the multidisciplinary nature of AV systems.

This project addressed that need through the development and implementation of an interdisciplinary workforce development program focused on AV education. A review of existing AV-related educational efforts showed that most programs emphasize electrical engineering, computer science, computer engineering, and mechanical engineering, while transportation engineering is often underrepresented. This omission is significant because transportation engineering plays a critical role in infrastructure design, traffic systems, safety, roadway operations, and urban mobility planning, all of which are essential for successful AV deployment.

In response, this study developed the Workforce for Autonomous Vehicle Engineering (WAVE) program at California State University, Sacramento. The goal of WAVE was to bridge transportation engineering and electrical engineering and prepare students for careers in AV systems through a combination of theoretical instruction and hands-on learning. The curriculum followed a two-step design. First, educational modules were created to cover core theoretical concepts. Transportation engineering topics included traffic control devices, traffic signal timing and phasing, traffic flow theory, roadway geometric design, and supplementary topics such as human factors, level of service, and intelligent transportation systems. Electrical engineering topics included signals and systems, sensor technologies, sensor fusion and artificial intelligence, control systems, and communication systems. Second, laboratory activities were developed to provide experiential learning using the QCar AV platform in a Self-Driving Car Studio environment. These activities exposed students to camera-based perception, LiDAR mapping, depth sensing, lane following, manual control, and multi-sensor integration.

The WAVE program was implemented in Spring 2026 as a seven-week certificate program. Fifty-three students, including 28 civil engineering students and 25 electrical engineering students, participated. During the first five weeks, students completed self-paced online modules through a customized Canvas platform. During the final two weeks, they participated in hands-on laboratory sessions in interdisciplinary teams.

Program effectiveness was evaluated using a three-layer framework: pre- and post-surveys, student program evaluation, and review by a panel of industry experts. Results showed substantial improvement in both student competence and confidence, strong positive student

perceptions of the curriculum and laboratory experience, and strong validation from industry experts regarding the program's interdisciplinary structure and workforce relevance.

Overall, the project demonstrates that an interdisciplinary framework integrating transportation engineering and electrical engineering can effectively prepare students for the emerging AV workforce. WAVE addressed a significant gap in existing AV education and offers a scalable model for future workforce development.

1. Introduction

1.1 Background

Autonomous vehicles (AVs), also known as self-driving cars, are rapidly advancing across multiple domains, including research and development, engineering and design, policymaking, and commercialization. This accelerating growth is poised to significantly impact workforce development. Industry forecasts estimate that the AV market will surpass $2 trillion by 2030, generating over 100,000 jobs directly within the sector, along with an additional 30,000 engineering positions requiring specialized skills (Bajracharya & Khan, 2022). While the AV industry is expected to create substantial new employment opportunities, it will also disrupt traditional automotive sectors. Projections suggest that more than 4.5 million existing jobs, representing approximately $168 billion in annual wages, could be at risk due to this technological shift (Rayome, 2019). The disparity between projected job creation and potential job displacement highlights a critical workforce challenge associated with AV adoption. Although new positions are expected to emerge in advanced engineering, software development, systems integration, and data analytics, many displaced workers may not possess the technical qualifications or educational backgrounds required to transition directly into these emerging roles. As a result, the AV transition may create significant labor market gaps unless substantial investments are made in workforce retraining, reskilling, and education pathways that support mobility into technology-oriented occupations. Given the scale of this transformation, it is imperative to proactively prepare a workforce equipped with the knowledge and competencies necessary to thrive in an increasingly automated and innovation-driven transportation landscape.

In response to these anticipated disruptions and opportunities, extensive planning is already underway to prepare the workforce for the AV-driven future. For example, in 2022, the State of California introduced the "Autonomous Vehicle Strategic Framework," a comprehensive plan outlining a statewide vision for seamlessly integrating AVs into daily life and the broader transportation ecosystem (Driving the Future: Autonomous Vehicles Strategic Framework Vision and Guiding Principles, 2022). The framework is guided by eight key principles: mobility, safety, equity, health, environmental sustainability, land use, quality of life, and workforce development. Notably, it emphasizes the creation of high-quality jobs during the transition to AV, ensuring fair wages and benefits for California workers while strengthening the competitiveness of the state's employers. As the gradual deployment of AVs could lead to incremental changes or the elimination of existing jobs, potentially displacing portions of the workforce, the strategic plan calls for proactive measures to prepare the workforce for these transitions. These measures include implementing training programs to support workers in the AV sector or related industries, ensuring they are equipped to adapt to new opportunities.

Due to the complexity of AVs, addressing the associated workforce and educational challenges demands a multidisciplinary approach that draws on expertise from a wide range of fields, including engineering, computer science, data analytics, ethics, public policy, management, and urban planning. This is precisely where the current study is positioned. The primary objective of our project is to develop and implement educational materials that prepare the future workforce for seamless integration into the autonomous transportation industry. This project revolves around two key areas of knowledge that are particularly critical: electrical engineering, which focuses on designing the hardware for these advanced systems, and transportation engineering, which ensures a smooth transition from human-driven to machine-driven transportation systems.

1.2 Project Objectives

Several academic institutions have adopted multidisciplinary approaches to train the transportation engineering workforce (Ehteshami, 2020; Polzin & Ward, 2002). A comprehensive review of the literature consistently highlights the positive outcomes of these efforts. For instance, an interdisciplinary team of educators at Texas A&M University developed a certificate program in transportation planning. Their findings indicated that student participants acquired a robust set of analytical and practical skills, making them highly competitive candidates for transportation-related jobs (Joh & Li, 2015). In another initiative, educators at the University of Vermont established the Transportation Education Development Pilot Program to train the transportation workforce using a multidisciplinary approach. The program demonstrated favorable outcomes, with 19 out of 21 first-year participants reporting job changes, including six individuals who received promotions (Vallett et al., 2014).

However, a review of current curricula, as discussed in the next chapter, shows that AVs are less emphasized as a key topic for workforce development. Civil and electrical engineering disciplines often operate in isolation, leading to students developing narrow expertise. For example, electrical engineering students excel in sensor technologies and hardware design but often lack knowledge of transportation engineering topics such as highway design or traffic flow theory. Conversely, civil engineering students typically lack foundational knowledge in AV technologies, such as machine learning for vehicle perception or vehicle-to-infrastructure (V2I) communication.

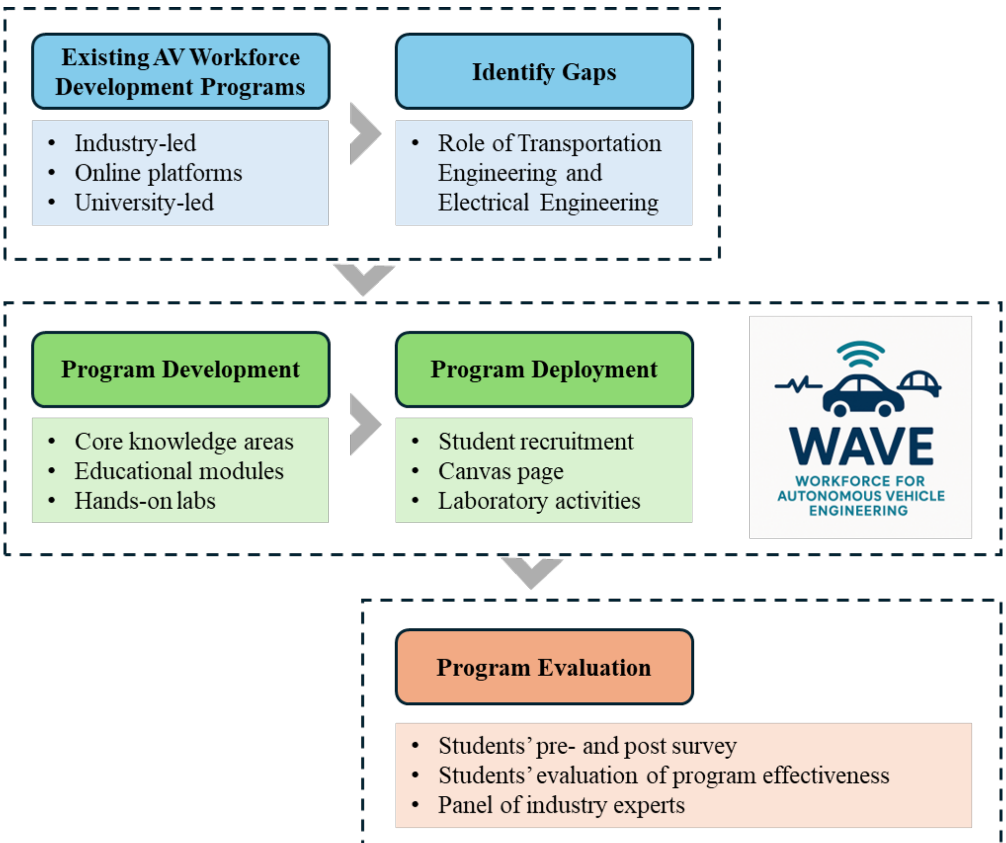
The objectives of this project are twofold. First, the project aims to develop educational modules that cover the fundamental theories relevant to AV development and deployment, thereby equipping students in civil and electrical engineering with essential interdisciplinary knowledge. Second, the project seeks to complement this theoretical foundation with hands-on learning experiences through laboratory-based design projects and targeted workshops, enabling students to apply theoretical concepts in practical, real-world contexts.

Consistent with these objectives, the project is designed to prepare the future workforce for careers in autonomous transportation by enhancing students' knowledge of AV systems while fostering interdisciplinary collaboration between civil and electrical engineering. More broadly, this effort addresses the research question of how multidisciplinary education, combined with experiential learning in AV technologies, can effectively equip students with the skills and competencies required for emerging careers in autonomous transportation.

1.3 Methodological Framework

Figure 1 presents an overview of the methodological framework used in this study. The process began with a review of existing AV-related workforce development courses, certificates, and programs to identify areas of coverage as well as existing gaps. Next, considering the roles of civil engineers and electrical engineers in addressing these gaps, a set of educational materials was developed, including both theoretical modules and hands-on learning components. The developed program was then deployed at California State University, Sacramento. In the final step, the effectiveness of the program was evaluated.

Figure 1. Methodological Framework



2. Literature Review

Workforce development for AVs is occurring across multiple levels and institutional capacities. One major avenue is through industry-led training programs designed to equip new employees with the specific skills needed for AV-related roles. For instance, PerceptIn, a robotics company that specializes in visual perception and autonomous mobility solutions, created a two-week intensive onboarding program. This initiative was designed to quickly upskill incoming engineers, most of whom had backgrounds in embedded systems and general software engineering, to meet the specific demands of AV development and deployment (Tang et al., 2018).

Another significant avenue of workforce development is through online learning platforms. A notable example is Udacity's Self-Driving Car Engineer Nanodegree Program. Developed in collaboration with Waymo, this program offers comprehensive, project-based training in topics such as computer vision, deep learning, sensor fusion, and path planning (*Online Self-Driving Car Engineer Training Course | Udacity*, n.d.).

These types of industry and online programs have largely emerged in response to the lack of standardized or comprehensive AV-focused curricula in traditional university or higher education settings. While such programs have been instrumental in closing immediate skill gaps, they also highlight the need for formal educational systems to adapt and evolve. Encouragingly, educational initiatives focused on AVs are beginning to gain momentum within universities and other higher education institutions. In line with the objectives of this study, the following section explores current trends in AV-related education and training at the postsecondary level. Our aim is to understand how existing programs are structured, which knowledge domains they emphasize, and where opportunities remain for more integrated and interdisciplinary approaches.

A structured search of publicly available online sources was conducted to identify existing AV-related training programs and educational offerings. This included keyword-based searches (e.g., "autonomous vehicle course," "self-driving car training," "AV certification program") using major search engines, as well as reviews of university websites, professional society resources, and well-known online learning platforms (e.g., Coursera, Udacity). Given the limitations of a literature review chapter, the following sections highlight only a select number of prominent examples, primarily those most relevant to the objectives of the present study.

2.1 Conventional AV-Related Courses

Several universities have begun offering standalone AV-related courses to address emerging educational needs in this field. For example, the Massachusetts Institute of Technology (MIT) provides a free course titled Deep Learning for Self-Driving Cars, which introduces students to the core techniques used in autonomous driving systems, including neural networks, convolutional models, and behavioral cloning. The course emphasizes hands-on experience with end-to-end deep learning models applied to real-world driving tasks (Carmezim, 2017/2026).

At Western Michigan University, educators developed a multidisciplinary, 3-credit course titled Autonomous Vehicle Engineering. This course is designed to address existing academic gaps while aligning with industry demands. Notably, it is open to students from all majors and does not require any prerequisites. The course combines theoretical foundations with practical applications, covering topics such as vehicle sensors, perception, and control systems, and aims to foster interdisciplinary collaboration and accessibility across diverse student populations (Brown et al., 2024).

Northwestern University offers Connected and Autonomous Vehicles: Challenges and Design, addressing the critical intersection of advanced driver-assistance systems (ADAS) and autonomous mobility. The course explores central technical challenges, including real-time sensing, high-performance computing and communication architectures, system safety, security, and reliability, while situating AVs within broader transportation ecosystems (*COMP_ENG 395, 495: Connected and Autonomous Vehicles: Challenges and Design | Electrical and Computer Engineering | Northwestern Engineering*, n.d.).

Princeton University offers Introduction to Computing: Programming Autonomous Vehicles, an entry-level course that introduces fundamental programming concepts through hands-on experience with autonomous robotic systems. Students learn key topics such as control flow, functions, recursion, and data structures. The course emphasizes practical application, debugging skills, and real-world problem solving, providing students with early exposure to autonomous systems through a project-based format (*Introduction to Computing*, n.d.).

The University of California, San Diego offers Introduction to Autonomous Vehicles, a 4-credit technical elective available to both electrical/computer and mechanical/aerospace engineering students. The course combines lectures with hands-on lab work, where students design, build, and program AVs to navigate a simulated city track. In this course, students learn about key topics such as computer vision, machine learning (using frameworks like ROS and TensorFlow), embedded systems, and project management (University of California, San Diego, n.d.).

2.2 AV-Related Certificate Programs

In addition to conventional courses, many universities and higher education institutions now offer AV-related certificate programs aimed at students and professionals. These certificate programs supplement university coursework by offering focused, flexible training designed to address specific technical and societal aspects of AVs, a gap often missed by traditional degree programs. For example, the University of Delaware offers the Autonomous Driving Academy Pre-College Summer Program, a competitive, five-day noncredit immersion held on its Newark campus, developed in collaboration with the Connected and Autonomous Research Laboratory (CAR Lab) and the Department of Computer and Information Sciences. Designed for high school students with an interest in robotics, engineering, artificial intelligence (AI), and programming, the program covers vehicle control fundamentals, sensor technologies, and programming using ROS, Python, and C++ ("Autonomous Driving Academy," n.d.).

Riverland Community College, a community college in Minnesota, offers an Autonomous Vehicle Technician certificate, aimed at preparing students and working technicians for careers in servicing and maintaining AV technologies. The program includes three specialized courses: ADAS Technology and Applications, AV Technology and Applications, and Automotive Service, ADAS and AV Internship. Graduates gain proficiency in ADAS/AV diagnostics and calibration (optic, radar, LiDAR), understand autonomy levels and connectivity systems, and are equipped for technician roles in the evolving automotive sector (*Autonomous Vehicle Technician Certificate | Riverland Community College*, n.d.).

The University of Michigan provides an online Connected and Automated Vehicles certificate series as part of its Michigan Engineering Professional Education offerings. This program includes three self-paced courses, including Adversarial Machine Learning, Dynamics and Control of Connected Vehicles, and Behavioral Implications of Autonomous Vehicles (*Connected & Automated Vehicles*, n.d.).

The University of Detroit Mercy offers a Smart and Autonomous Vehicle Graduate Certificate designed to provide advanced, multidisciplinary training in key areas of autonomous systems. The program consists of five courses (15 credits), including three required core courses and two electives. The core courses include Autonomous Mobility Robotics, Controls II, and Image Processing and Computer Vision. Students then select two electives from a broad list; among the most compelling options are Probabilistic Robotics, Artificial Intelligence, and Vehicle Dynamics (*Smart and Autonomous Vehicles | University of Detroit Mercy*, n.d.).

2.3 AV-Related Graduate Programs

Several universities and higher education institutions have advanced their commitment to AV education by establishing dedicated graduate-level programs. For example, Kettering University, a private, technology-focused institution in Flint, Michigan, offers a comprehensive Master of Engineering (M.Eng.) in Autonomous Vehicles, a two-year, 30-credit program tailored for engineering professionals in the automotive industry. Students complete two mobility systems fundamentals courses, chosen based on their undergraduate background, as well as technical courses in Automotive Control Systems and Digital Signal Processing. The core AV curriculum includes Mobile Robotics, AI for Autonomous Driving, Computer Vision for Autonomous Driving, and Internet of Things (IoT). Complementing the technical depth, the program also integrates two management courses (Project Management and Technology Management) and leverages its location in Michigan's automotive corridor to access research facilities, including the GM Mobility Research Center (*Autonomous Vehicles, M.Eng. | Kettering University*, n.d.).

The University of Warwick, a leading UK research institution, offers a 12-month, full-time Master of Science in Smart, Connected and Autonomous Vehicles through Warwick's Manufacturing Group. This program includes core technical modules covering automotive sensor fusion, embedded systems, Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) communications, machine intelligence, data science, human–technology interaction, and fundamentals of automotive research and development (R&D). Additionally, the program covers elective options such as automotive electrification, algorithm programming, and functional safety, while it also offers hands-on experiential learning through industry-led projects (*MSc Smart, Connected and Autonomous Vehicles | WMG*, n.d.).

Another example is Cranfield University, a specialist postgraduate public research university in the UK, which offers a Master of Science degree in Connected and Autonomous Vehicle Engineering (Automotive). This is a one-year, full-time program designed to equip graduates and experienced engineers with advanced technical and transferable AV skills. The curriculum covers areas such as vehicle navigation, sensing and perception, systems integration, human factors, ethical and regulatory considerations, and sustainable transport solutions. The program is also closely aligned with industry standards and best practices, guided by an industrial advisory panel with representatives from organizations such as Jaguar, Land Rover, and Mercedes-Benz (*Connected and Autonomous Vehicle Engineering (Automotive) MSc*, n.d.).

2.4 AV-Related Educational Gaps

A review of existing educational efforts aimed at addressing workforce development for AVs reveals noteworthy observations. Technical aspects of AV education are predominantly centered on disciplines such as computer science and electrical engineering. For example, many programs emphasize topics such as artificial intelligence, machine learning, and perception algorithms, areas typically grounded in computer science, as well as sensor technology, control systems, and embedded electronics, which fall under electrical engineering. Even when programs broaden their scope, they tend to remain within the boundaries of computer engineering, covering system integration and software-hardware interfaces, or mechanical engineering, focusing on vehicle dynamics and mechanical design. In fact, a recent novel study explicitly identified four primary pillars of AV education as electrical engineering, computer science, computer engineering, and mechanical engineering (Liu et al., 2021).

Notably absent from this framework is civil engineering, and more specifically, transportation engineering, whose relevance is critical in areas such as infrastructure design, traffic systems, safety, traffic control, and urban mobility planning (Hossain et al., 2024). This omission suggests that the role of civil and transportation engineers in AV education may be underestimated or overlooked altogether. This shortcoming has an important reciprocal implication: professionals trained within the identified "four pillars" (electrical engineering, computer science, computer engineering, and mechanical engineering) often lack exposure to transportation-related knowledge that is essential for a comprehensive understanding of AV systems. Transportation engineering students are also trained separately from other relevant AV topics. As a result, graduates from these technical fields may be ill-prepared to address the broader challenges inherent to the deployment and integration of AVs.

In response, the objective of this study is to propose a comprehensive set of educational topics that prepare students with the core interdisciplinary knowledge necessary for workforce development in the AV sector, with a focus on transportation engineering and electrical engineering topics. Our comprehensive program will train a future workforce with the necessary knowledge (theory) and confidence in their understanding and abilities (application).

3. Program Development and Deployment

This chapter presents the development and implementation of the program. It begins by outlining the rationale for the selection of topics within both the civil/transportation engineering and electrical engineering disciplines. The learning objectives associated with each knowledge area are then defined using Bloom’s Taxonomy, a widely adopted educational framework that classifies learning objectives according to progressively higher levels of cognitive complexity (Krathwohl, 2002). The revised taxonomy consists of six hierarchical levels: remembering, understanding, applying, analyzing, evaluating, and creating. These levels provide a structured approach for designing educational outcomes that move students from foundational knowledge acquisition toward higher-order critical thinking and problem-solving skills. Bloom’s Taxonomy was used in this study to systematically align learning objectives, instructional activities, and assessment strategies across the interdisciplinary AV curriculum.

Subsequently, the chapter describes the pedagogical approach guiding the design of the laboratory exercises, emphasizing their role in reinforcing theoretical concepts through practical application. The chapter further details the processes, methodologies, and key considerations involved in the development of the educational modules and laboratory activities. Finally, it describes the pilot implementation of the program at California State University, Sacramento.

3.1 Transportation Engineering Topics

3.1.1 Traffic Control Devices

Traffic Control Devices encompass the signs, signals, markings, and other visual or electronic indicators used to regulate, warn, and guide drivers on roadways. For professionals in the AV domain, particularly those with backgrounds in electrical or computer engineering, understanding traffic control devices is essential for enabling machine interpretation of roadway environments. An important example in this area is the application of The Manual on Uniform Traffic Control Devices (MUTCD). For instance, MUTCD defines 13 distinct color codes, each associated with specific functions. Fluorescent pink, for example, is designated for incident management, while purple is used for electronic toll collection (ETC) lanes, accessible only to vehicles with registered transponders (Federal Highway Administration, 2023). Although these colors may appear visually similar, they convey very different meanings. Such standards have historically been developed based on human visual perception and cognition. However, in a future where AVs play a dominant role in traffic environments, it becomes necessary to reconsider these conventions through the lens of machine perception. Questions arise regarding the sensor detection capabilities of AVs, such as how reliably cameras, LiDAR, or other systems can distinguish between subtle color variations under varying environmental conditions. These considerations have direct implications for updating or redesigning traffic control devices and roadway communication systems to ensure compatibility with both human and machine interpreters. Bridging this gap between transportation standards and AV sensor technology will be essential for ensuring safe and effective traffic management in increasingly automated road networks.

To address the fundamental principles of traffic control devices, six learning objectives were established across multiple levels of Bloom's Taxonomy. By the end of this learning module, students will be able to:

- Identify the main types of traffic control devices and their purposes.
- Explain the principles that govern the design and use of traffic control devices to promote safety and efficiency.
- Apply MUTCD color, shape, and pattern conventions to interpret traffic control information.
- Distinguish between regulatory, warning, and guide signs based on their visual characteristics and functions.
- Evaluate the appropriate selection and placement of traffic control devices for different roadway conditions.
- Design a basic traffic control device layout that complies with MUTCD standards and principles.

3.1.2 Traffic Signal Timing and Phasing

Traffic signal timing and phasing represent a critical intersection between transportation engineering and electrical engineering, particularly in the context of increasingly automated and connected transportation systems. Traffic signals are not merely visual indicators; they are complex, real-time control systems that rely on embedded electronics, sensors, communication networks, and control algorithms to manage competing traffic movements safely and efficiently. For electrical engineers working in the AV domain, an understanding of how signals are timed and phased is essential for both interpreting infrastructure behavior and contributing to its design and optimization.

To address the fundamental principles of signal timing and phasing, six learning objectives were established across multiple levels of Bloom's Taxonomy. By the end of this learning module, students will be able to:

- Define and explain key traffic-signal terminology, phasing concepts, and intersection control principles.

- Differentiate between signal operation types and left-turn treatments.
- Interpret typical signal-head configurations and their implications for safety and operations.
- Apply formulas for yellow and all-red intervals to determine safe change and clearance times.
- Compute critical flow ratios and determine appropriate cycle lengths.
- Develop a basic signal timing plan including phase selection, cycle length, and green time allocation.

3.1.3 Traffic Flow Theory

Traffic Flow Theory is a foundational area within transportation engineering that studies the movement of vehicles on roadways using mathematical and empirical models. It provides the theoretical underpinnings for understanding how traffic behaves under different conditions and is essential for designing safe and efficient transportation systems. For computer scientists and electrical engineers involved in AV development, knowledge of traffic flow theory is particularly valuable for enhancing decision-making algorithms. For example, car-following models, which describe how one vehicle responds to the speed and distance of the vehicle ahead, can inform the design of longitudinal control systems, enabling AVs to maintain safe following distances and adapt smoothly to traffic dynamics. Similarly, lane-changing models offer insights into the conditions under which drivers choose to change lanes, incorporating factors such as gap acceptance, speed advantage, and driver aggressiveness. Incorporating these behavioral models into AV software allows for more human-like, context-aware decision-making, improving the AV's ability to operate safely and efficiently in mixed traffic environments.

To address the fundamental principles of traffic flow theory, six learning objectives were established across multiple levels of Bloom’s Taxonomy. By the end of this learning module, students will be able to:

- Define key traffic stream parameters, including speed, flow, and density.
- Differentiate between time-mean speed (TMS) and space-mean speed (SMS), and calculate TMS and SMS using given data sets and formulas.
- Calculate traffic flow and density based on observed headways and spacings.
- Apply the fundamental relationship among speed, flow, and density ($q = u \times k$).

- Interpret Greenshield's linear speed–density model and derive flow–density and speed–flow relationships.
- Evaluate how theoretical models compare to real-world traffic behavior and assess their limitations.

3.1.4 Roadway Geometric Design

Roadway Geometric Design is a fundamental area within transportation engineering that focuses on the physical layout and dimensions of roadway elements, such as curves, grades, and intersections, to ensure safe and efficient vehicle movement. For engineers working on AVs, understanding these geometric principles is essential for aligning vehicle design with real-world operating conditions. For example, horizontal curves are designed based on vehicle cornering dynamics, which require knowledge of lateral acceleration, frictional forces, and superelevation. A curve's radius must accommodate the vehicle's speed and turning capability, ensuring that tires maintain sufficient grip without skidding. This design is rooted in an understanding of how forces act on the vehicle during motion, knowledge that directly connects with engineering principles.

To address the fundamental principles of roadway geometric design, six learning objectives were established across multiple levels of Bloom's Taxonomy. By the end of this learning module, students will be able to:

- Describe the role of highway geometric design in providing safe and efficient roadways.
- Identify the main components of roadway alignment: horizontal, vertical, and cross-sectional.
- Interpret stationing notation to locate points along a roadway alignment.
- Recognize key terminology and geometry of vertical curves, including PVC, PVI, and PVT.
- Explain the concept of stopping sight distance and how it differs for crest and sag curves.
- Identify common horizontal curve types and their basic geometric elements.

3.1.5 Supplementary Topics

In addition to core topics, a well-rounded understanding of transportation engineering for AV workforce development requires exposure to several supplementary areas that provide essential context for system design and operation. Topics such as human factors, level of service (LOS), and intelligent transportation systems (ITS) offer foundational insights into how transportation systems are experienced, evaluated, and enhanced. Human factors focus on the interaction between users and transportation infrastructure, emphasizing how human perception, cognition, and physical limitations influence the design of roadways and control systems. This is particularly important even in an increasingly automated environment, as human drivers, pedestrians, and cyclists will continue to coexist with AVs. Level of service introduces a framework for assessing the quality and efficiency of transportation facilities, enabling engineers to quantify congestion and operational performance under varying conditions. Meanwhile, ITS and emerging vehicle-to-everything (V2X) technologies highlight the growing role of communication, sensing, and data-driven decision-making in modern transportation networks.

To guide students in this area, the following learning objectives have been established:

- Define key transportation terms such as human factors, LOS, and ITS.
- Describe how human abilities and limitations affect transportation design.
- Explain the roles of signifiers, constraints, and feedback in user interactions.
- Differentiate basic roadway facility types and their ideal conditions.
- Apply introductory LOS measures to simple transportation scenarios.
- Summarize the main components and benefits of ITS and V2X technologies.

3.2 Electrical Engineering Topics

The selected modules in the electrical engineering area were intentionally designed to provide civil engineering students with a foundational yet interdisciplinary understanding of autonomous vehicle systems, aligning with the project's goal of bridging gaps between civil and electrical engineering domains. The sequence begins with *Introduction to Signals and Systems*, which equips students with the mathematical and analytical tools needed to understand signals and system definition, skills that are essential for interpreting sensor exchange information. This is followed by *Sensor Technologies* and *Sensor Fusion and Artificial Intelligence*, which introduce how autonomous vehicles perceive their environment using multiple sensing modalities such as LiDAR, radar, cameras, and GPS, and how combining these sensors improves reliability and safety. These topics are critical because modern autonomous systems rely on integrating heterogeneous data sources to achieve robust decision-making in complex environments. The later modules, *Control Systems* and *Communication Systems*, focus on how autonomous vehicles interact with infrastructure and operate safely within transportation networks. Control systems provide the theoretical basis for autonomous vehicle control strategies, while communication systems (e.g., V2I and V2V) are essential for enabling connected vehicle ecosystems. This selection of topics reflects key priority areas identified in transportation education. Overall, the modules collectively ensure that civil engineering students gain both system-level understanding and technological awareness.

3.2.1 Introduction to Signals and Systems

This module introduces the fundamental concept of signals as time- or space-varying information and systems as entities that transform inputs into outputs. It connects everyday examples, such as traffic flow, vehicle speed, and sensor data, to engineering representations used in autonomous vehicles. The module explains different signal types (continuous, discrete, digital, periodic) and highlights the impact of noise and disturbances on system performance. It also emphasizes how signals and systems form the foundation for perception, control, and communication subsystems in autonomous transportation. Learning objectives of this module are:

- Define signals and systems in the context of autonomous transportation.
- Classify different types of signals (continuous, discrete, digital, periodic).
- Identify real-world signals used in AVs.
- Understand the effects of noise and disturbances.
- Explain how systems transform inputs to outputs.
- Describe the role of signals and systems in AV subsystems.

3.2.2 Sensor Technologies in Autonomous Vehicles

This module provides an overview of the primary sensing technologies used in autonomous vehicles, including LiDAR, radar, cameras (2D/3D/thermal), ultrasonic sensors, and GPS/IMU systems. It explains how sensors operate, their strengths and limitations, and their roles in perception, localization, and safety. The slides also emphasize that no single sensor is sufficient, highlighting the need for redundancy and complementary sensing to ensure reliability under different environmental conditions. Learning objectives of this module are:

- Identify major sensor types used in AVs.
- Understand operating principles of each sensor.
- Compare sensors based on range, accuracy, and robustness.
- Describe applications such as perception, localization, and obstacle detection.
- Analyze limitations under weather, lighting, and occlusion conditions.
- Recognize the need for sensor redundancy.

3.2.3 Sensor Fusion and Artificial Intelligence

The module focuses on how multiple sensors are combined (sensor fusion) to create a reliable understanding of the environment and how artificial intelligence enables perception and decision-making. It explains that individual sensors have limitations but combining them improves robustness and safety. The module introduces key fusion algorithms (e.g., Kalman filters) and AI concepts such as machine learning, neural networks, and convolutional neural networks (CNNs), which are widely used for object detection and scene understanding. Learning objectives of this module are:

- Describe perception systems and sensor roles in AVs.
- Explain why multi-sensor fusion is necessary.
- Understand principles and benefits of sensor fusion.
- Identify common fusion algorithms.
- Understand AI/ML concepts used in AV perception.
- Recognize how fusion improves safety and robustness.

3.2.4 Control Systems for Autonomous Transportation

This module explains how control systems enable autonomous vehicles to execute planned motions by regulating steering, speed, and braking through feedback mechanisms. It introduces the “See–Think–Act” architecture and shows how control integrates with perception and planning. Key concepts include feedback control, vehicle dynamics, tracking errors, and common control techniques such as PID and Model Predictive Control (MPC). The module also highlights how roadway design (civil engineering factors) directly influences control performance and safety. Learning objectives of this module are:

- Define control system fundamentals and feedback principles.
- Understand the role of control in AV operation.
- Identify vehicle states, inputs, and tracking errors.
- Explain integration with perception and planning.
- Compare control techniques (PID, MPC).
- Recognize the impact of roadway design on control performance.

3.2.5 Communication Systems in Autonomous Vehicles

The module introduces communication systems as a critical component enabling data exchange within the vehicle and with external entities. It covers both wired and wireless communication protocols, internal vehicle networks (e.g., CAN bus), and external communication frameworks such as V2V, V2I, V2P, and V2N. The module highlights how communication enhances safety, mobility, and efficiency by enabling cooperative driving and real-time traffic management. It also discusses cybersecurity and privacy challenges associated with connected vehicle systems. Learning objectives of this module are:

- Understand fundamentals of communication systems.
- Differentiate wired vs. wireless communication.
- Describe internal vehicle communication networks.
- Explain external communication (V2X) systems.
- Identify real-world applications in transportation.
- Recognize cybersecurity and privacy challenges.

3.3 Developing Educational Modules

After identifying the core topics and establishing learning objectives across both transportation engineering and electrical engineering domains, the next step involved the development of structured educational modules to effectively address these areas. We began by conducting a comprehensive review of existing resources to ensure alignment with current standards, methodologies, and best practices for each topic. The curated material was then organized into PowerPoint presentations designed for a one-hour lecture format.

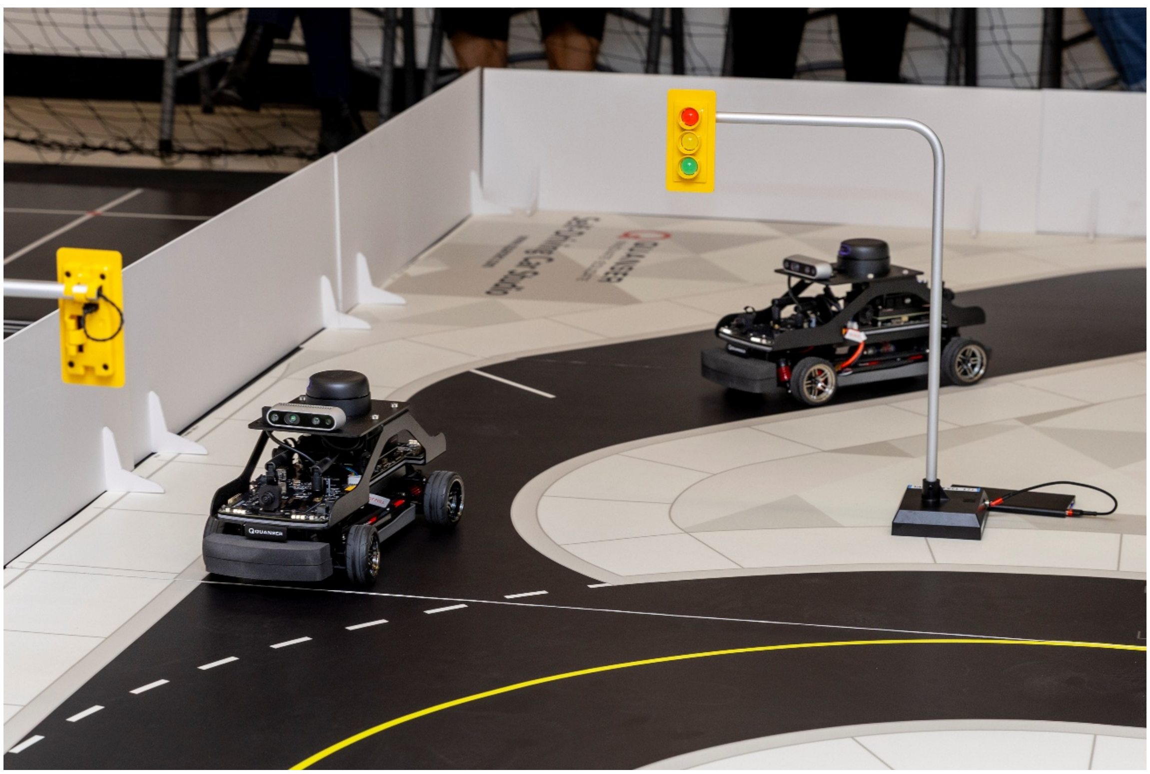
Drawing on our experience as educators, we carefully balanced breadth and depth to ensure that each module adequately supported the intended learning objectives while remaining accessible to students from diverse technical backgrounds. In doing so, we intentionally incorporated multiple levels of Bloom's Taxonomy, ranging from foundational knowledge and comprehension to application, analysis, and design, to ensure that students engage with the material at varying levels of cognitive complexity aligned with the goals of this study. Each lecture was delivered and recorded using Zoom to create reusable instructional content.

To support student learning and measure comprehension, formative assessments were developed in the form of 10-question quizzes aligned with the lecture material and key objectives. In addition, detailed lecture notes were prepared to assist future instructors in effectively delivering the modules. Supplementary resources, including online videos, professional blogs, technical manuals, and other relevant references, were also compiled to enhance student engagement and provide opportunities for further exploration beyond the core material.

3.4 Laboratory Activities

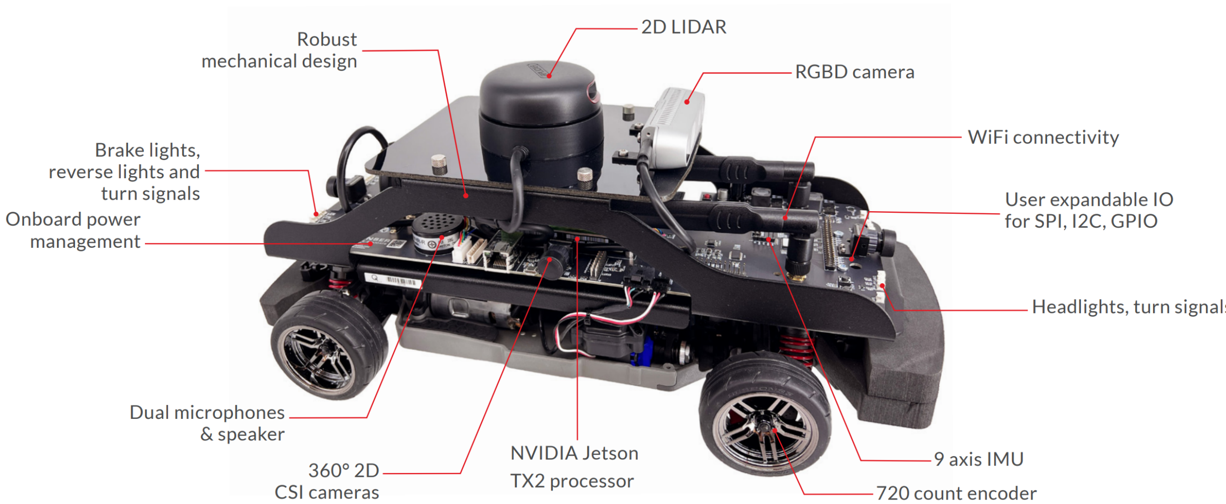
The laboratory activities were carefully selected to complement the theoretical modules by providing students with hands-on, experiential learning in key components of AV systems. All activities were conducted in the newly established Autonomous Systems and Robotics Laboratory within the College of Engineering and Computer Science at California State University, Sacramento. The lab is equipped with a Self-Driving Car Studio (Figure 2), which provides a realistic and controlled environment for experimentation and system development.

Figure 2. Self-Driving Car Studio



The laboratory includes QCar (Figure 3) as an advanced AV platform, which is integrated with the studio infrastructure to support the implementation of the lab activities.

Figure 3. QCar Platform



The primary goal of these activities was to expose both civil and electrical engineering students to the practical aspects of sensing, perception, and control in autonomous systems. Through structured experiments, including RGB imaging, LiDAR-based point cloud generation, lane following, and vehicle operation using the QCar platform, students progressively developed their skills. The activities were designed to build competency in a step-by-step manner, starting from understanding raw sensor data to real-time decision-making and control strategies. By engaging with real hardware and software platforms, students gain critical insight into how AVs perceive and interact with their environment, which is essential for understanding intelligent transportation systems and infrastructure integration. Overall, the selected laboratory topics aim to bridge the gap between theory and practice, enhance students' confidence, and foster the interdisciplinary skill set required for the emerging autonomous transportation workforce. All simulations were conducted in MATLAB/Simulink to help students better understand how different modules are integrated to accomplish a specific objective.

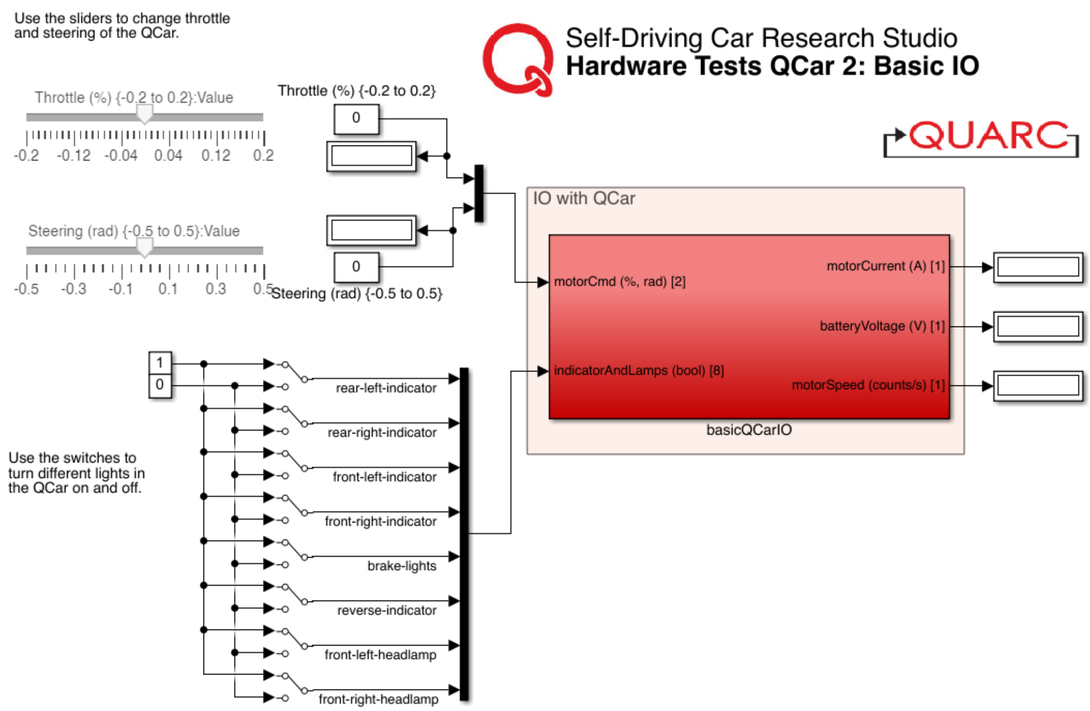
3.5 Developing Laboratory Activities

The following section outlines each hands-on activity and its associated learning objectives.

3.5.1 Hardware Tests Activity

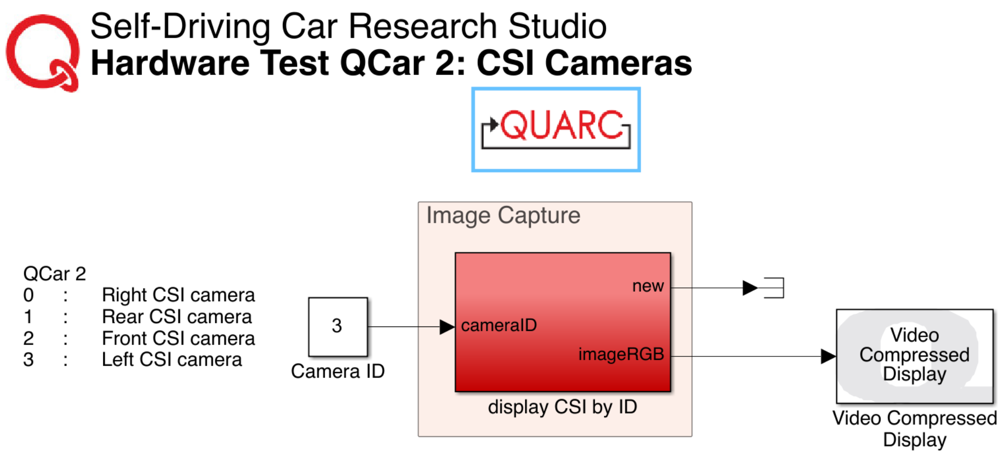
This activity focuses on verifying that all QCar system components, such as CSI cameras, LiDAR, motors, and sensors, are functioning correctly before running advanced experiments. Students perform connectivity checks, deploy real-time models, and test individual subsystems like cameras and LiDAR visualization. The goal is to ensure proper system setup and build confidence in interacting with hardware and real-time systems. The simulation models used in the hardware test activities are given below. The simulation model shown in Figure 4 is the basic input and output test model. It allows students to send commands to the throttle and steering motors and to set the eight LEDs to either high (1) or low (0). In addition, the model enables monitoring of motor current, battery voltage, and motor speed. A positive throttle command drives the wheels forward, while a positive steering command turns the front wheels to the left, resulting in a counterclockwise rotation of the vehicle.

Figure 4. Basic Input and Output Test Simulation Model



The simulation model in Figure 5 displays the output of the four CSI cameras installed around QCar 2. Depending on the selected camera ID constant (0 to 3), the model shows the corresponding CSI image in the video display. This allows students to confirm proper camera functionality and understand how multiple camera views can be accessed in the vehicle platform.

Figure 5. CSI Cameras Test Simulation Model



The Simulink model in Figure 6 captures LiDAR data from the QCar 2 LiDAR sensor and displays it in a polar plot to visualize the laser scans. In this plot, the 0-degree mark corresponds to the front of the vehicle, and the scan proceeds in the positive counterclockwise direction. This activity helps students observe how LiDAR data represents the surrounding environment and introduces them to one of the key sensing technologies used in autonomous vehicles.

Figure 6. LiDAR Test Simulation Model

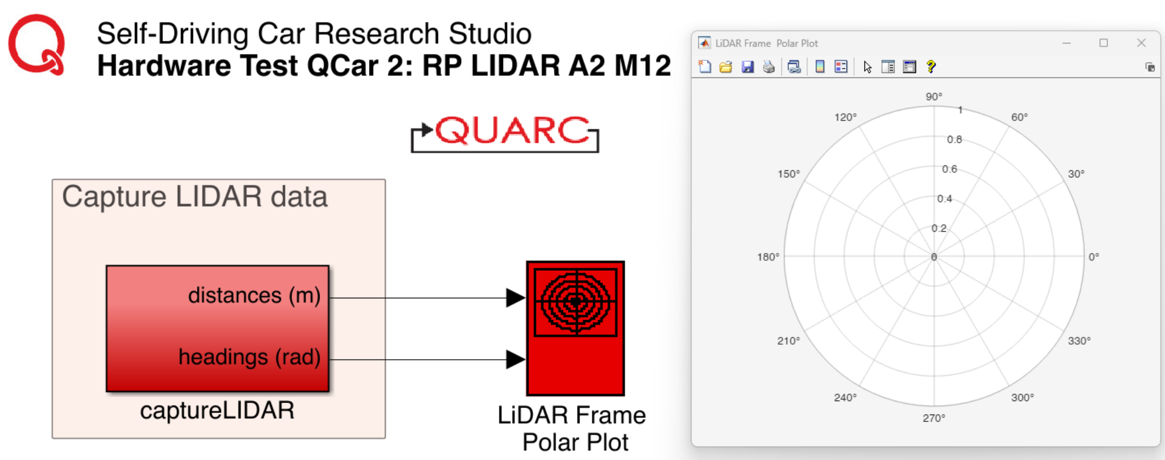
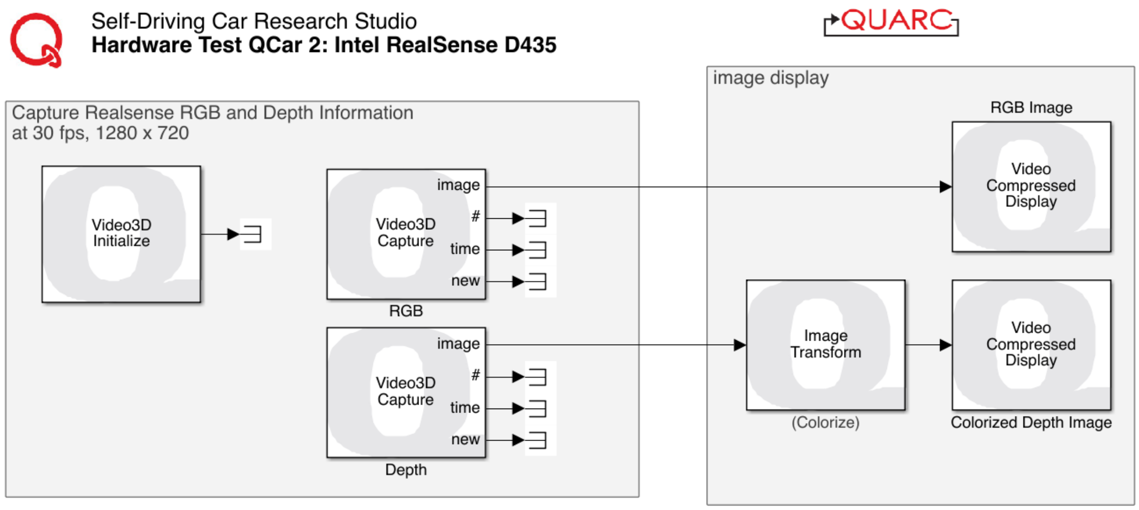


Figure 7 presents the depth camera simulation model, which launches RGB and depth video displays to demonstrate the performance of the QCar 2 depth camera. Through this model, students can observe both color imagery and depth information, helping them understand how depth cameras contribute to environmental perception in autonomous systems.

Figure 7. Depth Camera Simulation Model



3.5.2 RGB-D Imaging Activity

In this activity, students capture synchronized RGB and depth images using an Intel RealSense camera and apply image processing techniques to detect a red stop sign. The system then estimates the distance to the detected object using corresponding depth data. The goal of this activity is to introduce students to depth sensing and demonstrate how visual and depth information can be combined for object detection and distance estimation.

Figure 8. RGBD Imaging Simulation Model

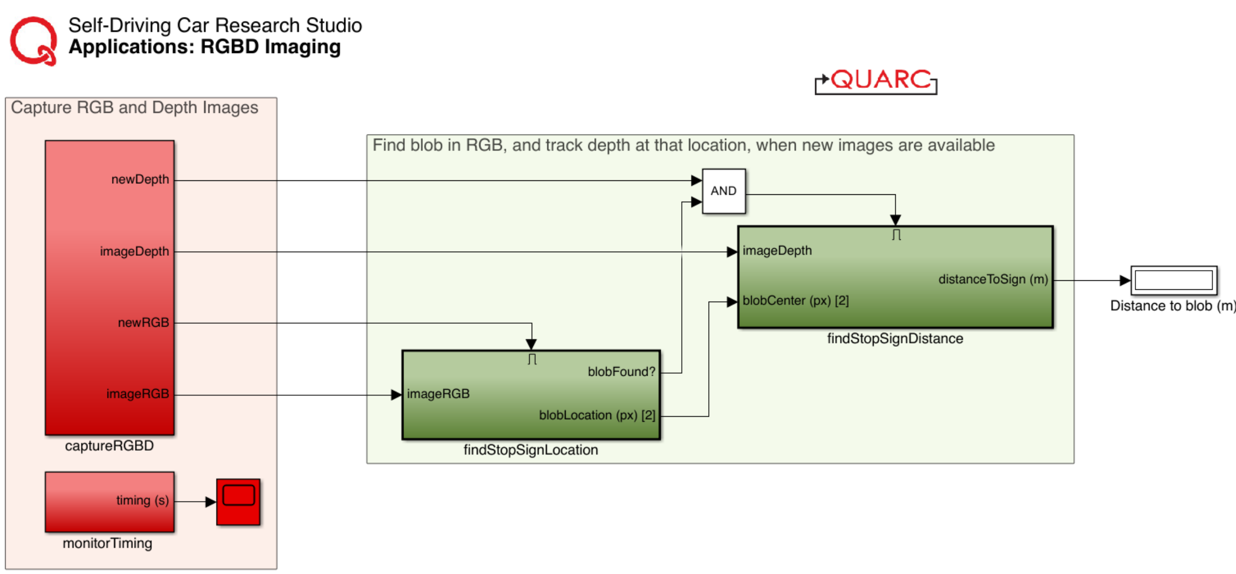


Figure 8 presents the RGB-D imaging simulation model used for detecting a stop sign and estimating its distance using synchronized RGB and depth data. In this model, RGB and depth images are captured simultaneously from the Intel RealSense camera. The RGB image is processed through a color thresholding module (in HSV space) to isolate the red stop sign, and an image processing block is used to identify the coordinates of the detected object. These coordinates are then mapped to the corresponding location in the depth image to extract the distance to the object. The model also includes display blocks to visualize the raw RGB image, the thresholder binary image, and the depth image, as well as a timing module to monitor system performance. This integrated approach demonstrates how visual perception and depth sensing can be combined to perform real-time object detection and distance estimation, which are essential capabilities in autonomous vehicle systems.

3.5.3 LiDAR Point Cloud Generation Activity

Students collect LiDAR data and convert it into a 2D/3D point cloud representation of the environment. The system processes distance and angle data to generate spatial maps of the surroundings. Students understand how autonomous vehicles perceive their environment using LiDAR and build spatial awareness through mapping.

Figure 9. LiDAR Point Cloud Simulation Model

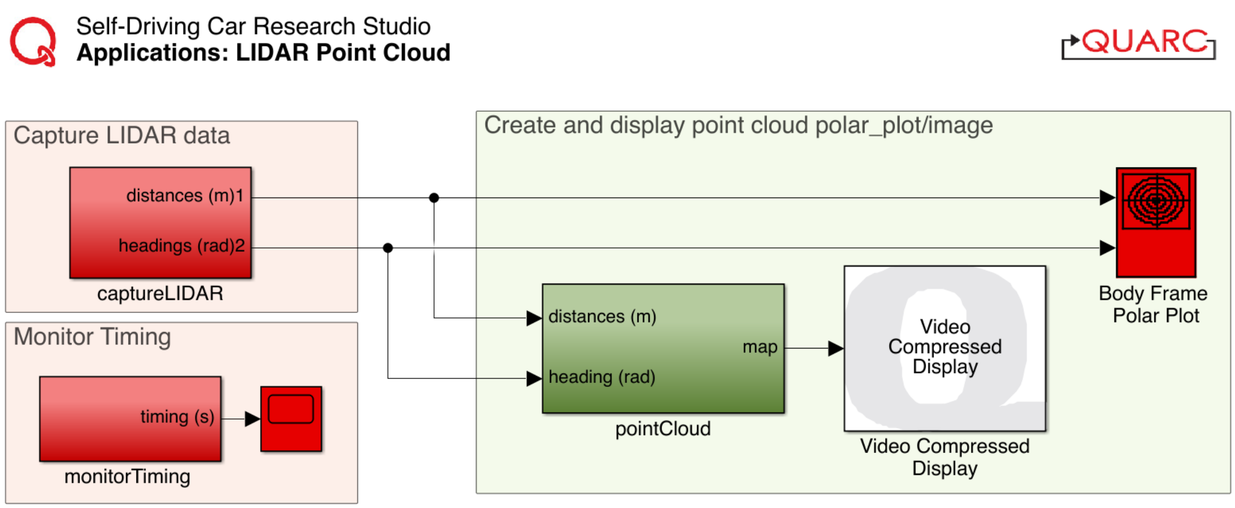


Figure 9 presents the LiDAR point cloud simulation model used to capture and visualize the surrounding environment. In this model, LiDAR data is collected from the QCar platform and processed to generate a spatial map in the form of a point cloud. The system first captures distance and angular (heading) measurements from the LiDAR sensor, which are then converted into Cartesian coordinates (X–Y points) to represent the environment. These points are plotted and accumulated over time to form a 2D map of the surroundings, while older data gradually decays to maintain a real-time representation. The model also includes visualization blocks to display the generated point cloud and a timing module to monitor system performance. This simulation demonstrates how LiDAR sensors enable autonomous vehicles to perceive their environment by constructing spatial maps from raw sensor data, which is essential for navigation, obstacle detection, and situational awareness.

3.5.4 Manual Drive Activity

This activity allows students to manually control the QCar using a gamepad while monitoring system parameters such as speed, battery level, and power consumption. The goal is to familiarize students with vehicle dynamics, control inputs, and system feedback in a controlled environment.

Figure 10. QCar Manual Drive Simulation Model

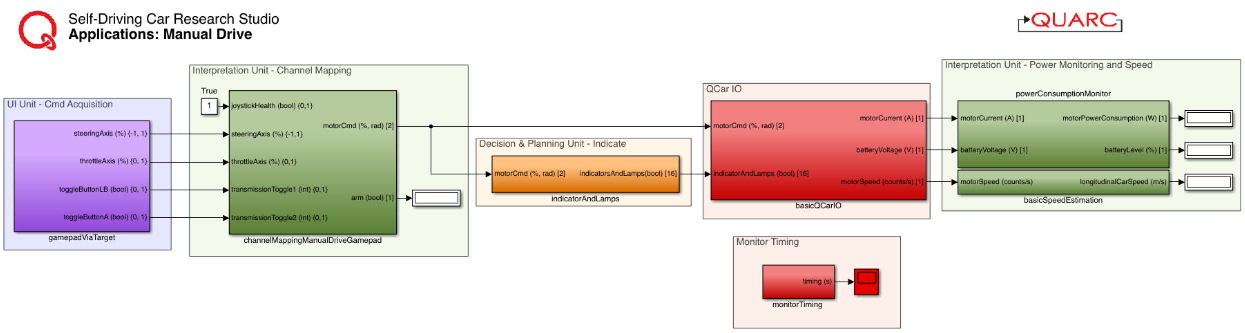


Figure 10 presents the manual drive simulation model used to control the QCar platform using a gamepad interface. In this model, user inputs from the gamepad are captured and interpreted into steering and throttle commands that are sent to the QCar system. The simulation includes modules for processing control inputs, interfacing with the vehicle hardware (QCar I/O), and updating indicators such as LEDs and status signals. In addition, the model integrates feedback components that estimate vehicle speed and monitor power consumption and battery level in real time. A timing module is also included to track system performance during operation. This setup allows students to observe the relationship between control inputs and vehicle response while monitoring key system parameters, providing hands-on experience with vehicle dynamics, control, and real-time system feedback.

3.5.5 Lane Following Activity

Students implement a vision-based lane-following system using camera input, color thresholding, and image processing to detect lane markings. The system also incorporates obstacle detection using depth data and adjusts speed accordingly. The goal is to develop an understanding of perception, decision-making, and control algorithms for autonomous driving.

Figure 11. Lane Following Simulation Model

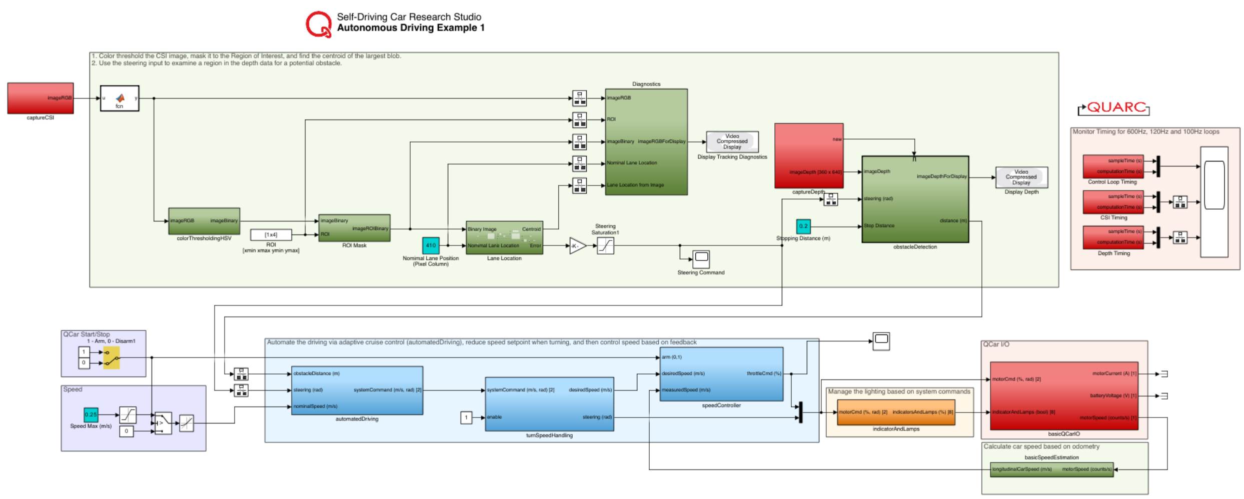


Figure 11 presents the lane-following simulation model with integrated obstacle detection used on the QCar platform. In this model, image data from the CSI camera is processed to extract lane markings using color thresholding in the HSV color space, followed by filtering and region-of-interest selection to isolate the relevant portion of the road. The system identifies the lane position by detecting the largest valid lane region and estimating its trajectory, which is then used to generate a steering command. In parallel, depth data from the Intel RealSense camera is analyzed to detect obstacles within a defined region ahead of the vehicle, allowing the system to estimate obstacle distance. Based on this information, a control module adjusts the vehicle's speed to maintain safe operation, slowing down or stopping when necessary. Additional subsystems handle speed control, steering adjustments, and indicator signals, while a timing module monitors overall system performance. This integrated model demonstrates how perception (vision and depth sensing), decision-making, and control are combined to enable autonomous lane-following behavior in real time.

3.5.6 The 360° Vision Activity

This activity captures images from four cameras mounted around the vehicle and stitches them into a single panoramic view for full environmental awareness. The objective is to demonstrate multi-camera systems and provide a comprehensive view of surroundings, which is critical for safe navigation and situational awareness.

Figure 12. 360° Vision Simulation Model

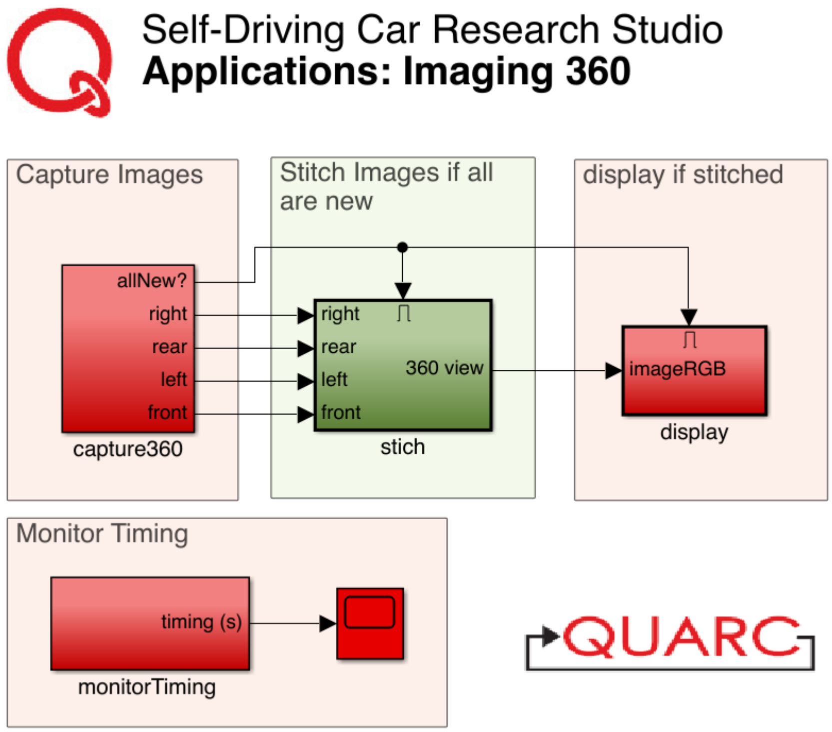


Figure 12 presents the 360° vision simulation model used to generate a panoramic view of the vehicle's surroundings. In this model, images are simultaneously captured from four CSI cameras mounted around the QCar (front, rear, left, and right). These images are processed and stitched together to form a single composite view, which is displayed to provide a comprehensive representation of the environment. The model includes a synchronization mechanism that ensures images are only stitched and displayed when all camera frames are updated, improving performance and consistency. A timing module is also incorporated to monitor system execution. This simulation demonstrates how multi-camera systems can be integrated to achieve full situational awareness, which is essential for safe navigation and perception in autonomous vehicle applications.

Overall, these activities progressively guide students from basic system interaction to advanced perception and autonomy concepts, reinforcing both theoretical knowledge and practical skills.

3.6 Program Deployment

After the educational modules and laboratory activities were fully designed and developed, the next phase involved program deployment. A certificate program titled Workforce for Autonomous Vehicle Engineering (WAVE) was established to deliver the curriculum. A dedicated Canvas course page was created under this title, and all instructional materials were organized and uploaded accordingly. The platform included a welcome page outlining the program structure, expectations, and navigation guidance, directing students to the relevant educational modules (Figure 13).

Figure 13. WAVE Canvas Page

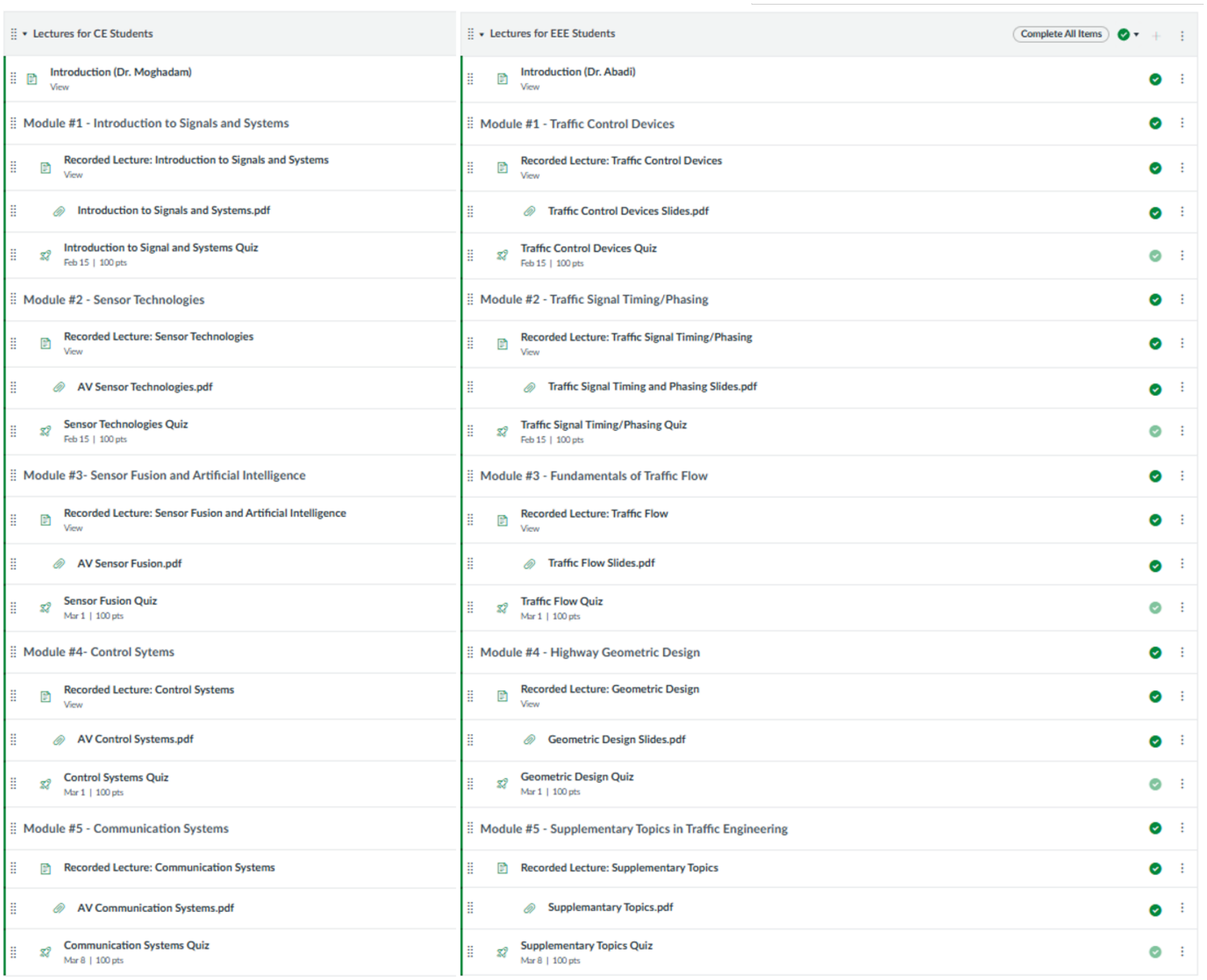
A structured 7-week implementation plan was developed to guide program delivery (Table 1). A total of 53 students from California State University, Sacramento (28 from Civil Engineering and 25 from Electrical Engineering) were recruited and enrolled in the program. During the first five weeks, students progressed through the educational modules, which were released sequentially. Canvas was configured to enforce a mastery-based progression: students were required to watch the recorded lecture, complete the associated quiz, and achieve a minimum score of 80% before advancing to subsequent modules.

Table 1. Program Delivery Schedule

Topic			**Week**	**Date**
Module #1	EEE Students	Traffic Control Devices	1 and 2	2/2 to 2/15
	CE Students	Introduction to Signal Processing		
Module #2	EEE Students	Traffic Signal Timing and Phasing		
	CE Students	Sensor Technologies		
Module #3	EEE Students	Traffic Flow Theory	3 and 4	2/16 to 3/1
	CE Students	Sensor Fusion		
Module #4	EEE Students	Roadway Geometric Design		
	CE Students	Control and Decision		
Module #5	EEE Students	Supplementary Topics	5	3/2 to 3/8
	CE Students	Communication Systems		
Hands-On Experience Learning Workshops (both EEE and CE Students)			6 and 7	3/9 to 3/22

Although students were primarily assigned modules outside their home discipline (e.g., civil engineering students focused on electrical engineering topics and vice versa), all course materials were made accessible to every participant. This approach ensured exposure to interdisciplinary content while also allowing students to explore the full set of resources for future reference. Figure 14 shows the educational modules on Canvas.

Figure 14. WAVE Educational Modules



Following completion of the modules, students participated in two weeks of laboratory activities. They were organized into groups of four, with each group intentionally composed of two students from each discipline to promote interdisciplinary collaboration. Students attended a 90-minute lab session designed to provide hands-on experience with AV systems, with a total of eight lab sessions conducted. Each group was required to produce a final report based on their laboratory work.

Upon successful completion of all program components, students were awarded a certificate of completion (Figure 15).

Figure 15. WAVE Certificate of Completion

4. Program Evaluation

Evaluation is a cornerstone of any educational initiative, particularly for interdisciplinary programs such as the one developed in this study. To ensure a comprehensive assessment of both the curriculum and its impact, we implemented a three-layered evaluation framework. First, pre- and post-program surveys were administered to participants to measure changes in knowledge, skills, and perceptions, thereby assessing the effectiveness of the curriculum. Second, students were asked to evaluate their learning experience throughout the program, providing insights into content delivery, structure, and overall engagement. Finally, a panel of industry experts was convened to review the curriculum and offer professional feedback, ensuring alignment with current industry needs and expectations.

4.1 Pre- and Post- Student Surveys

The first component of the evaluation consisted of pre- and post-program surveys designed to assess changes in student knowledge and self-perception. A questionnaire was developed comprising ten technical questions from each discipline, aligned with the topics covered in the curriculum (Table 2). To emphasize interdisciplinary learning, students were asked to answer questions from the discipline outside their primary field of study. These surveys were administered at two points in time: prior to the start of the program and after its completion. Using an identical set of questions for both pre- and post-assessments enabled direct measurement of gains in knowledge, as well as shifts in understanding, problem-solving ability, and familiarity with cross-disciplinary concepts.

Table 2. Pre- and Post-Survey Questions

Part A: Transportation Engineering Questions Asked of Electrical Engineering Students			
1) Imagine a driver traveling on a highway suddenly encounters a box in the middle of their travel lane. How long, on average, does it take for the driver to perceive the hazard and react to it?			
a) 0.5 seconds	b) 1.0 second	**c) 2.5 seconds**	d) 5.0 seconds
2) What is the ideal width of a travel lane on a highway?			
a) 9 feet	b) 10 feet	**c) 12 feet**	d) 16 feet
3) Which statistical distribution is typically used to model vehicle arrivals at a signalized intersection?			
a) Normal	**b) Poisson**	c) Uniform	d) Exponential
4) What is a commonly used safe design value for pedestrian walking speed in transportation planning and engineering?			
a) 2.0 ft per second	**b) 3.5 ft per second**	c) 4.5 ft per second	d) 5.0 ft per second
5) In traffic flow theory, what is the relationship between traffic flow, density, and speed?			
a) As density increases, speed decreases.	b) As flow increases, speed increases.	c) As density increases, speed increases.	d) There is no relationship between these parameters.
6) Which color is primarily used in traffic signs to indicate temporary traffic control, such as construction zones?			
a) Yellow	**b) Orange**	c) Red	d) Blue
7) With a protected left-turn:			
a) The turn is made across opposing traffic.	b) The turn is allowed unless prohibited by a sign.	c) The signal uses only circular indications.	**d) Drivers may turn only when a solid green arrow is displayed**.
8) Time-mean speed (TMS) is calculated based on:			
a) Average travel time over a section of road	b) Harmonic mean of speeds	**c) Spot speeds of vehicles passing a point**	d) Spacing between vehicles
9) Which curve is commonly used for vertical alignment in highway design to ensure smooth rate of change of grade?			
a) Circular	**b) Parabolic**	c) Polynomial	d) Triangular
10) Which curve is most used for horizontal alignment in highway design to connect two tangents?			
a) Circular	b) Parabolic	c) Polynomial	d) Triangular
Part B: Electrical Engineering Questions Asked of Civil Engineering Students			
1) What is the primary role of LiDAR sensors in autonomous vehicles?			
a) Detecting fuel efficiency levels	**b) Measuring distances and creating 3D maps of the environment**	c) Communicating with nearby vehicles	d) Controlling vehicle speed
2) Which of the following technologies is primarily used to detect lane markings on the road?			
a) GPS	b) Infrared sensors	**c) Camera-based vision systems**	d) Ultrasonic sensors
3) What is the purpose of SLAM in autonomous vehicles?			

a) To detect road signs	b) To navigate through traffic signals	c) To build a map of an unknown environment and track the vehicle's position within it	d) To optimize fuel efficiency during navigation

4) What redundancy systems are in place to ensure safety in case of sensor failure in autonomous vehicles?

a) Autonomous vehicles rely on a single type of sensor to maintain accuracy.	b) Sensor fusion combines data from multiple sensors (e.g., LiDAR, radar, cameras) to ensure continuous operation if one sensor fails.	c) Backup systems for critical components (e.g., braking, steering) are designed to ensure safe operation in case of primary system failure.	d) Software fail-safe algorithms detect sensor failure and trigger emergency maneuvers, such as slowing down or pulling over.

5) How do autonomous vehicles adapt to varying weather conditions like rain, snow, fog, and extreme temperatures?

a) Autonomous vehicles rely solely on GPS to navigate through all weather conditions.	b) They use sensor fusion, combining data from multiple sensors like radar, LiDAR, and cameras to detect obstacles and adjust vehicle behavior.	c) They adjust vehicle speed and driving behavior based on real-time weather data from environmental sensors.	d) The vehicle automatically activates safety mode to reduce risk during poor visibility or slippery road conditions.

6) What is the main purpose of a control system in an autonomous vehicle?

a) To provide entertainment and navigation maps	b) To transmit data between vehicles	c) To store sensor data for later use	d) To decide how the vehicle should steer, accelerate, and brake to follow a desired path

7) Why is feedback important in autonomous vehicle control systems?

a) It allows the vehicle to predict traffic congestion.	b) It replaces the need for sensors.	c) It helps the vehicle compare desired motion with actual motion and correct errors.	d) It increases internet connectivity.

8) What is the main goal of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication?

a) To allow vehicles to share information for safety and traffic efficiency	b) To improve vehicle styling and design	c) To replace onboard sensors	d) To control the vehicle without a driver

9) How do communication systems support autonomous vehicle control?

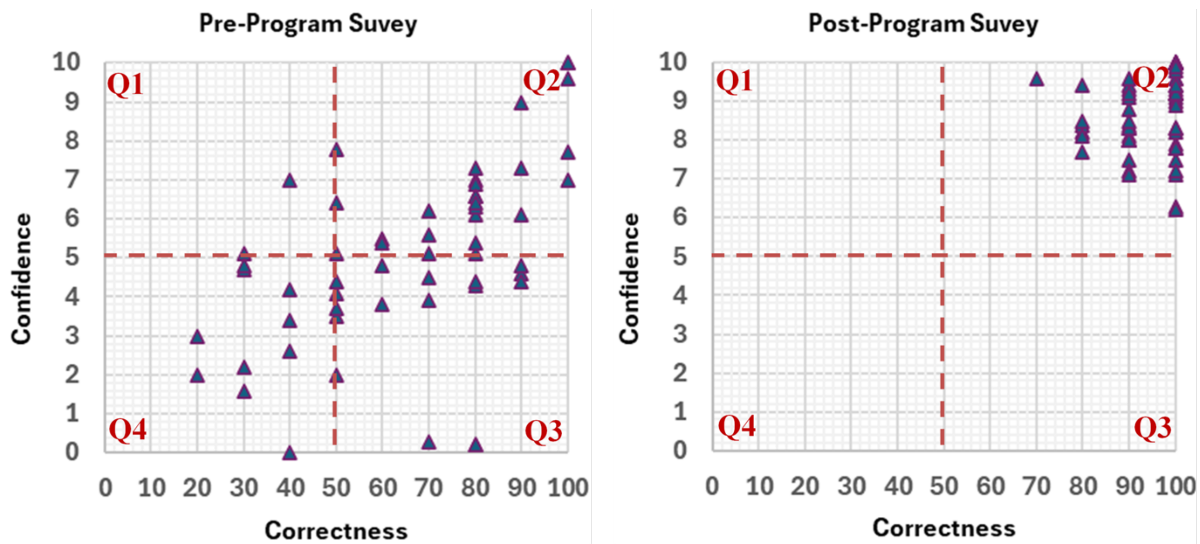
a) By directly steering the vehicle	b) By providing additional information (e.g., traffic signals, nearby vehicles) that helps control decisions	c) By eliminating the need for control algorithms	d) By increasing vehicle speed

10) Which scenario best shows control systems and communication systems working together?			
a) A vehicle using only GPS to display a map	b) A vehicle playing a warning sound for the driver	c) A vehicle recording camera data	d) A vehicle adjusting its speed after receiving a red-light warning from a traffic signal

In addition to answering each question, students were asked to rate their confidence in their responses immediately afterward on a scale from 0 (not confident at all) to 10 (very confident). This approach allowed us to capture not only objective learning outcomes but also self-efficacy and perceived competence. By combining performance data with confidence ratings, the evaluation provided a more comprehensive view of student development, highlighting both improvements in technical knowledge and changes in students' confidence in applying that knowledge.

The results of the pre- and post-survey analysis demonstrate a strong and consistent improvement in both student performance and confidence. Figure 16 presents the relationship between response correctness and average self-reported confidence for each of the 53 participants before and after completion of the program. The figure is divided into four quadrants, each representing a distinct combination of competence and confidence. Quadrant 1 represents students with low correctness but high confidence. This misalignment is particularly concerning, as it may lead to overconfidence in incorrect understanding, potentially resulting in poor engineering decisions. Quadrant 3 includes students with high correctness but low confidence; while these students possess the necessary knowledge, a lack of confidence may limit their willingness to engage in technical tasks or contribute effectively in professional settings. Quadrant 4 consists of students with both low correctness and low confidence, indicating a need for foundational development. In contrast, Quadrant 2 represents the desired outcome: students who demonstrate both high correctness and high confidence, reflecting strong competence coupled with the ability to apply that knowledge effectively.

Figure 16. Students' Performance in Pre- and Post-Surveys



An effective educational program should aim to develop a workforce that not only possesses the required technical knowledge but also demonstrates confidence in applying that knowledge in practice. As illustrated in Figure 16, the goal is to guide students from Quadrants 1 (low competence, high confidence), 3 (high competence, low confidence), and 4 (low competence, low confidence) into Quadrant 2 (high competence, high confidence). While the pre-survey results showed students distributed across all four quadrants, the post-survey results indicate a clear shift, with participants converging into Quadrant 2. This outcome suggests that the developed program was highly effective in improving both technical understanding and self-confidence, aligning with the intended learning objectives and workforce development goals.

One might argue that confidence in one’s knowledge does not necessarily correspond to the actual ability to apply that knowledge effectively in practice. In this study, correctness and confidence are evaluated as complementary but distinct dimensions. Response correctness serves as an indicator of technical understanding, while confidence is interpreted as a proxy for self-efficacy, or students’ perceived readiness to apply their knowledge in practical settings. This distinction is particularly important in engineering education, where willingness to engage in problem-solving, decision-making, and collaborative technical tasks may be influenced not only by knowledge acquisition but also by perceived capability. Since the current study did not include direct measures of workplace performance in AV-related environments, confidence was incorporated as an indirect indicator of students’ preparedness to apply learned concepts.

At the same time, the framework explicitly recognizes the potential risks associated with overconfidence. Excessive confidence unsupported by demonstrated competence may discourage individuals from questioning assumptions, seeking additional knowledge, or remaining responsive to evolving technical standards and industry practices. For this reason, the study does not interpret high confidence alone as a desirable educational outcome. In fact, students categorized in Quadrant 1 (low correctness, high confidence) represent a potentially problematic condition in which confidence is misaligned with actual understanding. The desired outcome is therefore not confidence in isolation, but an appropriate alignment between competence and self-efficacy. The program's laboratory activities and hands-on exercises were intentionally designed to promote confidence through mastery experiences and experiential learning, which have been identified as key contributors to self-efficacy development (Bandura, 1997). By grounding confidence in demonstrated task performance and practical problem-solving activities, the program sought to encourage informed self-efficacy while minimizing unsupported overconfidence.

4.2 Students' Evaluation of Program Effectiveness

To further evaluate the effectiveness of the program, a post-program survey using Likert-scale questions was administered to capture students' perceptions and experiences. A five-point Likert scale (ranging from "strongly disagree" to "strongly agree") was selected as it provides a structured and reliable way to quantify subjective feedback, enabling the assessment of attitudes, satisfaction, and perceived learning outcomes. The survey was designed to evaluate multiple dimensions of the program. First, questions related to learning materials assessed the clarity, quality, and instructional effectiveness of Canvas modules, recorded lectures, presentation slides, and quizzes. Second, program design and organization were evaluated to understand how well the course structure, expectations, and interdisciplinary balance supported student learning. Third, the hands-on laboratory component was examined, focusing on the clarity of instructions, the adequacy of support, and the effectiveness of the AV platform (QCar) in enhancing practical understanding. Finally, overall experience questions captured broader outcomes such as workload appropriateness, the effectiveness of interdisciplinary integration, increased interest in autonomous vehicle technologies, and students' confidence in working across disciplines. The results of these Likert-scale responses are summarized in Table 3 and provide an overview of student perceptions across these key areas.

Table 3. Students' Evaluation of Program Effectiveness

		Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree
Part 1 – Learning Materials	The Canvas modules were well-structured and easy to navigate.	46	6	0	0	1
	The recorded lectures were clear and easy to follow.	44	8	0	0	1
	The PowerPoint slides supported my understanding of key concepts.	41	10	1	0	1
	The quizzes helped reinforce my learning.	41	11	0	0	1
Part 2 – Program Design and Organization	The program was well-organized.	39	12	1	0	1
	The expectations and objectives were clearly communicated.	35	15	2	0	1
	The balance between civil engineering and electrical engineering content was appropriate.	31	12	6	3	1
Part 3 – Hands-On Labs	The lab instructions and support were clear and sufficient.	31	16	0	5	1
	The hands-on labs enhanced my understanding of the course material.	38	12	2	0	1
	The autonomous vehicle platform (QCar) was effective for learning.	47	4	1	0	1
Part 4 – Overall Experience	The workload for this program was appropriate.	45	6	2	0	0
	The integration of topics from both disciplines was	38	11	2	2	0

		Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree
	meaningful and effective.					
	The program increased my interest in autonomous vehicle technologies.	40	10	3	0	0
	I feel more confident working across disciplines after completing this program.	30	17	4	2	0

The results summarized in Table 3 indicate a highly positive student response across all aspects of the program. A strong majority of participants either strongly or somewhat agreed that the learning materials were clear, well-structured, and effective in supporting their understanding. Similarly, the program design, organization, and interdisciplinary balance were well received, with only minimal disagreement. The hands-on labs, particularly the use of the AV platform, were rated very favorably and contributed meaningfully to student learning. Overall, students found the workload appropriate, reported increased interest in autonomous vehicle technologies, and expressed greater confidence in working across disciplines. These findings collectively demonstrate the success of the program in achieving its educational and workforce development objectives.

Following the quantitative assessment, open-ended questions were included to gather more detailed qualitative feedback. These prompts asked students to (1) reflect on which aspects of the program were most effective, (2) identify areas for improvement, and (3) provide suggestions for the instructor. The open-ended responses revealed several clear and consistent trends across participants. Students overwhelmingly identified recorded lectures, slides, quizzes, and especially the hands-on lab experience as the most effective components of the program. In particular, the ability to interact with the QCar platform and observe real-world system integration significantly enhanced understanding, while quizzes and structured materials reinforced key concepts. In terms of areas for improvement, a dominant theme was the need for more time and depth in the hands-on labs. Many students felt that the lab sessions were short. Related suggestions included extending lab duration, offering multiple sessions, and reducing group sizes. Additionally, some students recommended more practice problems. Overall, the feedback suggests that while the program was highly effective and well-received, students consistently expressed a desire for expanded hands-on engagement and deeper exploration of technical concepts, particularly in connecting theory to practice.

4.3 Panel of Industry Experts

As part of the project, a panel of industry experts was convened to evaluate the developed educational materials and provide guidance on aligning the program with current and future workforce needs in the autonomous vehicle sector. The panel included representatives from leading industry organizations and public agencies, including:

1. Lindy Johnson, Director of External Affairs, Contra Costa Transportation Authority (CCTA) (*External Advisor*)
2. Sydnee Journel, Senior Manager of Government Relations, Aurora
3. Leslie Keaveney, Senior Manager of Policy Engineering, Aroura
4. Mohammed Tayarani, Senior Transportation Data Analyst, California Public Utilities Commission (CPUC)
5. Justin Ellis, Chief of the Electrical Quality Assurance Department, California Department of Transportation (Caltrans)
6. Arielle Fleisher, Policy Development and Research, Waymo

All project materials, including the developed educational modules and hands-on laboratory activities, were shared with the industry panel in advance of the Panel of Industry Experts meeting to enable a thorough and informed review. In addition to the panel meeting, an Industry Advisory Board survey was distributed to collect structured feedback on multiple aspects of the program, including technical content, hands-on activities, and workforce alignment. The survey included open-ended questions addressing program strengths, gaps, emerging technologies, and future directions.

Based on the survey responses, industry experts highlighted several strengths of the program, particularly its interdisciplinary structure and the integration of theoretical and hands-on components. At the same time, they proposed specific improvements and future directions. These included expanding the technical content to incorporate emerging topics such as connected and autonomous vehicle technologies, artificial intelligence, and data-driven methods. Regarding hands-on activities, respondents emphasized the importance of increasing real-world relevance by incorporating industry-standard tools, datasets, and platforms, as well as strengthening the connection between laboratory exercises and practical AV system development.

Survey participants also provided recommendations for future program growth. These included developing new modules or short courses, establishing industry-recognized certification pathways, creating internship and workforce development opportunities, and aligning the curriculum with industry standards and practices. Additionally, respondents suggested expanding outreach efforts, including potential K–12 engagement, to broaden the impact of the program. From a workforce development perspective, the feedback emphasized the need to strengthen student competencies in areas such as system integration, data analysis, and understanding of regulatory and policy frameworks, which are critical for careers in the evolving AV industry.

The panel meeting served as a critical platform for interdisciplinary exchange, where industry professionals evaluated the effectiveness of the WAVE (Workforce for Autonomous Vehicle Engineering) program. Experts reinforced the value of integrating transportation engineering topics (e.g., traffic control devices and signal timing) with emerging technologies such as sensing, perception, and control systems. Panelists emphasized that such interdisciplinary training is essential for preparing a workforce capable of addressing real-world AV challenges, which require both infrastructure knowledge and advanced technological skills.

In addition to evaluating the current program, the panel identified several opportunities for further enhancement. Key recommendations included incorporating connected vehicle (V2X) technologies, big data analytics, cloud computing, and artificial intelligence/machine vision into future modules. Industry participants also stressed the importance of integrating policy, regulatory frameworks, and transportation planning concepts to ensure students understand the broader system-level implications of AV deployment.

Furthermore, the panel highlighted the value of strengthening partnerships between academia and industry through initiatives such as access to real-world testbeds (e.g., connected vehicle facilities), internship opportunities, and co-developed certification programs. The discussion also underscored the importance of hands-on, experiential learning using advanced platforms, enabling students to gain practical experience with integrated AV technologies, including sensing, communication, perception, and real-time control.

Overall, the panel of industry experts played a pivotal role in validating the program's interdisciplinary approach, ensuring alignment with workforce needs, and identifying strategic directions for future development.

5. Conclusion

AVs are rapidly transitioning from emerging technology to an integral component of future transportation systems. Their widespread adoption is expected to significantly influence multiple dimensions of society, including mobility patterns (e.g., shifts in commute modes), safety (e.g., interactions with pedestrians and bicyclists), equity (e.g., access to AV technologies), public health (e.g., increased reliance on motorized travel in an already car-centric society), environmental sustainability (e.g., impacts of AV and electric vehicle integration on vehicle miles traveled), and land use (e.g., reduced need for parking infrastructure). Collectively, these changes have the potential to reshape the overall quality of life.

Among these impacts, workforce transformation is likely to be one of the most significant. The deployment of AV technologies will disrupt traditional roles within the transportation and automotive sectors while simultaneously creating new opportunities that require interdisciplinary technical expertise. Addressing this evolving demand for skills and knowledge is critical. It is within this context that the present study is positioned, focusing on the development and implementation of an interdisciplinary educational framework to prepare the future workforce for AV systems.

AV development and deployment inherently require a multidisciplinary approach, encompassing a wide range of technical domains such as engineering and computer science, as well as broader areas including project management and data analytics. Accordingly, effective AV workforce development programs must reflect this interdisciplinary nature. However, a review of existing programs indicates that electrical engineering and computer science are often emphasized as the primary foundational disciplines, while the role of transportation engineering is frequently underrepresented. In response to this gap, the program developed in this study intentionally integrates fundamental transportation engineering concepts with core electrical engineering principles, highlighting their interconnected roles in preparing a comprehensive AV workforce.

To bridge the gap between civil/transportation engineering and electrical engineering, a two-step curriculum design was developed following the identification of core knowledge areas. First, through a review of current state-of-practice and up-to-date standards, a series of educational modules was created to cover the theoretical foundations in each discipline. Subsequently, hands-on learning modules were developed to demonstrate the practical application of these concepts within AV systems, enabling students to connect theory with real-world implementation. While the lectures and accompanying slides introduced key concepts in transportation engineering (e.g., traffic control devices, traffic flow theory, and roadway geometric design) and electrical engineering (e.g., sensing technologies, perception, control, and real-time system implementation), the laboratory exercises provided students with direct, hands-on experience using the QCar platform. These activities included camera-based perception, LiDAR mapping, depth sensing, manual vehicle control, lane following, and multi-sensor integration, allowing students to apply theoretical knowledge within a practical AV system context.

The developed program, titled Workforce for Autonomous Vehicle Engineering (WAVE), was implemented at California State University, Sacramento. During Spring 2026, a total of 53 students from Civil Engineering and Electrical Engineering were recruited to participate in the program. A structured seven-week schedule was designed for delivery. During the first five weeks, students completed the theoretical modules in a self-paced format through a customized Canvas platform, with five modules from each discipline. This was followed by a two-week period during which students attended the Self-Driving Car Studio to gain hands-on experience with AV systems.

To evaluate the effectiveness of WAVE, a three-layered assessment framework was implemented, with results consistently indicating the success of the program. First, a pre- and post-program survey was conducted to assess students' technical knowledge and their confidence in their responses. The results revealed an ideal shift in student outcomes: by the end of the program, participants not only demonstrated high levels of technical competence but also exhibited strong confidence in their knowledge. This alignment between competence and confidence highlights the effectiveness of the two-step curriculum design, which integrates both theoretical instruction and hands-on experiential learning.

At the second layer, an anonymous program evaluation was conducted to capture student perceptions. The responses were overwhelmingly positive across all aspects of the program. For instance, 96.2% of participants agreed or strongly agreed that the hands-on labs using the QCar platform were effective, 94.3% reported increased interest in AV technologies, and 88.7% indicated greater confidence in working across disciplines. These results underscore the program's strong impact not only on learning outcomes but also on student engagement, motivation, and interdisciplinary readiness, which are key indicators of successful workforce development initiatives.

The third layer of evaluation involved input from industry professionals through a panel of experts. The panel strongly endorsed the program's interdisciplinary structure and the integration of theoretical and hands-on components as major strengths and reinforced the value of the WAVE program as a forward-looking model for preparing a workforce capable of addressing the complex, multidisciplinary challenges of AV systems.

Despite its overall success, the WAVE program revealed several areas for improvement. Student feedback consistently indicated a desire for increased time in the hands-on laboratory component; however, extending lab duration was constrained by the project's timeline and logistical limitations. In addition, the industry expert panel identified opportunities to further strengthen the curriculum by incorporating emerging topics such as connected vehicle technologies, artificial intelligence, data-driven methods, and cloud-based systems. These findings provide a clear direction for the continued development of the program. Future iterations of WAVE should expand beyond the current focus on transportation and electrical engineering to include additional core disciplines such as computer science, mechanical engineering, and data analytics. With broader and more in-depth theoretical coverage, the program should also offer expanded opportunities for hands-on, experiential learning to further enhance student engagement and workforce readiness.

Overall, this study demonstrates that a carefully designed, interdisciplinary educational framework can effectively prepare students for the evolving demands of the AV workforce. By intentionally integrating transportation engineering with electrical engineering and combining theoretical instruction with hands-on experiential learning, the WAVE program successfully addressed a critical gap in existing workforce development efforts.

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