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Undergraduate Research Experiences for Automated and Connected Vehicle Algorithm Development using Real Vehicles

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Abstract

We are experiencing a revolution in vehicle operation, with fully automated robotaxis deployed and available for public use in major U.S. markets in 2023. These vehicles, while imperfect, already are arguably safer than the average human driver. Despite this rapid progress, there remain significant research and development problems that must be addressed; beyond this, there is an underdeveloped workforce for skilled researchers, developers, and practitioners in these areas, a fact that may delay necessary advances. We have created and run for two years a National Science Foundation funded Research Experience for Undergraduates (NSF REU) focused on solving both unmet research needs, and workforce development and pipeline programs. In our REU, which makes use of simulation and two full-scale, street-legal drive-by-wire electric vehicles with perception, planning, and control capabilities, our primary goals include to (1) provide hands-on experiences to undergraduate students who otherwise might not have research opportunities to learn fundamental theories in autonomous vehicle development, (2) allow students to design algorithms to practice software development and evaluation using real vehicles on real test courses, (3) strengthen their confidence, self-guided capabilities, and research skills, and (4) increase the number of students, including those from diverse backgrounds and technical disciplines, interested in graduate programs to ultimately provide a quality research and development workforce to both academia and industry.

Over the initial two years, a cohort of 8 diverse students each year learned fundamental self-driving and computer networking skills including coding for drive-by-wire vehicles, computer vision, use of localization, and interpretation of richer sensor data, as well as network and communication protocols. The students were introduced to research ideation and publishing concepts, mentored in designing and testing hypotheses, and then involved in two challenges related to self-driving and networked vehicles. Two teams of 4 designed, implemented, tested various self-drive and V2X algorithms using real vehicles on a test course, analyzed/evaluated test results, wrote technical reports, and delivered presentations. After the summer program was over, the technical reports were published in peer reviewed conferences and journals.

Survey results show that students attained significant & real-world computer science skills in autonomous vehicle development leveraging real vehicles available. The programs also

increased research career interests and strengthened students' confidence, self-guided capabilities, and research skills, while additionally supporting the development of workshop materials, simulators, and related content that provide valuable resources for others planning to develop an undergraduate curriculum to teach self-drive and networked vehicle development.

Introduction

Electric, automated, and connected vehicles represent a leap in mobility with the potential for increased efficiency, safety, and sustainability. Such vehicles will reduce emissions, alleviate congestion through optimized routing, and minimize accidents caused by human error. Global industries and governments are funneling resources into research and development in anticipation these vehicles will play a pivotal role in tomorrow's transportation networks and smart cities. Despite growing interest, there remains a gap in undergraduate education concerning electric and autonomous vehicle technologies, particularly for students who wish to engage with real (rather than simulated) vehicles. Most academic programs lack the specialized courses and hands-on experiences critical for preparing the next generation of engineers and innovators in this rapidly advancing field. Bridging this educational divide is essential to ensure a workforce ready to support intelligent vehicles and transportation networks. Meeting this need, we developed and ran an NSF-supported Research Experience for Undergraduates (REU) geared at building a competent, self-actualized, diverse and effective workforce with experience engaging with simulated and real automated vehicles. To do so, we drew upon the automated vehicle experience of Lawrence Technological University (LTU) and Michigan State University (MSU).

LTU has extensive automation expertise; it acquired its first drive-by-wire electric vehicle (EV) in 2016 and a second in 2019. Using the two vehicles with camera, LiDAR, and GNSS sensors, primarily undergraduate student teams participate annually in the Intelligent Ground Vehicle Competition (IGVC)[10] to develop a self-driving vehicle for urban environments[1]. Additional research using the vehicles includes vision-based self-drive algorithms for driving in full sun[2], software engineering for ROS-based robots[3], lane detection and steering algorithms using Deep Learning[4,5,6], mobile app control of autonomous unmanned vehicles with the US Army's Robotic Technology Kernel[7], and controlling vehicles with gestures.[8,9]

MSU offers mobility research programs, including Connected and Autonomous Networked Vehicles for Active Safety (CANVAS), graduate-, undergraduate, and post-graduate automated vehicle competition teams, undergraduate and graduate curriculum related to self-driving, and a portion of campus usable for evaluating connected and automated vehicle technologies. Students and faculty have access to extensive simulation capabilities and automated vehicle data capture and testing platforms across scales, including through ADASTEC, a partner organization operating a street-legal automated electric bus on campus.

The REU draws upon these foundations to build a novel theoretical and practical curriculum to expand the skillset of the future workforce and to address research questions including (1) "what are the advantages and disadvantages of using real vehicles in teaching self-drive algorithms for undergraduates?" and (2) "what are the most effective strategies to teach self-drive algorithms using real vehicles for improving undergraduate education through research?" Research hypotheses (adapted from[11]) include:

- Real cars make learning automation more enjoyable and effective than scale/simulated platforms
- Self-efficacy in autonomous vehicle research and development is improved using real vehicles
- Problem testing & solution in real environments improves students' research skills in topics such as smart mobility's ethical, social, and legal issues.

These questions address opportunities unmet by existing engineering curriculum, with specific programmatic objectives including to (1) provide research experiences to underrepresented undergraduate students who otherwise might not have opportunities to learn fundamental theories in autonomous vehicle research & development (eligible undergraduate students include freshmen through juniors, including community college students); (2) allow students to design algorithms to practice software development using real vehicles on real test courses; (3) strengthen their confidence, self-guided capabilities, and research skills; (4) increase the number of students interested in graduate programs to provide a quality R&D workforce to industry.

The program is structured as a blend of educational components designed to foster comprehensive learning. Lectures on key technologies and important topics in career building and academia impart foundational knowledge, while simulated and real-world lab activities prioritize hands-on experience, embracing a 'mind and hand' philosophy. Students and their teams lead on various, directed – but open-ended - research projects, developing self-efficacy as they investigate, analyze, and present their findings to peers and broader audiences. We overwhelm by design, using forgetting as a means of building better facility and retention alongside knowledge reinforcement through student-led teaching sessions. Field trips and social events extend learning beyond the classroom, providing real-world context and fostering community. The program's philosophy is rooted in blending theory with practice, with a focus on repetition and active engagement to solidify learning.

The rest of this paper is organized with a program overview, methods, outcomes and evaluation, and a conclusion reflecting on the program's findings to-date and plans for the future.

Program Overview

The REU is run as an interactive opportunity bringing together eight previously-unfamiliar students to tackle existing and novel challenges over an eight-week period. Students are introduced to, and immersed in, industry-standard tools and the latest advancements in computer vision and automated systems. Exposure is critical in bridging theoretical knowledge with practical skills, preparing students for the evolving demands of industry. The development of algorithms using full-scale vehicles reflects the significance of testing in actual operating environments, where variables are uncontrolled and outcomes are unpredictable—conditions that simulations cannot fully replicate. The "reality gap" is where many valuable insights are often gleaned, as algorithms must navigate the complexities of real-world dynamic situations.

The research environment is hosted at LTU's Southfield, Michigan campus, with students living in on-campus dorms and working out of a dedicated classroom for the program's duration. LTU has a dedicated test track for self-driving evaluation featuring road marking lines, as well as a three-way intersection for stopping, starting, and turning (Figure 1). Real-world conditions, such as weather, potholes, shadows, and varying road markings, add complexity to the environment.

Figure 1. A drone photo of a dedicated test track at LTU.

LTU has two vehicles dedicated for REU use; modified Polaris Gem e2 EVs equipped with Dataspeed's drive-by-wire system, and sensors such as a Mako G-319 Camera, Velodyne VLP-16 PUCK Lidar, and Piksi Multi GNSS. See Figure 2.

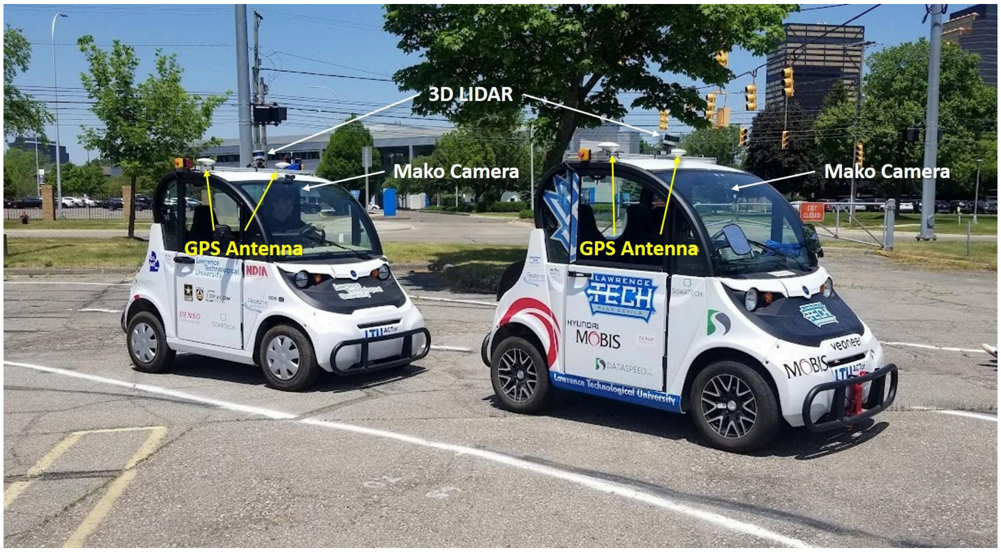

Figure 2. Two electric vehicles on the test track

The program was structured to address four quantifiable metrics, shown in Table 1.

Table 1. Quantified Objectives

(1) % of underrepresented student participants **or** students from PUI (Primarily Undergraduate Institution)	> 90%
(2) % of successful completion of individual assignments in the training workshops and research team projects; % of official publication of research papers from the REU program	> 90%
(3) Post-assessment content exam scores must be improved by at least X%	X > 30%
(4) % of participants who will actually enroll in graduate degree programs	> 40%

Table 2. 2023 Schedule, showing the program cadence and blend of instructor- versus student-led work

Full day workshop	9am-Noon; 1pm-4pm meeting in room M210; Free lunch by LTU
2 Hr workshop day	10am-Noon in M210

	Mon	Tue	Wed	Thu	Fri
Wk1 May 24-26			Orientation (Chung, Siegel, Wilson, +), Pre-survey	Field Trip - Automate Show in Detroit	ROS boot camp (by Chung) & Intro to research, AV (Siegel)
Wk2 May 29-June 2	Memorial Day (No meeting)	ROS boot camp (Chung, +)	ROS & Vehicle boot camp (DeRose, Chung, +)	ROS & CV boot camp (Chung, +)	Intro to V2X; V2X research project (Siegel, +)
Wk3 June 5-9	Field Trip - IGVC (morning & lunch)	ROS & CV boot camp (Chung, +)	Self-drive research project (Chung, Dombecki, +)	ROS & Vehicle boot camp (Chung, Kaddis, +)	OpenCV, CV boot camp (Paul, +)
Wk4 June 12-16	(C*, +)	V2X research project (Siegel, +)	Self-drive research project (DeRose, +)	ROS, DL, Others (Chung, Kaddis, +)	Field Trip M-City & MSU (Siegel)
Wk5 June 19-23	Self-drive research project (Paul, +)	V2X research project (Siegel, +)	V2X research project (GPS, Dombecki, +)	(C*, +)	Self-drive demo & presentation 1 (Chung, +)
Wk6 June 26-30	Self-drive research project (Chung, +, D*)	V2X research project (Siegel, +)	(C*, +)	(C*, +)	V2X demo & presentation 1 (Siegel, +)
Wk7 July 3-7	Campus Closed	Independence Day (No meeting)	V2X research project (Siegel,+)	Self-drive research project (Chung, +)	Self-drive demo & presentation 2 (Chung, +)
Wk8 July 10-14	Self-drive research project (Chung, +)	V2X research project (Siegel, +)	(C*, +)	(C*, +)	V2X Final Demo & Presentation (Siegel, Chung, +)
Wk9 July 17-18	Final Demo & Practice (Chung, +)	Final Presentation; Post-survey (Chung, Wilson, +)			

(+) A mentor either Kaddis or Dombecki available, 1pm-4pm

(C*) Dr. Chung mentoring hours, 10am-1pm

(D*) Dr. DeRose mentoring hour, 3pm-4pm

In the REU's first year, technical content covered in lectures, often with an associated exercise, included computing fundamentals and detailed technology implementation specifics. Topics included: Linux, Git, GitHub, VS Code, Robot Operating System (ROS), Python, Computer Vision, OpenCV, Deep Learning (DL) Libraries, Object detection using YOLO, robotic control loops: perceive, plan, control; embedded computing, traffic and intersection management strategies, Localization and Mapping, Communications and networking technologies, V2X connectivity and applications[17]. Non-technical sessions covered careers in academia, reading and writing academic papers, presenting, and effective communication. Key activities included development, deployment, and evaluation of algorithms for autonomous vehicle perception, planning, and control in both simulation and reality. Students also experimented with small-scale remote controlled vehicles to better understand planning and evaluating multi-vehicle motion coordination for intersection management.

There was an instructional and mentoring team comprising seven graduate students, faculty, and industry mentors, while students were given license to lead work independently. Activities revolved around one or more projects, designed with Principal Investigator input to address real-world challenges in automated vehicle development and to reflect interesting, engaging, and pedagogically-sound opportunities for learning. Students also participated in multiple field trips, including tours of LTU and MSU's campus and facilities, a visit to the Intelligent Ground Vehicle Competition[10], the Detroit Automate Expo, a ride on a self-driving bus, a stop at MSU's Dairy Store, a visit the MSU's student AutoDrive team and a tour of the CANVAS vehicle, and a field trip to University of Michigan's MCity connected and automated vehicle test facility (held jointly with MSU's Sociomobility REU). Table 2 above shows the 2023 schedule.

Students were recruited by mailing lists, word of mouth, web advertising, and through addendums to talks and presentations given by the REU affiliates. To address the desire for broader impacts including wider interest in computing and expanded opportunities for students underrepresented in engineering, target demographics included minority students, veterans, first in family students, students at minority serving and primarily undergraduate institutions, and historically black colleges and universities. HBCU and MSI STEM Department Chairs and Deans were contacted to provide information about the REU opportunity, its benefits, and its application process. We reached a wide audience, which was necessary to ensure a cohort reflecting unique backgrounds, skills, talents, and interests, and that the experience could have transformational impact on communities as well as individuals. We received 38 complete applications in 2022 and 61 in 2023 through NSF's Education & Training Application Portal (ETAP). Table 3 shows demographics of year 1 and 2 as reported within NSF's ETAP system.

Candidates were evaluated on a cover letter, résumé, and three letters of support; in the first year, all candidates were interviewed on Zoom by a PI using a common set of objective questions, and recordings and notes were shared between PIs for joint selection. In Y2, the process added additional screening questions; due to a larger number of applicants (a result of a longer marketing timeline and increased recruiting efforts), candidates not meeting requirements were not given formal interviews. Participant demographics are reported in Table 3; note that not all applicants who accepted the offer attended the program, requiring late replacement.

In the first year each team of four students was assigned to a vehicle and was given two projects: the first, related to lane detection and control strategies. The second was related to Automated Intersection Management System (AIMS) design, deployment, and evaluation.

In the second year of the program, the content was modified based on student feedback and instructor and mentor observations. The technical curriculum was changed to consolidate introductory sessions into a "Bootcamp" that is more information-dense, to reduce classroom time and free research time. Coverage of networking technologies was expanded, and additional non-technical content was added, including sessions on effective technical communication and intellectual property management, human factors, innovation and ideation techniques, concept selection, and business considerations. Trips were changed by reducing time at the IGVC and eliminating the bus ride. Instead, the students met with undergraduate researchers at MSU to explore their self-driving Chevrolet Bolt EV. Projects were changed to focus more on object detection and smart hazard reporting, with students developing a real-time hazard map for "collaborative, over-the-horizon awareness." Rather than each team having two projects (lane following and intersection management), the connectivity element was integrated into both teams' lanekeeping and object detection algorithms to allow cross-pollination of ideas across teams; this change increased student focus, leading to better learning and research outcomes. One of the program participants from Y1, Ryan Kaddis, returned as a mentor in Y2, drawing upon skill learned in the program to support the student projects and to build the necessary equipment for the intersection management portion of the student research tasks. Two faculty mentors from Y1 returned.

Table 3. Demographics of year 1 and 2 for applicants and selected students (data from NSF's ETAP)

		Applicants		Selected	
		2022	2023	2022	2023
Underrepresented racial group in STEM	Underrepresented in STEM	18.4%	32.8%	37.5%	0.0%
	Not underrepresented	76.3%	59.0%	62.5%	75.0%
	Unknown	5.3%	8.2%	0.0%	25.0%
RACE/ ETHNICITY	American Indian or Alaska Native	0.0%	0.0%	0.0%	0.0%
	Asian	34.2%	21.3%	37.5%	12.5%
	Black or African American	2.6%	16.4%	0.0%	0.0%
	Hispanic or Latino of any race	10.5%	13.1%	25.0%	0.0%
	Native Hawaiian or Other Pacific Islander	0.0%	0.0%	0.0%	0.0%
	White	39.5%	36.1%	25.0%	62.5%
	Two or more races	2.6%	4.9%	0.0%	0.0%
	Do not wish to provide	10.5%	8.2%	12.5%	25.0%
Gender Identity	Female	36.8%	11.5%	37.5%	0.0%
	Male	57.9%	85.2%	62.5%	87.5%
	Other	0.0%	1.6%	0.0%	12.5%
	Do not wish to provie	5.3%	1.6%	0.0%	0.0%
Carnegie Basic Classification	Doctoral Universities: R1 or R2	50.0%	50.0%	50.0%	62.5%
	Doctoral/Professional Universities	2.8%	6.7%	0.0%	0.0%
	Master's colleges or universities	30.6%	15.0%	37.5%	12.5%
	Baccalaureate colleges	8.3%	16.7%	0.0%	25.0%
	Associate's colleges	2.8%	10.0%	0.0%	0.0%
	Special focus (two and four year)	0.0%	0.0%	0.0%	0.0%
	Carnegie classification unknown	5.6%	1.7%	12.5%	0.0%
Other classifications	Minority-serving institutions	25.0%	30.0%	37.5%	0.0%
	Hispanic-serving institutions	19.4%	15.0%	37.5%	0.0%
	Historically Black Colleges and Universities	2.8%	8.3%	0.0%	0.0%
	Tribal Colleges	0.0%	0.0%	0.0%	0.0%
	MSI or HSI classification unknown	5.6%	1.7%	12.5%	0.0%
Highest level of education of any parents	First-gen student (Parents did not complete a 4 year college degree)	34.3%	39.3%	25.0%	25.0%

Y1 output included two accepted, peer-reviewed papers[12, 13]. Y2's output included two accepted, peer-reviewed papers[14,15] and another submitted conference paper[16]. Both years' students presented their work mid-summer check-in, and again at the end of the REU. Presentations were open to the public and had a small audience both live and on the web[18]. Some Y1 participants joined the presentations in Y2 via Zoom.

Methods

To provide an effective learning environment, we were interested in: 1) finding out whether using real cars can make learning more effective than scale/simulated platforms; 2) whether self-efficacy in autonomous vehicle research and development is improved using real vehicles; and 3) finding how problem testing and solution in real environments can improve students' research skills, e.g. in smart mobility's ethical, social, and legal issues. Students were evaluated by intake, exit, and weekly surveys and assessments, as well as informal, longitudinal studies by way of continued communication beyond the first year. We asked the following same survey questions using Canvas during the orientation day (pre-survey) and at the end of the program (post-survey) after 8 weeks.

On a scale of 1 (Strongly disagree) and 10 (Strongly agree) note your opinion:

RQ1. Real cars make learning self-drive algorithm development more enjoyable and effective than scale/simulated platforms.

RQ2. Self-efficacy in autonomous vehicle research and development is improved using real vehicles.

RQ3. Development in real environments can improve students' research skills into topics such as smart mobility's ethical, social, and legal issues.

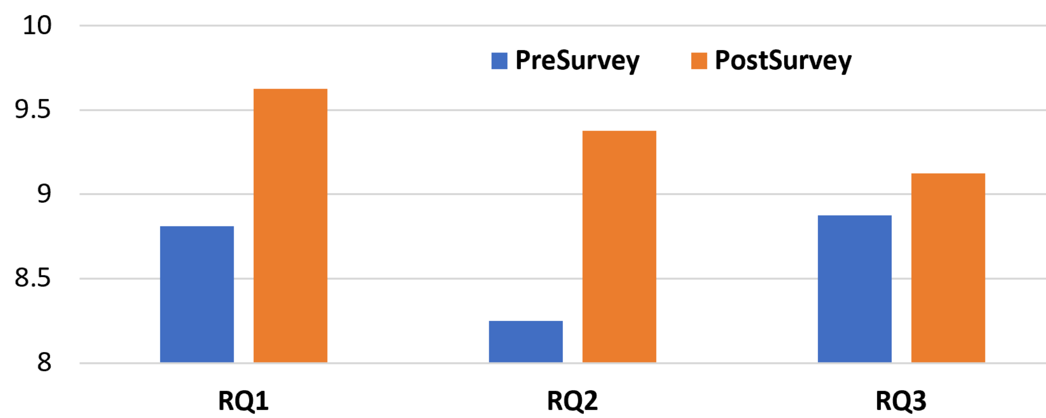

Figure 3. Pre and Post survey results for our 3 research questions shows the value of using real vehicles in education and training researchers and the future workforce

Figure 3 shows the results for survey responses from 16 students in both years; after 8 program weeks, all 3 survey responses were increased. Paired t-test results show that the improvements of RQ1 and RQ2 are statistically significant. p values are 0.022363699 and 0.000525731, respectively. The improvement of RQ3 is not statistically significant ($p = 0.595559837$).
We also asked the following skill-set related questions before and after the program:

On a scale of 1(Strongly disagree) and 10 (Strongly agree), note your knowledge of the following:

Q1. I consider myself knowledgeable about Linux operating systems and am confident in using the OS.

Q2. I consider myself knowledgeable about Git/GitHub and am confident in using it.
Q3. I am confident in Python programming
Q4. I consider myself knowledgeable about ROS (Robot Operating System) and am confident in writing programs in the ROS environment.
Q5. I consider myself knowledgeable about Computer Vision techniques and am confident in writing programs to implement Computer Vision algorithms
Q6. I consider myself knowledgeable about 2D & 3D LIDAR sensors and am confident in writing programs to implement object detection and ranging algorithms.
Q7. I consider myself knowledgeable about GPS sensors and am confident in writing programs to implement localization, mapping, and navigation algorithms.
Q8. I consider myself knowledgeable about self-drive algorithms and am confident in writing programs to implement algorithms for autonomous vehicles.
Q9. I consider myself knowledgeable about V2X and am confident in writing programs to implement the algorithms for autonomous vehicles.

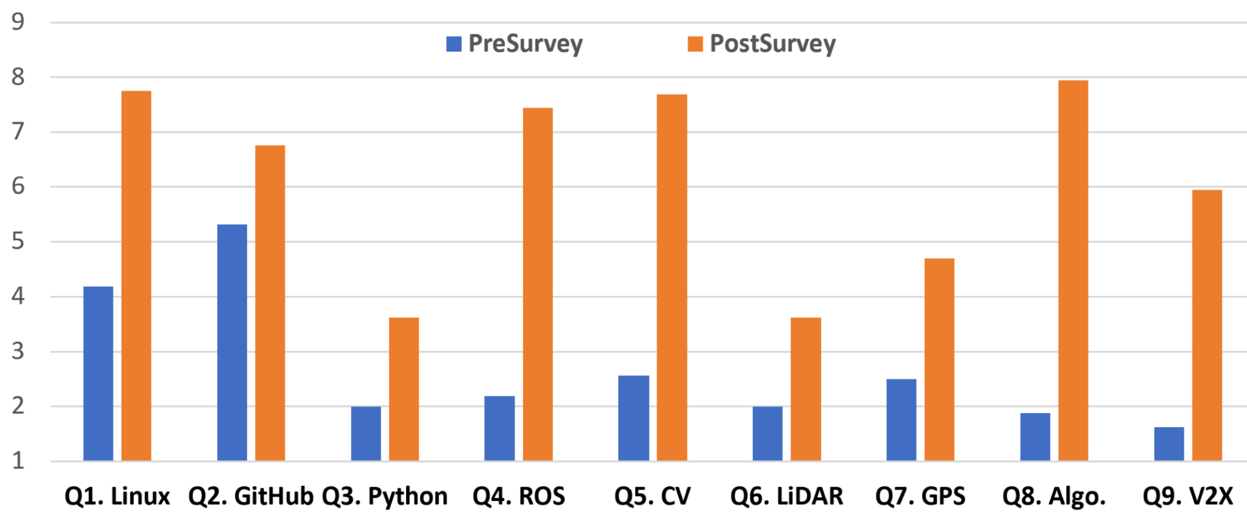

Figure 4. Pre and Post survey results for skill set questions show self-evaluation of knowledge increased in all evaluated categories.

Figure 4 shows the results of the pre and post survey questions; all 9 survey responses were increased. Paired t-test results show that the improvements of Q1, Q3, Q4, Q5, Q6, Q7, Q8, and Q9 are statistically significant. p values are 3.37754E-05, 0.001060826, 2.53149E-07, 1.38883E-07, 0.005919853, 0.012427676, 2.16601E-12, and 8.38251E-07 respectively. However, the improvement of Q2 is not statistically significant ($p = 0.063900239$).

Students involved in the program demonstrated decreased interest in graduate education upon the completion of the program (Figure 5) even though the observed difference is not statistically significant ($p = 0.117700185$). We suspect perhaps as a result of the pace and complexity of the program. Overall, many students always planned to attend graduate school (5/16) with increased likelihood (8/16) reported along with neutral feelings (3/16); Y1 was more strongly oriented to graduate study for all eight participants than Y2 (⅜ neutral). Despite this, multiple program participants have continued to work on autonomous vehicle technologies since the program ended, e.g. participating in invited, international hackathons[20]; it is also possible that the program cultivated interest in automated vehicles in industry, rather than in academic contexts. Additional study is necessary.

On a scale of 1(Strongly disagree) and 10 (Strongly agree) note your opinion: I am interested in graduate studies in STEM fields including self-driving, autonomous vehicles, and/or smart mobility.

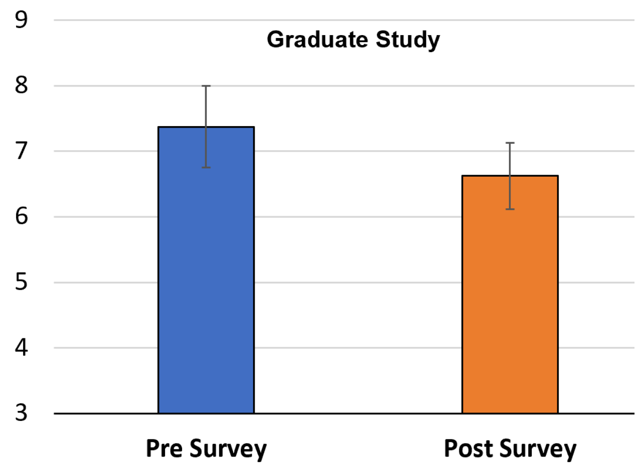

Figure 5. Pre and Post survey results for graduate study interest

Students also evaluated their preparation and experience for the REU. College course preparation received a mixed response with many (10/16) agreeing that prior courses prepared them well for the Program while two were neutral and four disagreed. Y1 felt less prepared than Y2, perhaps indicating growing alignment between Program goals and student skills.

Teamwork is a common element in research and valuable preparation for graduate study, but the compressed schedule for the Program means that students need to quickly adapt to team dynamics. Generally, students felt their teams were effective and worked together well (12/16), moreso in Y1 than Y2. Predominantly students agreed (Y2) rather than strongly agreed (Y1) that their teams worked well together; most students also felt a sense of accomplishment through their team (15/16). Students felt welcomed and included by participants (11 agreed strongly, 3 agreed and 1 neutral) especially Y1 (8/8 strong agreement) and supported by approachable Program faculty concerned with their success (16/16). Both cohorts felt a sense of accomplishment with most (13/16) feeling their academic progress advanced much more or more than expected, with two feeling neutral and one experiencing less than expected academic growth. In terms of overall outcomes, all participants felt very satisfied (13/16) or satisfied (3/16) by their achievements.

In addition to quantitative self-evaluation, the PIs measured student research productivity (reports, presentations, and publications). In Y1, student-authors led two papers[12][13] featuring self-driving lane keeping algorithms. The complexity and scope of the research presented in the papers illustrates the type of high-level work that undergraduate students are capable of undertaking within the REU program. This includes the development, analysis, and evaluation of algorithms, as well as addressing real-world problems such as lane detection in autonomous vehicles. Challenges faced and overcome during research indicate that students are not just participating in guided activities but are also engaging in problem-solving and critical thinking—key skills that are developed through effective research experiences. The students' contributions to a complex project like developing self-driving algorithms is a testament to the hands-on experience and learning opportunities provided by the REU program. The production of a paper itself, suitable for submission to an academic journal, demonstrates the successful outcome of the research experience and the program's effectiveness in guiding students through the process of scientific inquiry and dissemination.

In Y2, students developed papers revolving around computer vision[15] and vehicle connectivity[14]. With regard to vision, CNN based models were trained to steer vehicles in addition to a hand-crafted Computer vision algorithm. Between the two methods that were tested, the deep learning model was more robust for lane keeping and lane detection in various lighting and weather conditions. Also a statistical analysis indicates that the vehicle using the deep learning model is able to consistently maintain accurate lane keeping. For the connected vehicle paper, all students worked together to develop a Road Side Unit (RSU) that enables transmitting information such as time, position, obstacles & navigation information between each other; this paper won first place award in Smart Mobility paper competition[19]. An additional paper[16] is under review, featuring an algorithm combining deep learning- and hand-crafted approaches for lane keeping. In both years, students led final presentations summarizing their work, results, and key learning to small audiences[18].

Discussion and Conclusions

This paper presented an in-depth analysis of our NSF-funded REU program on self-driving. The program demonstrated a significant influence on the research interests and confidence of its participants by presenting a wealth of information and fostering an inclusive environment where students can explore, innovate, and contribute to the evolving landscape of self-driving technology. The strategies employed in the program to effectively teach and engage students – including a blend of lectures, lab activities, field trips, and project-based learning – have proven to be highly effective. These methods ensure that learning extends beyond the classroom, promoting a deeper comprehension of the subject matter and encouraging the development of critical thinking and problem-solving skills. The REU has already helped to provide a bridge between theoretical knowledge and practical application, equipping students with the skills and experiences necessary for the demands of the current job market in specialized areas such as autonomous vehicle technology. Evaluating against the metrics presented in the paper's opening, we find the following results (Table 4):

Table 4: Results assessment versus initial quantitative program goals

Project evaluation criteria	Goal	Self Assessment
(1) % of underrepresented student participants **or** students from PUI (Primarily Undergraduate Institution)	> 90%	Some students elected not to report some or all demographic data. From the known values reported through NSF's ETAP, 37.5% were underrepresented in Y1, 0% in Y2. 37.5% were from non R1/R2 in Y1, 12.5% in Y2. As we fell well short of our target, we are revamping recruiting efforts in Y3+.

(2) % of successful completion of individual assignments in the training workshops and research team projects; % of official publication of research papers from the REU program	> 90%	100% of students successfully completed individual assignments and published their results in peer-reviewed academic venues.
(3) Post-assessment content exam scores must be improved by at least X%	X > 30%	We did not collect readily quantifiable data in Y1 & Y2. Demonstrations and surveys provided qualitative assessments for substantial skill increase. Additional evaluation will be added in Y3.
(4) % of participants who will actually enroll in graduate degree programs	> 40%	Most participants remain undergraduates. At least two students have applied for graduate study thus far. Longitudinal studies will continue.

From these results, we see the REU as an important step advancing undergraduate education related to self-driving vehicles. Over two years, the program has not only imparted valuable technical skills to its diverse cohorts of students but also fostered a greater interest in research (if not graduate studies) in the field. The decrease in students' interest in graduate studies post-program, as highlighted in the surveys, does point to an unexpected outcome. This may reflect the realization of the complexity and challenges inherent in this field of study, underscoring the need for continued educational support and guidance for students, helping them navigate through the complex path towards advanced research education.

The REU program successfully achieved its goals, demonstrating skill improvements through surveys, producing high-quality technical reports, and publishing peer-reviewed research papers led by students. It has also addressed broader challenges, contributing to workforce development and promoting inclusivity and diversity. In its third year, a new project involving Internet-controlled traffic lights aims to enhance student learning in traffic flow modeling and intelligent transportation systems. Encouraged by early success, the program plans to apply for renewal, with potential updates to lectures, projects, field trips, and integration with Michigan State University’s Indy Autonomous Challenge race team to attract and engage new students in automated vehicle research.

Acknowledgements

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References

[1] N. Paul, M. Pleune, C. Chung, B. Warrick, S. Bleicher and C. Faulkner, "ACTor: A Practical, Modular, and Adaptable Autonomous Vehicle Research Platform," 2018 IEEE International Conference on Electro/Information Technology (EIT), Rochester, MI, USA, 2018, pp. 0411-0414, doi: 10.1109/EIT.2018.8500202.

[2] Nicholas Paul and ChanJin Chung (2018) Application of HDR algorithms to solve direct sunlight problems when autonomous vehicles using machine vision systems are driving into sun, Computers in Industry, Volume 98, June 2018, Pages 192–196.

[3] M. Pleune, N. Paul, C. Faulkner and C. -J. Chung, "Specifying Route Behaviors of Self-Driving Vehicles in ROS Using Lua Scripting Language with Web Interface," 2020 IEEE International Conference on Electro Information Technology (EIT), 2020, pp. 535-539, doi: 10.1109/EIT48999.2020.9208285. (*)

[4] Ian Timmis, Nicholas Paul, Chan-Jin Chung, Teaching Vehicles to Steer Themselves with Deep Learning, 2021 IEEE International Conference on Electro/Information Technology, May 14 - 15, 2021, Central Michigan University, Mount Pleasant, MI (presented online) (*) https://ieeexplore.ieee.org/document/9491894

[5] Mark Kocherovsky, Guiseppe DeRose, Nicholas Paul, Ian Timmis, Chan-Jin Chung, Autonomous Vehicle Steering through Convolutional and Recurrent Deep Learning, Autonomous Vehicles and Systems: A Technological and Social Perspective, Chapter 43, River Publishers, ISBN 9788770228855, https://www.routledge.com/Autonomous-Vehicles-and-Systems-A-Technological-and-Societal-Perspective/Sethi/p/book/9788770228855

[6] DeRose, G., Jr.; Ramsey, A.; Dombecki, J.; Paul, N.; Chung, C.-J. Autonomously Steering Vehicles along Unmarked Roads Using Low-Cost Sensing and Computational Systems. Vehicles 2023, 5, 1400-1422. https://doi.org/10.3390/vehicles5040077

[7] Justin Dombecki, James Golding, Mitchell Pleune, Nicholas Paul, Chan-Jin Chung, A Successful Integration Of The Robotic Technology Kernel (RTK) For A By-Wire Electric Vehicle System With A Mobile App Interface, arXiv:2208.03535 [cs.RO], 2022, https://arxiv.org/abs/2208.03535

[8] Schulte, J.; Kocherovsky, M.; Paul, N.; Pleune, M.; Chung, C.-J. Autonomous Human-Vehicle Leader-Follower Control Using Deep-Learning-Driven Gesture Recognition. Vehicles 2022, 4, 243-258. https://doi.org/10.3390/vehicles4010016

[9] Joseph Schulte, Mark Kocherovsky, Justin Dombecki, Nicholas Paul, Mitchell Pleune, Chan-Jin Chung, 2D and 3D Pose Estimation for Gesture Recognition in Deep-Learning-Driven Human-Vehicle Leader-Follower Systems, Autonomous Vehicles and Systems: A Technological and Social Perspective, Chapter 5, River Publishers, ISBN 9788770228855, https://www.routledge.com/Autonomous-Vehicles-and-Systems-A-Technological-and-Societal-Perspective/Sethi/p/book/9788770228855

[10] http://www.igvc.org/ (accessed on Jan 14, 2024)

[11] Pásztor A., Szigeti P., R., Török, E. & Vajda Z. Innovative Approaches to short-and long-term impact assessment of programming education. AWER Procedia Information Technology & Computer Science. Online. 2013, 04, pp 795-800

[12] Rao, Shika, Alexander Quezada, Seth Rodriguez, Cebastian Chinolla, Chan-Jin Chung, and Joshua Siegel. 2022. "Developing, Analyzing, and Evaluating Vehicular Lane Keeping Algorithms Using Electric Vehicles" *Vehicles* 4, no. 4: 1012-1041. https://doi.org/10.3390/vehicles4040055

[13] R. Kaddis, E. Stading, A. Bhuptani, H. Song, C. -J. Chung and J. Siegel, "Developing, Analyzing, and Evaluating Self-Drive Algorithms Using Electric Vehicles on a Test Course," 2022 IEEE 19th International Conference on Mobile Ad Hoc and Smart Systems (MASS), Denver, CO, USA, 2022, pp. 687-692, doi: 10.1109/MASS56207.2022.00101.

[14] Khalfin M, Volgren J, LeGoullon L, Franz B, Shah S, Forgach T, Jones M, Jostes M, Kaddis R, Siegel J, Chung C Vehicle-to-Everything Communication Using a Roadside Unit for Over-the-Horizon Object Awareness. In 1st International Conference on Smart Mobility and Vehicle Electrification 2023 Oct 10, https://doi.org/10.46254/EV01.20230202

[15] Shilpi Shah, Brendan Franz, Travis Forgach, Milan Jostes, Joshua Siegel, and Chan-Jin Chung, Comparing Traditional Computer Vision Algorithms and Deep Convolutional Neural Networks as Self Driving Algorithms for Use in Dynamic Conditions, 2023 IEEE MIT Undergraduate Research Technology Conference (URTC)

[16] M. Khalfin, J. Volgren, L. LeGoullon, M. Jones, J. Siegel, C.-J. Chung, Developing, Analyzing, and Evaluating Vehicular Lane Keeping Algorithms Under Dynamic Lighting and Weather Conditions Using Electric Vehicles, SoutheastCon 2024 (Submitted)

[17] J. E. Siegel, D. C. Erb and S. E. Sarma, "A Survey of the Connected Vehicle Landscape—Architectures, Enabling Technologies, Applications, and Development Areas," in IEEE Transactions on Intelligent Transportation Systems, vol. 19, no. 8, pp. 2391-2406, Aug. 2018, doi: 10.1109/TITS.2017.2749459.

[18] https://www.ltu.edu/arts-sciences/mcs/nsf-reu (accessed on Jan 20, 2024)

[19] https://www.ieomsociety.org/documents/awards-2023detroit.pdf (accessed on Jan 20, 2024)

[20] https://hackathon.sick.com/hacker-teams/ (accessed on Jan 28, 2024)