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Autonomy in Transportation Education

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Autonomy in Transportation Education

by

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CENTER FOR CONNECTED AND AUTOMATED TRANSPORTATION

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16. Abstract

Connected and automated vehicles (CAVs) represent a transformative technology that can revolutionize how people and goods move. The private sector is at the forefront of developing the technology, and many municipalities are attempting to prepare for a more connected and automated future. As such, both private and public sectors are in need of a skilled workforce with knowledge of CAVs. At the same time, as the CAV technology is not mature yet, academics are directing most of their attention to research on CAVs and their impact on the transportation system, overlooking needs for workforce development. The objective of this paper is to assess the needs for workforce development in CAVs, to identify potential obstacles that educators face in fulfilling those needs, and to propose ways to overcome the obstacles. Toward this end, a workshop was designed to bring together experts to identify the best ways to meet the demand for a workforce skilled in CAVs. As the field of CAVs can be diverse, a survey was distributed ahead of the workshop to identify the main themes around which the workshop was designed: (1) next generation infrastructure for CAVs, (2) human factors with CAVs, (3) modeling, simulation, and testing of CAVs, and (4) travel behavior in the context of CAVs. The identified themes do not comprehensively cover the educational needs in CAVs, but are rather poised to cover what were identified as the most prominent educational gaps in CAVs by the survey takers.

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Autonomy in Transportation Education

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Abstract

Connected and automated vehicles (CAVs) represent a transformative technology that can revolutionize how people and goods move. The private sector is at the forefront of developing the technology, and many municipalities are attempting to prepare for a more connected and automated future. As such, both private and public sectors are in need of a skilled workforce with knowledge of CAVs. At the same time, as the CAV technology is not mature yet, academics are directing most of their attention to research on CAVs and their impact on the transportation system, overlooking needs for workforce development.

The objective of this project is to assess the needs for workforce development in CAVs, to identify potential obstacles that educators face in fulfilling those needs, and to propose ways to overcome the obstacles. Toward this end, a workshop was designed to bring together experts to identify the best ways to meet the demand for a workforce skilled in CAVs. As the field of CAVs can be diverse, a survey was distributed ahead of the workshop to identify the main themes around which the workshop was designed: (1) next generation infrastructure for CAVs, (2) human factors with CAVs, (3) modeling, simulation, and testing of CAVs, and (4) travel behavior in the context of CAVs. The identified themes do not comprehensively cover the educational needs in CAVs, but are rather poised to cover what were identified as the most prominent educational gaps in CAVs by the survey takers.

Keywords: Autonomy, Connected and Automated Vehicles, Transportation Education, Backward Design

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2 INTRODUCTION

The CAV technology comes with the promise of revolutionizing transportation systems through enhancing driving safety, transforming how people and goods move, and curbing the environmental footprint of the transportation sector. Despite its potentials, CAV technology is for the most part at the research stage, with academics and the private sector focusing on CAV infrastructure (Saeed et al., 2021; Ersal et al., 2020; Liu et al., 2019; Sanusi et al., 2022; Mahdavian et al., 2019; Jiang et al., 2021), CAV-related human factors (Wang et al., 2022; Sarker et al., 2019; Zhang et al., 2022; Fisher et al., 2020; Zhang et al., 2021; Sharma et al., 2017; van Wyk et al., 2020; Hung et al., 2022), modeling, simulation, and testing of CAVs (Liu et al., 2022; Sun et al., 2021; Zhang and Masoud, 2020; Molnár et al., 2022; Gunter et al., 2019; Stern et al., 2018; Ge et al., 2018; Feng et al., 2018; Pariota et al., 2020; Do et al., 2019), and implications of CAVs on travel behavior (Zmud et al., 2018; Masoud and Jayakrishnan, 2017; Kröger et al., 2019; Lavieri et al., 2017; Rubin, 2016), among other topics. Parallel with academic research, the AV industry is looking for trained experts to participate in the sustainable development of AV systems (Ivanov et al., 2018).

There have been a few attempts in the literature to create inter- and cross-disciplinary courses that focus on AV design. For example, Lau et al. (2020) introduce a cross-disciplinary AV system design course that covers the design, implementation and evaluation of an AV system developed under the First Principles of Instruction (FPI) framework. They discuss how this course can be covered effectively through both in-person and remote instruction. The importance of learning-by-doing is emphasized in Lopez et al. (2015) and Liu et al. (2021) by having students participate in multi-disciplinary design/capstone projects in autonomous system design. Also, Ng et al. (2019) offer insights on effective instructional design for teaching in engineering. Implementing these insights within the FPI framework has led to the introduction of a cross-disciplinary course on designing AV systems in the Department of Electrical and Electronic Engineering at the University of Hong Kong (Lau et al., 2020). Using toy cars (Manley et al., 2009; Scheffe et al., 2020) and simulation platforms (Wang et al., 2020; Samak et al., 2021) are other avenues proposed in the literature for training students.

Despite the recent attention paid to re-structuring educational efforts in designing AV systems on one hand, and the uptake in CAV-focused research activities on the other hand, the scope of AV education remains mostly at the vehicle level. Research advancements at the vehicle level, and most importantly system-level views in the design of CAVs, have for the most part not been translated into educational content. As such, the goal of this study is to pinpoint educational gaps in CAV systems within the context of the four themes identified in this report, and to highlight the teaching material that needs to be developed to fill these gaps.

2.1 Study Motivation

After the invention of the automobile more than a century ago, the field of transportation has experienced three major waves of innovation revolution. The first revolution started in 1908 with the Ford Model T automobile, which is recognized by many as the earliest vehicle in mass production on moving assembly lines (Sovacool, 2009). As the first affordable automobile in the world, it completely changed people's perception of time and distance. The second revolution started in 1956, when the construction of the National Highway System considerably changed people's travel behavior in the United States. More specifically, it influenced people's choice of transportation mode for inter-city travel and led many to drive rather than take the railway for longer-distance trips. Finally, around 2010 the latest revolution started to emerge in the form of next-generation transportation systems that introduced connec- tivity, automation, shared transportation, and electrification to transportation, impacting almost all aspects of people's mobility patterns and travel.

Traditional transportation engineering programs have primarily focused on the design, operations, and planning of transportation systems while considering the interactions between road infrastructures, vehicles, and users. Although these focuses still remain of ut- most importance, our perspectives and approaches to them have been greatly impacted by the introduction of new technologies such as connectivity, automation, shared transporta- tion, and electrification. Therefore, it is crucial for transportation engineering programs to adapt to these technologies. This can be achieved by going beyond a strictly research- oriented focus and also adjusting curricula to reflect the current and future needs of the job market. Being governed by a system-level perspective, transportation engineering stands at the nexus of a number of fields in engineering, planning, and economics that bring together vehicles, infrastructures, and travelers. This cross-disciplinary focus of transportation engi- neering distinguishes it from other fields, thereby necessitating a careful examination of how technological advancements can be integrated into educational material.

The fact that automation requires significant knowledge of cloud computing, artificial intelligence, and big data may raise a question about whether computer scientists will eventually take over the field. In the past, transportation engineers were in full control of the design, operations, and planning of transportation systems. In recent decades, however, a wide spectrum of companies, from high-technology companies to original equipment manufacturers (OEMs) and mobility service providers, entered the market, resulting in a shift in the types of companies and professionals making major decisions. Despite this fact, the authors believe that the naturalistic driving environment is an important feature that makes a transportation engineering program distinct from other programs involved with CAVs in driving the advancement toward a driverless future. Therefore, it is safe to assume that the transportation engineering profession will remain a major player in this field as long as transportation educators feel the urgency to incorporate these technologies into their curricula.

Another factor that contributes to the urgency of incorporating CAV technology in transportation education is the change in the career prospects of transportation engineering graduates. Upon graduating from a traditional transportation engineering program, students used to be mostly employed by government agencies, such as departments of transportation (DOTs) and metropolitan planning organizations (MPOs), consulting firms, or research organizations. However, the graduates of current transportation engineering programs have the additional opportunity to work for high-tech companies, major OEMs, and mobility service providers in addition to the more conventional companies and organizations listed above. These new career prospects undoubtedly require different skill sets and tools, which must be reflected in the curriculum.

In order to discuss gaps in transportation education related to CAVs, and ways to fill in those gaps, the Center for Connected and Automated Transportation (CCAT), the Region 5 University Transportation Center (UTC), together with Mcity, the first dedicated, real-world test bed for CAVs located at the University of Michigan (UM) campus, held the *Autonomy in Transportation Education* workshop in April 2022. The workshop was preceded by a survey that was distributed to experts in industry and academia. The objective of this survey was to identify a few key domains in the broad field of CAVs on which the workshop could focus. The workshop involved a carefully selected group of experts from academia and industry with insights on job market demand for CAV experts as well as on current curricula in transportation engineering programs and how they can be improved. The rest of this report will elaborate on the outcomes of the survey and how the agenda for the workshop was informed by the survey outcomes, and will summarize the takeaways from the discussions during the workshop.

2.2 Objectives

Centering on the necessity of incorporating autonomy-related learning materials into transportation education, this workshop was designed to serve the following goals:

1. Identify the knowledge gaps of the existing transportation education programs;
2. Identify potential challenges in creating educational content, and ways to resolve them;
3. Identify the best ways to fill the gaps (by means of e.g., new or revised course modules, hands-on exercises, experiments on test tracks or on public roads, new courses and degrees, etc.).

2.3 Workshop Structure

The workshop was held virtually on April 11, 2022 from 12:00 EST to 17:00 EST (See Appendix I for the full list of workshop attendees and organizers.). The workshop was kicked off by providing the participants with some background on the vision for the workshop. The outcome of the survey (see Appendix II for the survey questions) that helped us to identify the four themes of the workshop was briefly presented to the audience. Next, a representative from the University of Michigan Center for Research on Learning and Teaching (CRLT) delivered a lecture on "Understanding by Design". This talk provided the attendees with the foundation and context based on which the rest of the discussions in the workshop were formed. After a short break, the audience were split into four break-out rooms, one for each theme, to dive into deeper conversations based on a list of questions (see Appendix III) shared with all the participants prior to the workshop. After another short break, the participants reconvened in the break-out rooms to finalize and summarize their discussions. Finally, the workshop concluded with the theme leads providing the entire audience with a summary of the takeaways from the discussions in their breakout rooms.

In the rest of this report, we first provide a brief background on learning and backward design in Section 3. In Section 4, we present the outcomes of the survey conducted prior to the workshop. Finally, Section 5 outlines the outcomes of the discussions in the four themes of the workshop.

3 BACKGROUND

As discussed earlier, this workshop aimed to identify the major knowledge gaps of recent transportation engineering graduates regarding CAVs, and find effective ways to fill in these gaps by designing new training modules and/or revising the existing curriculum. In the literature of pedagogy, this design process is referred to as "backward design". This section provides a brief introduction to this concept by first describing the basic principles of the science of learning and then explaining the design of learning and teaching materials "with the end in mind" as well as comparing different teaching methods and modalities.

3.1 The Science of Learning

According to one of the oldest and most popular theories of learning, namely social constructivism, knowledge is constructed by the learner in a social context (Dewey, 1923; Vygotsky and Cole, 1978; Bruner, 1996). This means that *i*) knowledge is constructed, not transmitted, *ii*) one learner may construct knowledge in one way, while somebody else might construct it in a different way, and *iii*) learners need to feel they belong in the classroom or any community in which they are trying to learn, and also the cultures that learners bring into the classroom affect the way that knowledge is constructed. As such, how learning occurs translates into the classroom in certain ways. First, we learn best when we are active, enabling us to do something with the attained knowledge. Secondly, we need to make connections because we learn better when we know the global picture, as opposed to little pieces that are disconnected. Also, we learn best when what we are learning connects to what we value. Thirdly, the sense of belonging is really tied to learning. We learn best when we feel that not only do we belong to a community of learners, but also we can be a part of the field. This brings us to the following quote from Herb Simon:

> *"Learning results from what the student does and thinks and only from what the student does and thinks. The teacher can advance learning only by influencing what the student does to learn."*

As a key takeaway, we should move from content-centered teaching toward student-centered teaching when designing learning, and obviously, the first step is to know who is going to be our students.

3.2 Backward Design

Having in mind what we discussed in the previous subsection, a popular model to design lessons or curriculum is backward design (Wiggins et al., 2005). In backward design, once we know who the students are, we think about what we want the students to know at the end of a lesson or at the end of the learning experience. That is why it is also referred to as "beginning with the end in mind". The first step in backward design is to identify the desired results that are going to be our goals and objectives. Once we have done that, the second step is to determine what is going to be acceptable evidence informing us that the students are actually making progress toward those learning objectives. The last step is to plan the learning activities so that the learning experiences become the process by which we take the students to the desired result. In what follows, we dig deeper into these three steps.

Identifying Desired Results

In a common language, goals and objectives are used interchangeably. But in curriculum design, we can separate them out. Goals are overarching aspiring statements, the purpose of which is to inspire, organize, and motivate the students. Each goal can be further parsed into learning objectives that are more specific, serving as the basis for the design and the center of our teaching. Learning objectives enable us to *i*) direct the practice that the students are going to be doing, *ii*) evaluate the student progress and observe their performance, and *iii*) provide targeted feedback. A good learning objective must be in active language, learner-centered, attainable, relevant to the students, measurable/observable, and specific.

Acceptable Evidence

Once the learning objectives are determined, the next step in backward design is to identify acceptable evidence of learning, which ultimately results in how student assessments are designed. Assessments are very important to understand whether the lessons are working, and help us certify the learning. We can divide assessments into two general categories. One is called formative assessment defined as low-stake tasks in the classroom, such as quizzes, exit tickets, and homework, which inform the students where they stand, and also determine whether we need to adjust the instruction. The other one is called summative assessment, including exams and projects among others, which are more often used to give grades in order to certify that students have learned the material. For student-centered learning, the former assessment is more important as this helps students to be engaged with learning because they are not only receiving and listening but also retrieving information from their memory which can help them to remember the material later.

Planning Learning

The third step in backward design is to finally create the learning activities. The main task here is to identify ways for students or participants to meet the objectives of learning. Obviously, there are many options for doing this. In what follows, we categorize these teaching options from two angles, namely inductive versus deductive, and online versus in-person.

In deductive teaching, we begin with general principles and then follow with examples and applications. The advantages include being efficient, organized, teacher-controlled, and elegant. Following this approach, however, can make students bored and eventually lose interest. In inductive learning, we start with a concrete example and get to the abstract concepts later on so that students can learn to use the course content to meet a challenge. This approach creates motivation, and it is more compatible with the science of learning and its principles. More precisely, it makes learning active, helps to connect what students know to the larger context, and improves students' sense of belonging. However, we must point out that this approach requires the students to be trained to some extent and build the culture, and set expectations. Finally, it is important to make sure that we balance the challenge with the appropriate support, and stay in touch with students to get feedback and revise lessons.

Modes of teaching may include online and in-classroom teaching. While online teach- ing offers benefits such as centralized course organization and management and flexibility in learning pace, its downsides include the difficulty of getting to know other participants, building rapport, and meaningful interactions that need intentionality. On the other hand, the benefits of in-person teaching include familiarity of students with the learning environ- ment, hands-on learning, and non-verbal communication. Its downside is that all students are expected to learn at the same pace. Table 1 summarizes the benefits and disadvantages of each mode. Given the benefits and disadvantages of each mode, a question arises: can we combine the best of both worlds? This hybrid mode is typically referred to as blended learning. It comprises any teaching method that uses technology in the classroom to support students, such as using clickers in the classroom or using online discussion boards, such as Piazza, for students to ask questions. If we think about the science of learning and best practices in pedagogy, we can teach well in any environment–online, in-person, or blended.

Table 1. Online Teaching vs. In-Classroom Teaching.

Online	In-Classroom
Pros:	**Pros:**
– Centralized course organization and management	– It is familiar
– Flexibility (students can learn at their own pace, and in remote locations)	– Hands-on learning
	– Non-verbal communication
– Automatic feedback/monitoring	– Unplanned interactions are easy
Con:	**Con:**
– Getting to know each other, building rapport, and meaningful interactions needs intentionality	– All students learn at the same pace and in the same way

It is worth mentioning that Garrison et al. (1999) suggest that effective educational experience for teaching and learning online lies at the intersection of cognitive, teaching, and social presences. Cognitive presence governs how the student or the practitioner interacts with the material/content. The teaching presence controls how the teacher interacts with the students. Finally, social presence, the element that often gets left behind, defines how students interact with each other. Obviously, a strong social presence combined with a strong teaching presence typically leads to a strong cognitive presence.

4 SURVEY OUTCOME

As mentioned earlier, we conducted a short survey to help set the direction for the workshop. The purpose of this survey was to acquire a general idea about the existing gaps between what is needed in the workforce and what transportation engineering programs offer to students. As such, we distributed the survey presented in Appendix II among CAV experts in academia and industry, both in the private sector and the public sector. In what follows, we present a summary of 75 valid responses that we received from Dec 21, 2021 to Jan 30, 2022.

The first three questions served to provide us with a general background on the survey takers. As depicted in Figure 1, the majority of participants were from academia (37%) and government agencies (21%), respectively. Also, a total of 22% of survey takers were involved in consulting jobs and about 20% of them belonged to research institutions in the public and private sectors.

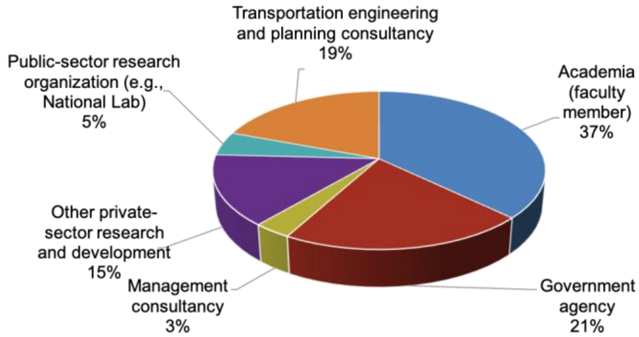

Figure 1. The distribution of the participants' corresponding sector

As shown in Figure 2, 43% of the participants held Ph.D. degrees, 31% held Master's degrees, 24% received a Bachelor's degree, and only 2% had other professional degrees.

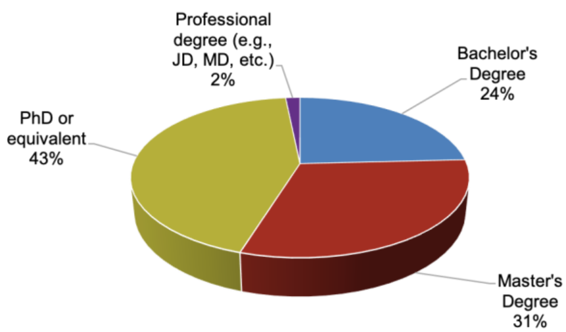

Figure 2. The distribution of the participants' highest level of education

Finally, Figure 3 suggests that the majority of participants were reported to be professors, in academic institutions (26%), and the rest were involved in a variety of positions including directors, engineers, researchers, consultants, managers, CEOs, vice presidents, etc.

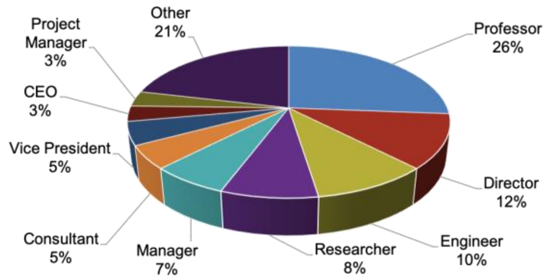

Figure 3. The distribution of the participants' positions within their organizations

As a segue into the rest of the survey, we asked participants whether they noticed a knowledge gap in the skill set of recent graduates in their corresponding sector. As shown in Figure 4, 59 participants (about 79%) answered yes to this question, and as a result, they continued with the survey for follow-up questions.

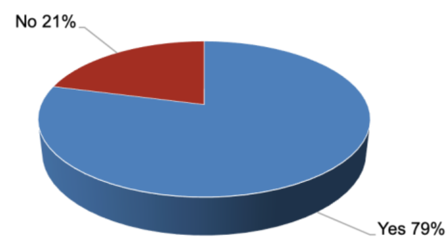

Figure 4. The percentage of participants who observed a knowledge gap in the skill set of recent graduates in their sector

Moving forward with the remaining 59 participants, we first asked them to identify the general areas in which they observed a knowledge gap. Figure 5 demonstrates only the most frequently perceived areas of deficiency: translating their knowledge to practical solu- tions, system-level thinking, state-of-the-practice tools and technologies, working with data in practice, and theoretical foundations.

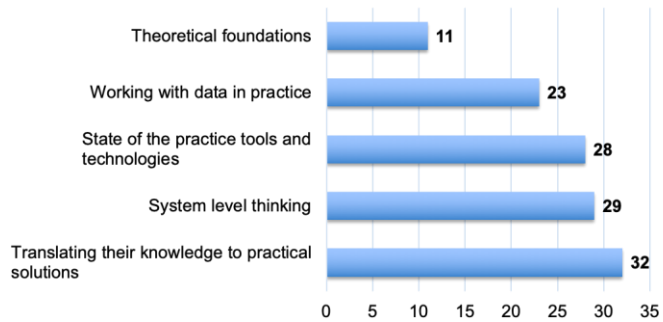

Figure 5. The distribution of the general areas with perceived knowledge gaps

The next question was more specifically targeting the CAV sector as the participants were asked to identify the knowledge gaps related only to CAVs. In Figure 6, we present only the areas with the highest frequency of being selected. Among these areas, connectivity between vehicles, infrastructure, and other road users was the most frequently selected option, followed by infrastructure support for CAVs, human factors with CAVs, testing and evaluation of CAVs, and finally, travel behavior in the context of CAVs. These areas collectively helped us form the main four themes of the workshop, as mentioned earlier.

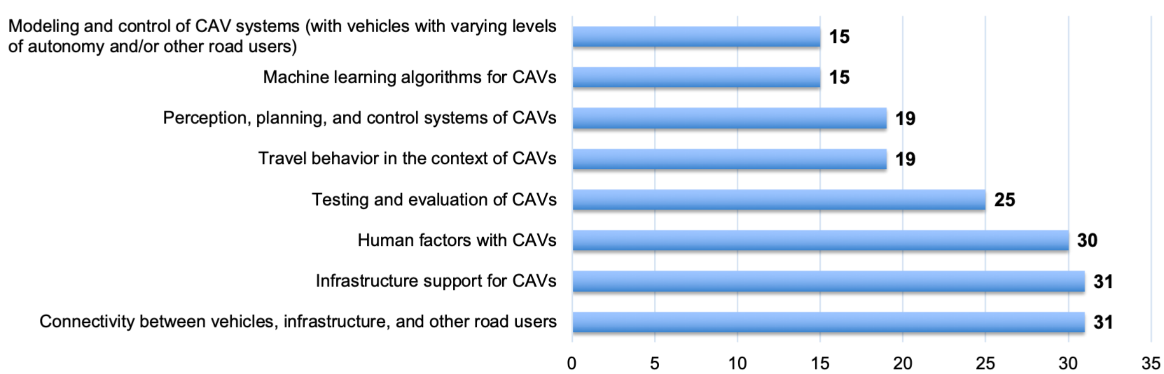

Figure 6. The distribution of the CAV-related knowledge gaps

As the last question of the survey, we asked the participants to choose the key ways to enhance the skill set of transportation engineering graduates, and thereby, fill in the existing knowledge gaps. As shown in Figure 7, the most frequently selected options are certificate programs with short modules, either in person or online, while the least suggested options are those pertaining to traditional degree programs.

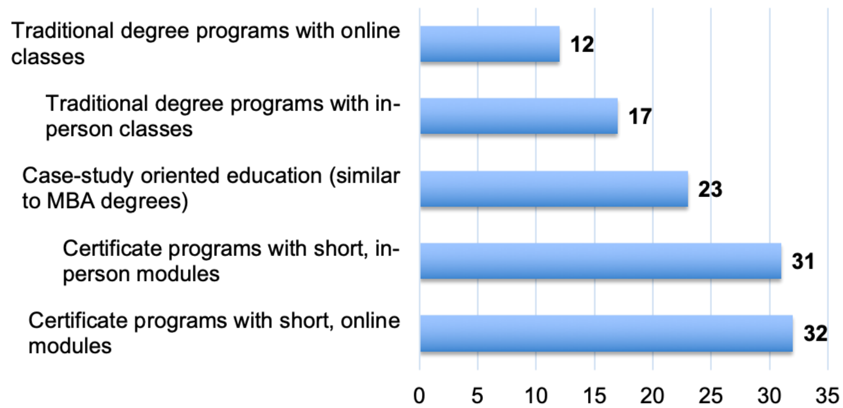

Figure 7. The distribution of the key ways to enhance the skill set of transportation graduates

5 WORKSHOP DISCUSSIONS

Having the principles of backward design in mind, we asked the participants of the workshop to engage in a round-table discussion to achieve consensus on the existing knowledge gaps related to CAVs and think of the best ways to address them. In order to facilitate more effective discussions, we introduced four themes based on the outcomes of the preliminary survey discussed in Section 4, and split participants between these themes based on their experience and expertise. In order to invoke a more smooth and organized discussion, we specified a lead for each theme and asked them to cover a list of topics (see Appendix III) within their groups. In the following subsections, we summarize the outcomes of the discussions in these four themes.

5.1 Theme 1: Next Generation Infrastructure for CAVs

Learning Objectives

The next generation infrastructure for CAVs is an interdisciplinary field, drawing knowledge from a wide range of disciplines including civil engineering, mechanical engineering, electrical engineering, and computer science, each with a unique set of perspectives. Considering the involvement of all these domains in the design, deployment, and operation of the next generation infrastructure systems, it is crucial for experts with different backgrounds to have the ability to communicate effectively–a skill set that seems to be missing in cur- rent graduates. It is essential for students to gain fundamental knowledge in transportation, optimization, data analysis, dynamics, and control. Even though technologies may change quickly, having fundamental knowledge will allow graduates to quickly align themselves with new technological advancements.

In addition to acquiring fundamental knowledge in the field, system-level thinking is another skill that would benefit those graduates pursuing careers in the next generation infrastructure systems. Once graduates enter the field, they will have to partake in large- scale projects that may impact millions of users and require collaboration from multiple stakeholders. As such, having a system-level perspective is one of the greatest advantages of transportation engineers in general. Additionally, since transportation engineering graduates may pursue specific career paths with expertise in a narrow set of sub-fields, they need system-level thinking in order to understand institutional arrangements (government policy, how infrastructures are established, etc.). Students need to gain knowledge on how the transportation system in a country is designed, operated, and managed. Otherwise, they might have novel ideas, but not the ability to execute them.

The ability to blend theory and application is another fundamental skill that graduates should possess to lead successful real-world projects. Finally, the ability to self-learn and adapt to a rapidly evolving field is crucial. This ability requires a deep understanding of fundamental concepts as well as intellectual curiosity. Given these circumstances, the learning objectives for students in this field are summarized in Table 2.

5.2 Table 2. Learning objectives for next generation infrastructure for CAVs.

	Learning Objectives	Educational material exists (Y/N)
1	Understand fundamental knowledge of the field such as traffic diagrams, optimization, control, etc.	Y
2	Effectively communicate with people from other fields and reflect on perspectives from experts in other fields.	N
3	Conduct system level thinking in order to understand institutional arrangements.	N
4	Understand the connection between theoretical knowledge and the realities involved in real-world deployments.	N

5.3

Barriers and Proposed Solutions

To be successful in this field, students must be provided with interdisciplinary knowledge that can prepare them for careers in industry and academia. Although educational materials already exist, they span a diverse set of fields including transportation, optimization, data analysis, dynamics, and control. As such, a concerted effort needs to be made to package and deliver relevant materials to transportation students in a concise format. As a result, despite the fact that there are no systematic gaps in educational materials, transportation educators are facing a challenge to bring in other disciplines to transportation education, similar to what they have been doing in research. To this end, we need to communicate with domain experts when designing courses in which fundamentals from different disciplines are taught in conjunction with their applications in transportation infrastructure. These courses will enable us to actively integrate the required knowledge into the curriculum.

Additionally, many of the core transportation principles on infrastructure and related topics were created several decades ago, back in the 1950s and 1960s, when data availability was a much more substantial challenge than today. Considering the tremendous amount of data available today compared to six or seven decades ago, and the new advancements in the field of artificial intelligence, transportation educators are expected to restructure existing courses and revitalize the teaching materials in this field.

Recommended Mode of Teaching

When it comes to teaching style, active learning is the most useful tool, mostly owing to the fact that students in this field have a diverse set of backgrounds and can learn from each other. An effective active learning task is teaching with projects. Projects will allow students from different backgrounds to interact and view the same problem from multiple perspectives. Other effective active learning tools include watching videos, taking quizzes, and doing different group activities on the same topics but with slightly different focuses. These active learning tasks for students can be best practiced through in-classroom or online courses with a standard university format. For practitioners and researchers working in the industry, however, short courses, half-week summer camps, or certificate programs are more appropriate as they may not have the capacity and time to attend traditional courses that usually take 14 weeks.

Due to the interdisciplinary nature of this field, it may not be appropriate to set a rigid set of prerequisites for courses. Students from different backgrounds may be interested in advancing their knowledge in the field, and rigid prerequisites may stop them from pursuing their interests. Only basic knowledge, such as introduction to transportation engineering, or alternatively, an engineering degree or a certain level of calculus, physics, and algebra may be required. Being familiar with these basics, other domain fundamental knowledge can be taught by instructors in the program.

5.4 Theme 2: Human Factors with CAVs

Learning Objectives

Human factors is a diverse field. Students in this field must understand the fundamental concepts, terminologies, and theories of human factors, so that they can apply them appropriately to the domain of transportation and/or CAVs. Some examples of human factors theories include theories on takeover transition, task switching, and situation awareness. Students are also expected to learn about the common quantitative and qualitative research methods in human factors, the advantages and disadvantages of these methods, and how they can be utilized to address specific research questions in various contexts. This includes different types of data (e.g., naturalistic driving data, experimental data obtained from driving simulator studies, crash data, and self-reported data), and how they can be collected and used to serve different research purposes. Also, students need to learn about the design of experiments, e.g., the concepts of dependent and independent variables, and how to measure them in the context of transportation and/or CAVs, and are required to understand basic statistical analysis methods and applications.

Human factors in transportation is an interdisciplinary field, which requires students to be familiar with different applications and terminologies of human factors, e.g., infrastruc- ture design and system design, and link human factors concepts and theories to real-world problems. Finally, transportation engineering graduates are expected to leverage human factors findings to inform system designs in order to improve the interaction between vehicles and humans. The learning objectives for students in this field are summarized in Table 3.

5.5 Table 3. Learning objectives for human factors.

	Learning Objectives	Educational material exists (Y/N)
1	Obtain a relatively comprehensive knowledge of fundamental theories/concepts about human factors.	Y
2	Know how to identify and apply appropriate research methods (including both qualitative and quantitative methods) in solving a specific problem.	Y
3	Know how to apply human-centered design methods to develop and evaluate design solutions.	Y
4	Gain knowledge of specific applications of human factors in transportation as human factors is a multi-disciplinary domain.	Y
5	Appreciate the multi-disciplinary nature of human factors needs in automation and transportation.	N

5.6

Current textbooks already have many relevant materials about the fundamentals of human factors. Educational material on human factors in CAVs must include relevant concepts and theories from human factors as well as automation. Reading recent and most cited journal articles could provide students with insights on human factor topics, examples of how specific quantitative and qualitative methods are applied, and how studies with specific goals are conducted. The main focus of current human factors courses is on quantitative methods (e.g., machine learning methods) and observed data. However, qualitative research methods, such as task analysis and usability studies are also important. Transportation engineering graduates need to know how to conduct these qualitative studies and how to analyze the data. Furthermore, certain types of research methods may require more training than others to be correctly applied. Therefore, we must provide courses on both research methods and analytical methods. Another important fact is that emerging technologies may very likely be used by a limited/specific population at first. As a result, there should be considerations for more sustainable designs targeted at the general population.

Students interested in CAVs could have very different backgrounds (e.g., from computer science, industrial engineering, urban planning, psychology, sociology, economics, etc.). Curriculum design needs to take this into consideration. Standardization for emerging technologies in CAVs, such as the International Organization for Standardization (ISO) and Society of Automotive Engineers (SAE) standards, could be introduced but should not be a core. Finally, students need to understand the underlying rationale for the current standards and guidelines, but should not be limited by them. We must ensure that the goal is that graduates can optimize the design in the future.

Barriers and Proposed Solutions

There are a number of reasons behind the existing knowledge gaps. First, human factor is a multi-disciplinary area and traditional silos of academic departments can impede interdisciplinary studies. User-centered design principles have not been traditionally acknowledged in many other fields. Even when transportation educators and students are aware of human factors courses, they may not find the opportunity to take them. The existing curriculum is already heavy, and students in transportation engineering may not be able to fit human factors classes from different departments into their already heavy workload. A possible solution is to review existing classes and create a balance between classes on theories and applications. Another barrier that transportation educators face is that teaching human factors requires special equipment, tools, and test beds. Highâlevel vehicle automation is an emerging technology and active, hands-on learning experiences for CAVs can be difficult to achieve given that CAVs are not yet available. In fact, many people, even practitioners, nowadays may not have any experience with even SAE definition of L2 or L3 automated vehicles.

Recommended Mode of Teaching

Mode of teaching could vary significantly depending on the purpose of obtaining a degree and the professional background of the students. Certificate programs are a growing need in the industry, but they cannot replace traditional programs, especially for more profound educational purposes. They are, however, appropriate for continuing education purposes for practitioners and professionals already in this field and preparing to work on CAV- related topics. Certificate programs also have advantages in promoting knowledge in human factors as they encourage people to consider human interaction with systems and keep user consideration in the design loop. On the other hand, traditional degree programs are more appropriate for individuals without any human factors training, seeking deeper knowledge in human factors, such as transportation engineering students. For undergraduate students, the focus should be on the physical perspective of human factors, while for graduate students we must emphasize the cognitive perspective of human factors, as well as design and analytical methods.

Regardless, when designing human factor courses for CAVs, we must note the following: (1) Online learning for human factors is possible, but a fully remote degree can be limiting; (2) Courses must include both physical (e.g., inclusive design, motion sickness) and cognitive (e.g., situation awareness, user trust, task switching) perspectives; (3) Active and hands-on learning is important. This could be in the form of lab activities (e.g., on fatigue and eye-tracking), or in a driving simulator. Also, we can provide students with a more immersed experience of concepts and theories through designed course projects. For example, we can let students conduct a crash investigation to identify potential causes behind a car crash in a mock-up or simulated scenario of a real-world situation; and (4) Finally, we must point out that basic human factor courses do not require prerequisite knowledge/courses, but some more advanced topics do. For example, classes on analytical methods could require prerequisite knowledge in mathematics and statistics.

5.7 Theme 3: Modeling, Simulation, and Testing of CAVs

Learning Objectives

In the context of CAVs, modeling and testing are complementary approaches, and thus, both are needed. We need students to acquire decent skills on the modeling side to know where to test, and we need decent tests to be able to inform the models. Developing excellent modeling and testing skills requires knowledge on understanding and testing the assump- tions of the model, the context in which it is deployed, and the limitations of the model. Additionally, we need now more than anytime to change the paradigm of assuming that "the model is correct" to assuming that "the model is wrong until proven correct" and that every model has its limitations. Students are expected to know how to check if models make sense with respect to first principles, and how to integrate empirical testing into model setup and evaluation. Additionally, students must be able to communicate with interdisciplinary teams and integrate findings from other domains, because this field is multi-faceted and no one can be an expert in all aspects of the problems. This field requires knowledge on com- puter simulation, human driving modeling, traffic engineering, communications and sensor technology, testing and verification, vehicle technology, and design for safety (software and systems).

Transportation engineering graduates should be able to characterize the nature of mod- eling errors. Taking large datasets and building models that avoid large errors to better correlate to real-world testing is another important skill for graduates. Students should be trained on their ability to determine how to convert findings in simulation with real-world corollaries, and determine the correlation between a simulation and a real CAV application. The basis of modeling, simulation, and testing include vehicle dynamics, communication tech, sensor tech, traffic flow theory, probability with respect to the analysis of rare events, global navigation satellite system (GNSS) for positioning and timing, and sensor measure- ment models that require foundational skills such as mathematics, data analysis, signal processing, etc. Finally, students need to understand the implications and consequences of scaling CAV technologies, e.g., on the environment and transportation planning.

Taking a look at the current state of the field reveals that some models are being abused, while many better models are not being leveraged. The main limitation is that the field is very much still at the advanced research and development stage, not deployment/practice. This field continues to evolve very quickly and is a convergence field of many established disciplines. That being said, it is critical to develop lifelong learning skills in a field where things are rapidly advancing on 6-month timescales. It goes without saying that critical thinking and lifelong learning skills remain essential as always. The learning objectives for students in this field are summarized in Table 4.

5.8 Table 4. Learning objectives for modeling, simulation, and testing.

	Learning Objectives	Educational material exists (Y/N)
1	Compose CAV modeling components and analyze the components and the whole system for physical correctness with empirical data.	N
2	Design and execute a test to validate or invalidate a model in a specific domain.	Y
3	Learn how to design tests to link empirical testing with modeling concepts.	Y
4	Use models to accelerate real-world testing without introducing modeling biases	Y
5	Have a basic understanding of core components that underpin the field.	Y
6	Identify most important areas of impact and timeline to get there for potential benefits and perils of CAV deployments at scale.	N

5.9

Barriers and Proposed Solutions

Considering the educational outcomes of this field, we face two major barriers. First, training on modeling, simulation, and testing only pertains to Ph.D. level problems, because the models are complicated and the testing is expensive. This implies that it is very difficult to pack the required skill sets into undergraduate education. Secondly, the field is rapidly changing and the introduction of new technology might change what is not known in the field. As such, developing critical thinking skills and lifelong learning skills are going to be really important to tackle the educational gaps.

Recommended Mode of Teaching

A great deal of content can be covered in a special elective class at the undergraduate level. Although this will not cover all the knowledge gaps, it gives space to identify a number of key issues. Also, senior design projects can allow students to get a better feel for the research space and allow the exploration of emerging topics in more detail than a one-size-fits-all class. We must again point out that the field is moving too fast to wait for a student to get a 4-year degree, as by the end the knowledge may already be out of date. As alternatives, we can consider research seminars on emerging topics and certificates that cover core ideas in focused settings.

The prerequisites for training transportation engineering students in this field include elementary physics, introduction to electrical engineering, programming, probability, and statistics. The core courses include vehicle dynamics and control, fundamentals of communication, GNSS, timing and positioning, etc. Let us not forget that there is a wide spectrum of careers in this field, having different requirements and priorities.

5.10 Theme 4: Travel Behavior in the Context of CAVs

Learning Objectives

The educational needs of students in the area of travel behavior modeling can be divided into two core areas, namely, a methodological core and a behavioral core. The methodological core is not only applicable to travel behavior, but rather is of value for a variety of subjects. Nonetheless, it represents a foundation that is required to understand travel de- mand analysis. Currently, it typically includes an introduction to basic concepts of statistics and econometrics as well as the fundamentals of programming. As we argue below, further subjects should be added to the methodological core.

The behavioral core is more explicitly focused on travel behavior and includes microeconomic foundations, data sources for analyzing travel behavior, and the fundamentals of choice models. An introduction to choice models should include, but not necessarily be limited to, discrete choice models and activity-based modeling frameworks. Discrete choice models will continue to be the bedrock of travel demand modeling, and the teaching of such models should remain an integral part of any transportation engineering program. A strong understanding of discrete choice modeling also allows students to develop an intuition for how demand may be affected by various changes to the transportation system. Other sub- jects that underpin discrete choice modeling are microeconomics, statistical inference, and parameter estimation techniques.

The importance of these subjects is unlikely to change as the transportation system transitions to CAVs. Notwithstanding, the prevalence of CAVs is likely to affect travel behavior in new ways. Automation will give rise to new types of shared mobility services, where transportation demand is served by driverless taxis or shared-ride vans, and autonomous household vehicles can be shared more efficiently between household members because they can reposition themselves without a driver. Thus, autonomous vehicles that are part of shared mobility fleets or are owned by private households would likely be utilized rather differently from the way current-day vehicles are utilized. How to incorporate this vehicle utilization into demand models is an active field of research. A particular challenge is the accurate modeling of empty vehicle trips. Such trips can be generated by the repositioning of fleet AVs in shared mobility networks, the repositioning of private AVs to serve other household members, or the repositioning of a private AV to home, e.g., to avoid parking fees. Repositioning traffic is currently not captured by regional travel demand models.

Since the operators of shared mobility fleets typically employ large-scale optimization models to determine how to reposition their vehicles, it will become increasingly important for students to learn about basic optimization in transportation engineering programs. In the case of privately owned AVs, an autonomous household vehicle may be shared by multiple users throughout the day and repositioned accordingly. To model this repositioning traffic, will become more important for demand models to capture how the use of a household vehicle is negotiated. For instance, various hierarchies of users and activities may exist. Individuals are likely to apply various decision-making approaches to determine how a household AV is used, which may or may not correspond to a truly optimal solution. Regional travel demand models will need to be expanded to account for such intra-household interactions, and a useful framework for students to think about them is game theory. As new modeling techniques to capture such empty vehicle trips emerge, it will be important to incorporate them rapidly into travel demand analysis courses, which will also support their transfer into practice.

Lastly, the emergence of CAVs is expected to generate vast amounts of usage data. This represents an opportunity to integrate passively collected data from CAVs into the practice of travel demand analysis. In the past, the travel demand field has worked mostly with survey data, and not much emphasis has been placed on teaching students how to work with passively collected data. As passive data become more prevalent, it will become increasingly important for students to be trained in working with the types of passive data generated by CAVs and to know the fundamentals of data mining. This includes developing computational skills for the management, cleaning, integration, and validation of big datasets as well as knowledge of the fundamentals of machine learning. Of course, the need for increased training in data mining is not limited to applications in travel behavior analysis and the usefulness of these skills extends to other areas of transportation engineering as well, as was found by West et al. (2021). Therefore, these skills may be considered a new part of the methodological core. The workshop participants determined that the behavioral core of travel demand modeling, as well as some of the methodological core, would likely occupy two courses in a traditional graduate program in transportation engineering. Overall, five learning objectives for travel behavior and its application to CAVs were identified, as summarized in Table 5.

5.11 Table 5. Learning objectives for travel behavior analysis in the context of CAVs.

	Learning Objectives	Educational material exists (Y/N)
1	Understand basics of what drives behavior, and factors that influence traveler decision-making (long-term and short-term), given CAV context.	Y
2	Master basic modeling approaches and have foundations for learning advanced modeling techniques in depth; choice models, foundational econometrics, ability to derive composite models/model structures.	Y
3	Identify and critique various data streams available to study CAV systems and describe use cases.	N
4	Demonstrate the ability to manage and process traditional (survey-based, experiment-based) and passive data streams.	Y
5	Apply foundational knowledge in travel behavior and CAV technologies to design and development of research questions, hypotheses, measurement instruments, and analysis plans.	N

5.12

Barriers and Proposed Solutions

As Table 5 demonstrates, one of the barriers to preparing transportation engineering curricula for teaching travel behavior analysis in the context of CAVs is that the educational material for two of the learning objectives presently does not exist to the best of the workshop participants' knowledge. For two further learning objectives, materials exist in general, typically in other courses that are taught outside of transportation engineering programs, but they are often not specifically focused on the needs of transportation engineering programs. Finally, there is a lack of openly available CAV data for teaching purposes, especially pre-processed data that can help transportation educators to teach fundamental concepts and models of data mining in travel behavior analysis.

Recommended Mode of Teaching

Much of the foundational material, especially pertaining to the methodological core, could be generally taught in self-contained online courses. However, in courses pertaining to the behavioral core, especially those covering the design of travel behavior studies and hands-on analyses of behavioral data, students can benefit strongly from in-person interaction with an instructor and with classmates, and hence, they are not suitable for self-contained online instruction. The workshop participants noted that travel behavior courses do not necessarily have to be only lecture-focused, and that some learning objectives could also be achieved through applications-focused instruction and hands-on learning in case studies or projects.

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7 FINDINGS

This project investigated potential gaps in transportation education as they relate to CAVs. Toward this end, a workshop was held in which experts from academia and industry discussed their experiences and observations regarding such educational needs, how these needs can be addressed, what potential barriers exist to transitioning traditional transportation engineering curricula to curricula with a CAV focus, and what the best modes of instruction are to reach the instructional objectives.

Due to the diversity of the field, a pre-workshop survey was used to identify four themes that were the focus of discussions in the workshop: (1) Next-generation infrastructure for CAVs; (2) human factors with CAVs; (3) modeling, simulation, and testing of CAVs; and (4) travel behavior in the context of CAVs. Despite the differences in educational material, and thereby gaps and needs, between the themes, a few common issues and solutions were identified across all themes. There was a consensus that covering fundamental concepts and fostering critical thinking skills and lifelong learning skills in students will ensure that they can contribute to the field throughout their careers, despite the fast advancement of technology. Combining theoretical foundations with practical training through projects and other means of active learning was also universally identified as a critical component in training future transportation engineers.

In addition to these broad-based findings that are universally relevant across all themes, a number of theme-specific learning objectives were identified. These included a list of core concepts, methodologies, and data requirements for each theme. Some of the obstacles that were identified included a lack of access to high-quality and clean data that can be utilized for teaching as well as a lack of access to test beds, special equipment, and tools. Finally, although it is possible to use online courses or modules to cover some fundamental concepts, workshop participants agreed that in-person classes remain the most effective way of learning, as they allow for hands-on experiences and exchanges of ideas between students with different backgrounds. For undergraduate training, a 4-year degree program may still be the best way to teach fundamental knowledge and concepts. Nonetheless, such a program can offer more practical training through special elective courses and senior-year projects. CAV-focused seminars would also provide means to keep students informed of fast-paced technological advancements in the field. On the other hand, short certificate degrees can help professionals to stay up-to-date with technology.

8 RECOMMENDATIONS

Two main recommendations regardless of theme are as follows:

- Covering fundamental concepts and fostering critical thinking skills and lifelong learning skills in students
- Combining theoretical foundations with practical training through projects and other means of active learning

9 OUTPUTS, OUTCOMES, AND IMPACT

9.1 Outputs

1. Poster presentation (made by Jisoon Lim): Autonomy in Transportation Education, January 2023, TRB Annual Meeting, Washington DC.
2. Presentation (made virtually by Neda Masoud): Autonomy in Transportation Education, May 2022, Mcity, Ann Arbor, MI.

9.2 Outcomes

1. Increased understanding of the educational gaps in connected and automated vehicles, and ways to fill these gaps
2. Proposals on new courses, credentials, and degrees to train a workforce for connected and automated transportation systems

9.3 Impact

1. This work contributes to creating a skilled workforce for connected and automated

transportation systems

10 TECH TRANSFER

NA

11 CHALLENGES AND LESSONS LEARNT

NA

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13 Appendices

13.1 Appendix I. THE LIST OF ATTENDEES AND ORGANIZERS

Table 6 shows the list of attendees and organizers of *Autonomy in Transportation Education* workshop.

Fan	Bai	GM, Inc.
Jeff	Ban	University of Washington
Shan	Bao	University of Michigan-Dearborn
Debra	Bezzina	UMTRI (Organizer)
Linda	Boyle	University of Washington
Andre	Carrel	The Ohio State University
Sue	Chrysler	TTI, Inc.
Sharon	Di	Columbia University
Larry	Head	University of Arizona
John	Kenney	Toyota, Inc.
Xiaopeng	Li	University of South Florida
Henry	Liu	University of Michigan (Organizer)
Jiaqi	Ma	University of California, Los Angeles
Neda	Masoud	University of Michigan (Organizer)
Natasha	Merat	University of Leeds
Jim	Misener	Qualcomm, Inc.
Khandker	Nurul Habib	University of Toronto
Gabor	Orosz	University of Michigan (Organizer)
Ram	Pendayala	Arizona State University
Brandon	Pitts	Purdue University
Jeremiah	Robertson	QS-2
Reuben	Sharkar	ACM
Atiyya	Shaw	University of California, Berkeley
Siqian	Shen	University of Michigan (Organizer)
Steve	Shladover	University of California, Berkeley
Marina	Sofos	ARPA-E
Amanda	Stathopoulos	Northwestern University
Amirmahdi	Tafreshian	University of Michigan (Organizer)
Calvin	Tuttle	UMTRI (Organizer)
Joan	Walker	University of California, Berkeley
Dan	Work	Vanderbilt University
Jessee	Yang	University of Michigan
Terry	Yang	University of Utah
Yafeng	Yin	University of Michigan
Michael	Zhang	University of California, Davis
Xuesong	Zhou	Arizona State University

13.2 Table 6. List of attendees of the Autonomy in Transportation Education workshop.

13.3 Appendix II. THE SURVEY QUESTIONS

Figures 8-11 show the survey questions distributed to the experts.

Autonomy in Transportation Education

The objective of this survey is to identify the gaps in knowledge and skill set of new university graduates as it pertains to connected and automated vehicle (CAV) technology, and to propose proper delivery tools to fill them. We value your response to each question, and will keep your input confidential. This survey is supported by the Center for Connected and Automated Transportation (CCAT), and Mcity at the University of Michigan, Ann Arbor.

* Required

1. Please acknowledge that you have read and agree to the terms and conditions in the information sheet (see the link below). If not, you will be directed to the end of the survey. *

   https://drive.google.com/file/d/1AUpdXoL2ZPkEKXeYuzvGRjHf5TBPwVZ2/view?usp=sharing

   Mark only one oval.

   - Yes
   - No

Personal Information

2. Please indicate your sector. *

   Mark only one oval.

   - Academia (faculty member)
   - Academia (student)
   - Government agency
   - Management consultancy
   - Public-sector research organization (e.g., National Lab)
   - Transportation engineering and planning consultancy
   - Other private-sector research and development

Figure 8. The Survey Questions, page 1

3. Please state your position within your organization. *

____

4. Please state your highest level of education. *

Mark only one oval.

- ◯ High School
- ◯ Vocational-Technical program
- ◯ Associate Degree
- ◯ Bachelor's Degree
- ◯ Master's Degree
- ◯ Professional degree (e.g., JD, MD, etc.)
- ◯ PhD or equivalent
- ◯ Other

5. Do you observe a knowledge gap in the skill set of recent graduates in your sector? If no, you will be directed to the end of the survey. *

Mark only one oval.

- ◯ Yes
- ◯ No

Knowledge Gap

Figure 9. The Survey Questions, page 2

6. In what areas do you see a knowledge gap in general? Please select all that apply. *

Check all that apply.

- [ ] State of the practice tools and technologies
- [ ] Working with data in practice
- [ ] Theoretical foundations
- [ ] System level thinking
- [ ] Translating their knowledge to practical solutions
- [ ] None of the above
- [ ] Other: ____________________

7. What are the knowledge gaps related to Connected and Automated Vehicles (CAVs)? Please select all that apply. *

Check all that apply.

- [ ] Perception, planning, and control systems of CAVs
- [ ] Connectivity between vehicles, infrastructure, and other road users
- [ ] Infrastructure support for CAVs
- [ ] Machine learning algorithms for CAVs
- [ ] Modeling and control of CAV systems (with vehicles with varying levels of autonomy and/or other road users)
- [ ] Testing and evaluation of CAVs
- [ ] Travel behavior in the context of CAVs
- [ ] Human factors with CAVs
- [ ] None of the above
- [ ] Other: ____________________

Knowledge Delivery Tools

Figure 10. The Survey Questions, page 3

8. What are the key ways to enhance the skill set? *

Check all that apply.

- [ ] Traditional degree programs with in-person classes
- [ ] Traditional degree programs with online classes
- [ ] Certificate programs with short, in-person modules
- [ ] Certificate programs with short, online modules
- [ ] Case-study oriented education (similar to MBA degrees)
- [ ] None of the above
- [ ] Other: ____________________

Google Forms

Figure 11. The Survey Questions, page 4

13.4 Appendix III. THE LIST OF QUESTIONS FOR THE WORKSHOP DISCUSSIONS

Figure 12 shows the list of questions for the workshop discussions.

1. Introductions and sharing

Each participant takes about 2-3 minutes to briefly introduce themselves and share their perspective on these questions:

- What are the 2-3 most important things that students/practitioners should understand and be able to do in this area? Why?
- Why are these objectives important?

2. Consolidate learning objectives and identify curricular gaps

Based on the previous discussion, create a list of learning objectives for an educational program in this area. The learning objectives are statements of what a student will be able to know/understand/do after completing an educational unit. They should be actionable and observable.

	Learning Objectives *By the end of a program in this area, students/practitioners will be able to ...*	Educational material exists (Y/N)
1		
2		

For each objective listed, indicate whether educational material exists in today's curriculum or whether it needs to be developed.

3. Why do the curricular gaps exist?

Why do you think these gaps exist? In your response, please consider different aspects, including, but not limited to, the following:

- Low impact in practice
- Existing curriculum is already heavy (can anything in the curriculum be removed to create space?)
- Requiring special equipment/tools/test beds for teaching
- Interaction between research and education
    i. Lack of (adequate) funding opportunities for research
    ii. Lack of theoretical depth for research
    iii. Requiring special equipment or tools for research

4. What is the best educational format?

The result of our survey suggests that the best mode of education is for the transportation educators to develop certificate programs with short modules to close the educational gap.

- Why do you think traditional degree programs have failed to address these issues?
- What would you recommend about the format of such programs?
- Can we create new modules to integrate the material into our existing curriculum?

5. What is the prerequisite knowledge?

Do students/practitioners require any prior knowledge on any subject or need any advanced degree before taking these certificate programs? Please explain.

Figure 12. The List of Questions for the Workshop Discussion