Delivering Contextual Knowledge and Critical Skills of Disruptive Technologies through Problem-Based Learning in Research Experiences for Undergraduates Setting

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1.0 Introduction

Recent developments in transportation, including energy-efficient and autonomous vehicles, have become an important topic of study for students in transportation engineering. Students in this field should be prepared with new knowledge, skills, and sustainable engineering practices that meet the emerging needs of the industry.

During the summers of 2018 and 2019, we developed and implemented an eight-week program to increase the knowledge and skills of students coming from multiple fields related to autonomous vehicles. The participating students engaged in experiments and other activities to study autonomous vehicle platooning as a strategy to improve automobile fuel efficiency. Vehicle platooning is an intelligent transportation application for coordinating a number of vehicles to follow each other at a close, safe distance in order to save energy by reducing air drag and speed changes. The idea is similar to drafting in bicycle racing.

The engineering concepts of reducing cost and improving sustainability were embedded in the leading research question, "How much will platooning reduce fuel consumption and emissions per vehicle mile traveled?" Based on this question, we developed and implemented activities designed to help the students acquire an overall knowledge structure in autonomous vehicles. The goal of using problem-based learning (PBL) activities was to introduce the multidisciplinary knowledge and critical skills aspects of learning about disruptive technologies by using the case of autonomous vehicles.

In this paper, we will discuss how a multidisciplinary research approach was incorporated into a set of problem-based learning activities. The students were introduced to aspects of the problem related to math, physics, computer science, and biology, and were able to integrate this knowledge to address the question relative to autonomous vehicles. We will also present the results on students' use of critical skills such as machine learning and computer programming.

2.0 Voluntary and Interdisciplinary Research Experience

Imagine that we are a group of mountaineers who are camping in a valley. Above the valley is a beautiful mountain, and we set the goal to reach its summit on a one-week journey. Developing a strategy to approach this problem involves several aspects that need to be carefully considered if we are to understand, plan, and successfully achieve our goal.

Such a journey is a call to us to **explore** what we know and what we need to know about climbing the mountain. We have our preconceived notions and prior knowledge of climbing mountains, but we are challenged to increase our consciousness about the problem so that we may take ownership of the problem. We need to decide on how we will comprehend what we don't know. Once, our qualitative mindset can recall the references of our prior experiences in our structures of assumptions. Then, we begin listing our ideas of possible ways to reach our goal.

As the journey is set to be time-sensitive, we soon **engage** with the problem. Using our assumptions and facing the marvelous mountain directly helps us to articulate ways to visualize and simplify the problem. Then we can reason quantitatively to compare the possible solutions for the problem to make our journey most productive. The goal of reaching the summit is subject to our continued effort to understand and analyze the problem by using approximation, evaluation, observation, calculation, and experimentation. This communicative group effort involves locating the problem in our real-life context while optimizing concepts and ideas to reach the best solution.

Figure 1: Interdisciplinary Research with Problem-Based Learning

Once the group situates the problem in its real-life context and works on the smaller components of it, we then **experience** the process of problem-solving. Climbing the mountain requires both linear and non-linear approaches that promote higher order thinking and critical skills. The complexity of the problem encourages us to think reflectively and critically. The dynamic learning environment poses challenges but also opportunities for interdisciplinary collaboration.

Finally, when the mountain has been climbed and we have safely returned to our base camp, we **evaluate** our mountain climbing experience, analyzing our successes and difficulties, and drawing lessons that can be applied to similar challenges in the future.

This is the process we encouraged our research experiences for undergraduates (REU) participants to use as they addressed the problem. They had been ready for their summer research project.

2.1 Interdisciplinary Undergraduate Research

This section presents a literature review relative to the role of skill development of students using problem-based learning activities. Following this, Section 3 summarizes how students undertook a central role to acquire new knowledge and skills by working on the problem. As the students became critically reflective of the assumptions and approximations that they made, they were guided by the facilitators to use their reasoning skills qualitatively and quantitatively. Some of the technical skills that the students applied while solving the problem are data analytics, data mining, machine learning, and computer programming.

The disruptive technologies are expected to be used and advanced in the progress of producing new technologies. The recent development in transportation, such as autonomous and energy-efficient vehicles, defines a condition for the students in transportation engineering. So, students in the field of transportation engineering should be ready upon their graduation with new knowledge and skills that are compatible with the need of the industry. (Tang et. al, 2018; Li & Faghri, 2016).

Undergraduate student research is found to be useful when the research question or problem is embedded in the real-life context. Research activities for students to promote knowledge acquisition and developing critical skills can be practiced via different forms of pedagogical approaches, including problem-based learning (Lopatto, 2004; Savery, 2006).

Through problem-based learning activities, the learning experience of the students is enhanced when they collaborate and share their ideas. The collaborative environment of the research activity was provided to students to create an authentic experience in which they activate their prior knowledge, do independent research to increase their understanding of the subject matter (Savery & Duffy 1995).

Another aspect of using PBL as an instructional strategy lies in the fact that students are encouraged to think critically while working on solutions. They work and collaborate on ideas to elaborate on the possible solutions so that their communication and teamwork skills are improved (Johnson, 1999).

3.0 The Interdisciplinary Research Experience for Undergraduates

For the past two summers (2018 and 2019), groups of students from a college in the Southeast participated in a problem-based learning journey in the context of studying about autonomous vehicles. One of the long-term goals of this project was to prepare students, who are underrepresented minorities, for careers in transportation. They were part of a multi-disciplinary, eight-week summer research experience that integrated curricular and extra-curricular activities (see Table 1).

Table 1: Interdisciplinary Research with Problem-Based Learning

Explore	**Engage**	**Experience**	**Evaluate**
Activating Prior Knowledge	Visualization	Authentic experience	Reflection
Research	Identifying Key Elements	Immediate Feedback	Group Presentation
Concept Mapping	Simplification	Linear and Non-Linear Learning Activities	Concept Evaluation
	Simulate	Interdisciplinary Collaboration	
	Concept Optimization	Conceptual Reasoning	

During the summer 2018 REU, as shown in Table 2, a total of 8 undergraduate students majoring in mathematics (2), computer science (3), and computer engineering (3) participated. In this group, half of the students were internationals, six were sophomores, and two were juniors.

Table 2: Participants of the summer 2018 REU Program

Student	**Major**	**Class**	**In the Project**
1	Mathematics	Junior	2nd Year
2	Computer Science	Sophomore	1st Year
3	Computer Science	Sophomore	1st Year
4	Computer Engineering	Sophomore	1st Year
5	Computer Engineering	Sophomore	1st Year
6	Computer Engineering	Sophomore	1st Year
7	Mathematics	Junior	1st Year
8	Computer Science	Sophomore	1st Year

In summer 2019, the group included seven research students majoring in biology, mathematics (2), environmental health science, computer science, computer engineering (2). Students were with classifications of two sophomores, four juniors, and one senior (see Table 3), only one of whom was international.

Table 3: Participants of the summer 2019 REU Program

Student	**Major**	**Class**	**In the Project**
1	Mathematics	Senior	3rd Year
2	Biology	Sophomore	1st Year
3	Computer Science	Junior	2nd Year
4	Environmental Health	Sophomore	1st Year
5	Computer Engineering	Junior	2nd Year
6	Computer Engineering	Junior	2nd Year
7	Mathematics	Junior	1st Year

3.1 Explore

During the 2018 REU, the students engaged in a set of four structured learning activities designed to help them develop a number of technical and conceptual skills. In addition, they participated in regular workshops with topics including research and ethics, effective poster presentation preparation, reflecting on the research experience, and graduate school application preparation. The students also participated in a series of critical thinking sessions presented by project team on defining a research problem, literature search, and the research process. Table 4 summarizes the topics covered in the learning activities and workshops undertaken by the participants.

Table 4: Skill mapping of the summer 2018 REU Program

Skill Mapping 2018 REU Implementation								
DW: Energy saving and emission reduction by platooning								
	Technical Skill[1]				Conceptual Skill[2]			
	DA	DM	ML	CP	PS	TW	D-M	CT
Activity 1: Problem definition					X	X	X	X
Activity 2: Library Use						X	X	X
Activity 3: Active Learning of Assumptions and Approximations					X	X	X	X
Activity 4: Research as process	X				X	X	X	X
Communication Workshop				X	X		X	X
Regular Weekly Workshops						X		X

1. *DA: data analytics, DM: data mining, ML: machine learning, CP: computer programming*
2. *PS: problem solving, TW: teamwork, D-M: Decision-making, CT: critical thinking*

During the following summer (2019), we implemented a set of ten structured activities designed to equip the students with the technical and conceptual knowledge and skills required for successful achievement of the project's research goals. Table 5 gives details about the activities and the mapping onto interdisciplinary research with problem-based learning framework given in figure 1. Table 6 provides a summary of these activities and workshops. This cohort also participated in research and ethics workshop.

Table 5: Activities of the summer 2019 REU Program

The Problem: How much will platooning reduce fuel consumption and emissions per vehicle mile traveled?	
Phase 1: Explore	
Activity 1: Decision Worksheet (Platooning Activities)	
The following main problem was introduced to the students with the decision worksheet: How much will platooning reduce fuel consumption and emissions per vehicle mile traveled? It was a relevant question that the students can find in real life. In this activity, students were provided with questions to evaluate their current understanding of the problem.	
Phase 2: Engage	
Activity 2: Biosystem	**Activity 3: Active Learning of Assumptions and Approximations**
Various biological systems presented students to identify key concepts in platooning, such as following distance, communication, sensing, and formation.	In the reconstruct phase of the problem-solving activity, the students needed to use the skills for problem simplification and reduction. In this activity, students worked on using assumptions and approximation to

			identify and prioritize the fundamental concepts of a given problem.		
Phase 3: Experience					
Activity 4: Smart PI Vehicles	**Activity 5: A Traffic Signal Cycle**	**Activity 6: Control Game**	**Activity 7: Platoon VSP**	**Activity 8: Emissions**	**Activity 9: Operational Modes**
Students worked with a model smart PI vehicle to learn and apply the concepts of autonomous control, vehicle kinematics, and fuel-saving.	Students worked on simple python scriptwriting to learn and apply traffic signal cycles through computer programming.	A control game was utilized for the students to learn and apply fundamental concepts such as distance speed and acceleration in platooning.	The students worked on scriptwriting and coding to calculate emission in a vehicle-specific power.	Students worked on MOtor Vehicle Emission Simulator (MOVES), a vehicle emission simulation tool for different operating vehicle modes to learn and apply the criteria of air pollutants set by the Environmental Protection Agency.	Students wrote a function in python to understand vehicle operation modes better by identifying criteria such as vehicle speed and acceleration.
Phase 4: Evaluate					
Activity 10: Decision Worksheet (Platooning Activities)					
In this activity, students revisited the original problem with a renewed approach, new knowledge, and skills: How much will platooning reduce fuel consumption and emissions per vehicle mile traveled? They were given the same decision worksheet that they worked on the first week of the program.					

Table 6: Skill mapping of the summer 2019 REU Program

Skill Mapping 2019 REU Implementation								
DW: Energy saving and emission reduction by platooning								
	Technical Skill[1]				Conceptual Skill[2]			
	DA	DM	ML	CP	PS	TW	D-M	CT
Activity 1: Sketching a Platooning					X	X	X	X
Activity 2: Biosystems						X	X	X
Activity 3: Active Learning of Assumptions and Approximations					X	X	X	X
Activity 4: Smart PI Vehicles	X				X	X	X	X
Activity 5: A Traffic Signal Cycle				X	X		X	X
Activity 6: Control Game				X	X	X	X	X
Activity 7: Platoon VSP	X			X	X	X	X	X
Activity 8: Emissions	X			X	X		X	X
Activity 9: Operational Modes	X			X	X		X	X
Activity 10: Decision worksheet					X	X	X	X
Intrusion detection	X	X	X	X		X		
Sensor fusion and smart cars				X	X	X		X
Air drag reduction from platooning						X		X
Air quality estimation	X	X		X	X	X	X	X

Biosystems					X	X	X	X
Image processing			X	X	X	X	X	X

1. *DA: data analytics, DM: data mining, ML: machine learning, CP: computer programming*
2. *PS: problem solving, TW: teamwork, D-M: Decision-making, CT: critical thinking*

3.2 Engage

With their backgrounds in several STEM fields, the students were aware of using mathematical and scientific reasoning. The ability to use calculations and measurement is part of acquiring and applying knowledge and skills to math and science problems. Further, artificial intelligence technology such as autonomous vehicles sheds light on the importance of using mathematics and scientific reasoning not only for calculations and measurement but also for simplification, reduction, and prediction of possible outcomes. When an autonomous vehicle moves in a designated road, the car and the surrounding conditions provide multilayered structures where the operating system of the car collects the assumptions and calculates approximations to make the best possible decision.

3.2.1 Critical skill identification and delivery-targeted infusion

Based on our analysis of the participants' experiences during the first REU, we developed an expanded set of learning activities for the 2019 experience. Our goal was to better facilitate student learning, improve our interdisciplinary approach, and improve the research learning and critical thinking outcomes, giving the participants better knowledge and skills for independent work on the problem. As shown in Table 7, the activities were designed to address the students' learning needs, and be interesting for students from various majors. For the first four weeks, all students participated in these activities. However, some of the students had personal difficulties which prevented them from full participation in the second half of the experience. In particular, computer science-related activities were negatively impacted. The final poster presentations also revealed these knowledge gaps among some of the participants.

Table 7: Lower Level Targeted Infusion in 2019 REU Implementation

	Discipline	Low Level Infusion
Activity 1: Sketching a Platooning	transportation engineering	estimation, algebra, drawing
Activity 2: Biosystems	biology	estimation, drawing
Activity 3: Active Learning of Assumptions and Approximations	general engineering	estimation, approximation, algebra
Activity 4: Smart PI Vehicles	physics	calculus, experiment design, graphing
Activity 5: A Traffic Signal Cycle	computer science	logic, coding
Activity 6: Control Game	physics	calculus, control, logic, coding
Activity 7: Platoon VSP	computer science	logic, coding
Activity 8: Emissions	computer science	logic, coding

Activity 9: Operational Modes	computer science	logic, coding
Activity 10: Decision worksheet	transportation engineering	estimation, algebra, drawing

The activities presented in Table 7 can be mapped to higher level infusion topics for the multidisciplinary group (see Table 8). Students were able to relate themselves to the concepts that included intrusion detection (cybersecurity/computer science), sensors and control (computer engineering), air drag formulations (physics), air quality data analysis for schools open/close (environmental health science), biomimicry for vehicle platooning (biology, mathematics), and image analysis on cells (biology, computer science).

Table 8: Higher Level Targeted Infusion in 2019 REU by Students

	Discipline	Low Level Infusion
Intrusion detection	Cybersecurity	coding, python, R
Sensor fusion and smart cars	computer engineering	coding, python, control
Air drag reduction from platooning	Physics	calculus, modeling
Air quality estimation	environmental science	regression, unit conversions
Biosystems	biology-mathematics-engineering	calculus, literature review
Image processing	biology, computer science	coding, R, biology

3.3 Experience

3.3.1 Summer Research Program 2018

During the first year's REU program, the students were given tasks to find and read relevant literature and software tutorials, to write scripts in R on machine learning algorithms, and to write a script for basic algorithms in Python to control smart cars.

Although not defined formally as designed activities, the students' projects aimed to develop cyber-attack, detection, and mitigation models on transportation networks for connected and autonomous vehicles. Tasks contained methods to be applied such as attack tree modeling (graphical) and the development of traffic and communication simulations. These tasks included:

1. Students used ARC-IT architecture (i.e. connected vehicles, (U.S. DOT, 2018)) to import defined vulnerabilities (from various field implementations) to graphical models in traffic signal and cooperative adaptive cruise control (CACC) applications. Specifically, they used Bayesian networks as a graphical model to propagate and quantify the attack impact.
2. A group of two students also developed a process simulation model using a physical arc-it diagram in order to quantify communication delay impacts. For microsimulations, VISSIM with Matlab simulations were developed.
3. Another group explored possible cyberattacks and their impacts via hands-on and real network implementations and protocols. For this, the group used multiple Raspberry Pi vehicles (i.e., smart cars (Sunfounder, 2018)) with wireless communication capabilities (see Figure 2). Through interaction with a research team from Clemson University (CU),

students were able to send and receive vehicle basic safety messages (BSM-SAE standard for V2V and V2I messages (DSRC, 2007)) between two Raspberry Pis in a serial way (one sending one listening consecutively in a CACC application).

4. Students were also able to manipulate the frequency of basic safety messages for denial of service (DOS) attacks and the content of BSMs for false information attacks. This was achieved mainly towards the end of the summer.
5. Throughout the summer, students were able to revise the provided Python code by the smart car producer to control the Raspberry Pi vehicles' sensors and generate a working CACC platooning with on-board sensors, so mimicking autonomous vehicles (Figure 2).
6. During the last two weeks of research, one student also worked on computer vision to utilize video cameras as redundant sensors for connected and autonomous vehicles. This student used a Linux machine for TensorFlow, Python, and You Only Look Once-real time object detection (YOLO) to be able to classify detailed object detection. He also used an R-studio TensorFlow and Keras package to generate similar computer vision results.

Figure 2 CACC application with Raspberry pi vehicles (left) and communications training (right)

Aside from the regular day-to-day research activities mentioned above, the students attended five REU workshops at University of South Carolina (UofSC) on topics ranging from ethics, poster presentation preparation, and graduate school application preparation. The students also participated in the project team's critical thinking sessions on defining a research problem, doing a literature search, and the research process. The research group traveled to Clemson to visit the Cyberphysical Systems Lab and Tier 1 University Transportation Center for Connected Multimodal Mobility (C^2M^2) at CU (see Figure 3 (b)). The final research presentations were held at the end of the program on the college's campus. Students presented their posters to other summer research students, college faculty, and guests.

During this REU, we were able to involve a variety of collaborators to expose the students to multiple subjects. At the beginning of the REU, we had hoped to help the participants to prepare manuscripts with strong and promising results. However, this objective proved to be overly ambitious, in part because it took longer than anticipated do develop the newly recruited students' research skills, and several logistical issues that arose. This was one of the outcomes that prompted us to develop the expanded set of learning activities to be implemented in Year 2.

(a) (b)

Figure 3 Reflection on research experience (Project Team at UofSC Civil and Env. Eng) (a) and Clemson University C^2M^2 Field Trip (b)

3.3.2 Summer Research Program 2019

The second year's REU (summer 2019), consisted of a group of 7 research students (see Table 3). As shown in Tables 5-8, the students investigated vehicle platooning and biomimicry, computer vision, and sensor fusion on a problem defined as "Energy saving and emission reduction by platooning".

In addition to the weekly activities listed on Table 4, student attended workshop sessions on ethics and presentation preparation at the beginning of the program. Then, students were given a problem reduction, approximation, and estimation activity (see Figure 4 (a)). A workshop on Webots was given to students by graduate students from Clemson University's Tier 1 University Transportation C^2M^2 (see Figure 4 (b)). Designed around the activities, students were taught Matlab and R programming in robotics and machine learning+TensorFlow on RStudio.

(a) (b)

Figure 4 Activity delivered by the project team (a) and conducted by C^2M^2 at CU (b)

Students were given a series of Python programming tasks in the context of fuel consumption and emissions. They then presented their findings at the end of the summer research program on the college campus (see Figure 5).

Figure 5 Activities and lessons delivered by the project team

Comparing to the first year's REU, the second year activities and research tasks were better structured and aligned. At the beginning of the experience, more time was spent for design, and throughout the REU, more time was spent on management.

3.4 Evaluate

The college's faculty have been hosting REUs since 2011. Initially, selection of faculty and students were based on the proposal submitted. Students who were interested committed along with faculty and conducted the research. Typically, the number of students per faculty was 1 or 2, determined by the faculty's research domain and related students. Friday journal club presentations were held to let students with diverse backgrounds learn about a wide range of different research fields. Students participating in REUs all stayed on campus, in part because no off-campus facilities were available. Two to nine students participated in REUs each summer. Until 2018, all of these REUs were based on faculty-driven research, publications, and presentations. Students did not have other off-campus activities, and there were no structured interactions with faculty or students from other institutions.

REU participants were closely supervised by the faculty, and together, the participating students and faculty prepared presentations and competed for final presentation awards. One issue that emerged from this was that some students experienced high levels of stress as the time for final presentations approached, and as a result, a few even failed to make their presentations. On the other hand, some summers produced students with award-winning posters and oral presentations. In this individualized research culture, some students were able to thrive, while others' low levels of self-efficacy prevented them from having successful experiences. Since most REU students worked individually, opportunities for mutual support among research teams were not developed.

This project determined to create research experiences that would address these issues. With a PBL approach in mind, engineering faculty members recruited students with a variety of STEM backgrounds to work collaboratively on a complex problem in transportation engineering. The research was intended to be a collaborative effort among students to reach their common goal. This paper has described the REU as it has developed over two years.

During the first year of the project (summer 2018), the eight student participants were grouped in pairs, but they interacted with the entire team throughout the activities, workshops, trainings, field trips. What we learned from the student participants was that they needed more structured activities specifically based on research topics. Although the REU was quite successful overall, and addressed several of the issues that had been observed in previous REUs, the need for greater structure that was focused on the specific learning needs of the students was still evident. This was particularly clear from the fact that the students' presentations lacked a cohesive, cross-project theme.

During the second year (summer 2019), we again recruited students without regard to their STEM major. However, this time, the students worked in flexible groups on a more highly structured set of PBL activities that were designed to help them develop the research knowledge and skills they needed to address the larger research problem. The issue of automotive platooning provided a cross-cutting theme that would engage participants from fields as diverse as biology, engineering, and mathematics.

3.4.1 REU student participant interviews

To learn more about the student participants' experiences in the REU, we interviewed them in groups at the beginning and end of their summer research programs in both 2018 and 2019. In both pre- and post-experience interviews, we explored their ideas about what constitutes research, how it is conducted, and how they perceived their own as researchers.

At the beginning of the experience, the students tended to think of research as a goal-oriented problem-solving process. For example, one student said:

> *We basically say, it was basically, given like a problem and then—a problem that's widely recognized among, you know, everyone, in all communities, and then finding a different way to solve it. So most likely the inexpensive way…*

Another focused on the practical nature of the kind of research they envisioned:

> *I would say that we are involved in something from a real-world scenario and we are applying our knowledge, developing knowledge that we are gaining from this in order to achieve a goal that we're trying to get right here is something we can improve on…*

In addition, the students conceived the work as a group effort.

> *Lab research I would say is like a team effort where everyone's purpose is to solve this one question and at the end, present it to others so they can learn and also build off of what we've done.*

At the end of the first summer, the group again discussed their ideas about research. One aspect that had surprised many of them had to do with the many unanticipated difficulties and failures they had encountered.

> *Well, it didn't go as we expected. At first we had a lot of problems, but then we took time and tried to solve every problem and then we had progress after some weeks. And then we did a lot more than we expected.*

Another reflected that the research process was not linear:

> *I was [thinking that], it's going to be to point A to point B and just straight forward path, but it seems like it's just like curves and everything. Just twists and turns and everything to get to it.*

Several talked about how intellectually difficult and engrossing the research work turned out to be:

> *Sometimes you might be in your bed at night and 1 am thinking of what I'm going to do next or is this the right simulation or, do I need to do more [literature] research?*

Another student agreed and amplified this thought:

> *I think, when you are doing research, you always are studying because for me, every time that I go in my room or [I'm] doing something, I started thinking about it—What I'm doing, what I'm going to do next, what I'm going to do in the future. So everything is related [to] what I'm doing right now. So I think that when you're doing research you always have the main idea in your mind.*

Many of the 2019 REU students had participated the summer before, so they talked about their perceptions of research as they had evolved since participating the previous year. One talked about the relationship between a research question, hypothesis, and experiment:

> *We started with the question that you do like duplicates or models… It's like the scientific method. So you start with the hypothesis and then you go further into it and then you find a question and then you do your…experiment on that question. And if that fails then you go back and read and come up with and reconstruct another question. So, it's like a repetitive cycle of question and answer.*

At the conclusion of the 2019 experience, several students talked about what they had learned and achieved, and notably, about the personal qualities they had developed. One talked about learning to think more deeply about problems:

> *I think, in these past activities that we've been doing got me to think more of becoming a problem solver because I think most of the activities that we did…allow[ed] us to…get bits of our pieces of brain to think more broadly… Boom. We get results and we give them. And I'm also still learning, like you had to learn something that you don't know about at all. And sometimes it takes a while to learn it because it's so complex and deep learning is very complex.*

3.4.2 Follow-up survey

Late in the fall 2019 semester, we followed up with a survey of the 2019 REU participants to ask the students to reflect back on their summer research experience. The survey consisted of five open-ended items and six Likert scale, strength of agreement statements. Five of the seven students completed the survey.

The first survey question asked, "Looking back now, what was the most important thing that you learned during the summer research program? (This could be about doing research, specific learning about the topic you researched, or other things.)". Responses included statements about team work, critical thinking and problem solving, and personal skills. For example, one student said, "The most important thing I learned was to stay focused and while doing research you have to keep an open mind."

The strength of agreement items asked the participants to share some summary perceptions regarding their experiences (Table 9). The students indicated that they had found value in the cross-disciplinary set of peers they had worked with. They liked the style of problem-based learning they had experienced in the REU. Although not necessarily in transportation, students were able to see themselves in graduate study, academia, or research-based careers. That four of the five respondents "strongly agreed" that they were considering pursuing a graduate degree indicated that the research experience may have whetted their appetite for the kind of intellectual work they had experienced.

Table 9: 2019 REU Students' Perceptions

	Strongly Agree	Agree	Slightly Agree
Working with students from other majors helped me with my research	3 (60%)	1 (20%)	1 (20%)
I liked working with students from other majors on a common problem	4 (80%)	1 (20%)	0 (0%)
I prefer to learn by participating in an experience like the one I had last summer, compared to typical classes.	3 (60%)	2 (40%)	0 (0%)
Participating in the summer research experience has had a positive effect on my work in my classes since then.	3 (60%)	2 (40%)	0 (0%)
I am open to considering a career that is related to transportation.	1 (20%)	3 (60%)	1 (20%)
I am considering pursuing a graduate degree.	4 (80%)	0 (0%)	1 (20%)

Note: No respondents chose any of the three "Disagree" options.

Some of the open-ended questions added depth to the responses to the strength of agreement items. Asked what they liked best about the summer research program, one student said,

> *I liked the interactive group discussions[. They] helped to open my mind up to fully understand how research is really conducted. As well as the ethical standpoint research always provides.*

Asked whether they preferred open-ended problems or closed problems with a single correct answer, all five said they preferred open-ended ones. In explaining their answer, one student said, *"With an open ended problem you are able to discover more and add on to what you have discovered."*

The students were also asked to identify the most important research skill they had learned. Four of the five mentioned intellectual skills such as using logic, critical thinking, developing solutions, and open-mindedness. One said, *"The most important skill is knowledge in what you currently know or can apply."*

A major theme that emerges from the students' responses is that they had become much more self-directed and autonomous learners who said they enjoyed both the challenge and the teamwork they had experienced during the REU.

4.0 Future Directions

This REU has provided a powerful learning experience for a multidisciplinary group of undergraduates at an HBCU. The students who participated learned both research skills that they will be able to apply in a range of inquiry settings, and specific knowledge regarding transportation engineering. As for continuation, detailed evaluations of activities with a designed rubric are left for another study. Future REU development will include improved design of activities that lead participants to develop skills that will help them to more effectively address the main engineering problem. We would like to research the impacts of linear and non-linear activities from the literature to further improve the design of the REU experience. In addition, a longitudinal study will summarize our findings from 2018-2020.

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