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An Overview and Preliminary Assessment of a Summer Transportation Engineering Education Program (STEEP) for Ninth Graders

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An Overview and Preliminary Assessment of a Summer Transportation Engineering Education Program (STEEP) for Ninth Graders

Abstract

A summer educational and experiential learning program for rising ninth grade students was organized by the College of Engineering at the University of Tennessee, Knoxville. The purpose of the program was to raise awareness among high school students of engineering career opportunities and also to prepare these students for college. This paper summarizes the efforts and outcomes of the transportation engineering portion of the program, Summer Transportation Engineering Education Program (STEEP), held in June 2015. Thirty students from across the state of Tennessee and its neighboring states participated in a week long residential program.

STEEP had two parts. The first part consisted of lecture sessions and the second part of hands-on engineering projects. The hands-on portion included students working in teams of 4 using computers to perform calculations based on the lectures, and also conducting experiments using scale models to verify and validate their calculations The projects were designed first to introduce participants to aspects of transportation engineering, particularly on how human and vehicle factors impact the design and operation of roadways and secondly, to educate teenagers on why road safety should be of critical importance to them. The students were provided general guidance and support to conduct their hands-on learning projects.

To assess the effectiveness of STEEP, evaluations were conducted before and after the program. The first evaluation was a before and after on-line survey and the second, a before and after in-class test. Preliminary analyses of the surveys shows that such educational programs offer significant benefits. In this program, students enhanced their understanding of how human, roadway, and vehicle factors need to be considered in roadway planning, design, and operations, and in turn how they affect safety. Through the hands-on projects, students gained an understanding of how to perform some basic math and science computations using software programs and learned how transportation engineering concepts such as "stopping sight distance" play a role in the placement and posting of traffic control devices, operating intersection traffic signals, and the design of other roadway infrastructure elements. The program offers significant promise and can be adapted to other settings.

Introduction

The importance of developing the future transportation workforce has been recognized nationally across the United States[1-5]. There has been growing concern as to whether there will be enough qualified and skilled professionals in the future to meet the emerging demands and challenges of transportation systems[3, 4]. The impending retirement of the "baby boomer" generation poses threat to the transportation industry [4]. In 2003, the Transportation Research Board (TRB) in its Special Report 275 (The Workforce Challenge: Recruiting, Training and Retaining Qualified Workers for Transportation and Transit Agencies) indicated that by 2013, 50% of the transportation workforce would be eligible to retire[6].

One key strategy that have been identified to be effective in attracting, recruiting and retaining people in the transportation workforce is to build the “pipeline” starting with students in the pre-collegiate system; i.e., Kindergarten to 12th grade (K-12) [4]. Formal education and training in Science, Technology, Engineering, Mathematics (STEM) subjects is very important to meet the technical occupational needs in transportation. However, research has shown that enrolment in undergraduate degree programs in STEM fields are declining and that for students who major in STEM-related degree programs at college, many fail to complete their degrees or enter a STEM-related job field[7, 8]. The lack of interest of students in STEM programs points to the need to mobilize efforts to alert, engage, and introduce young minds to engineering careers including transportation. The literature documents that experiential learning approaches are extremely effective in this regard[5]. That is when context-based (or authentic) educational strategies that link real-world situations to concepts and principles are adopted by teachers. Such approaches are extremely effective at helping students attain a deeper and long-term understanding of the subject materials, which in turn stir their interest in their learning environment.

The Next Generation Science Standards emphasize inquiry-based curriculum, instruction, and assessment and provide guidelines for science teaching and learning. Science inquiry “encompasses not only an ability to engage in inquiry but an understanding of inquiry and of how inquiry results in scientific knowledge.[9]” Incorporating inquiry-based STEM instruction, rooted in real-world applications, allows students to connect conceptual learning to life outside the school walls. Active student engagement is a foundational component to helping students with the inquiry process[10]. Active engagement strategies are deeply rooted in cognitive learning theories such as constructivism and experiential learning and encourage students to interact with new content instead of passively observing. Active interaction with the curriculum encourages students to become engaged, thus allowing for a better understanding of the material and eliciting links to previous knowledge and experience[11]. Typically, experiential learning activities that use active engagement have hands-on elements that require students to use multiple learning skills and higher-order thinking to construct meaning and knowledge [12-14]. Experimental and experiential learning approaches have been noted in several studies to be effective in enhancing learning experiences through the application of theoretical concepts and principles in solving real world problems with examples related to transportation [15-20].

The review of the literature clearly shows that the transportation industry, both in the public and private sectors, faces the problem of recruiting and retaining individuals with the required set skills to meet the demanding transportation challenges. This is exacerbated by the lack of interest among pre-collegiate students in enrolling in STEM-related programs at the college level. The literature also documents that using experimental and experiential learning approaches are effective methods at engaging the interest of students in math and science material subjects. With this sense of need and learning instruction technique in mind, the authors partnered with the Office of Diversity Programs (ODP in the College of Engineering (CoE) at the University of Tennessee, Knoxville (UTK) to organize a summer educational and experiential learning program for rising ninth grade students. The program aimed to raise awareness among high school students of engineering career opportunities, especially in transportation engineering, and to start preparing them for college. This paper summarizes the efforts and outcomes of the transportation engineering portion of the program: Summer Transportation Engineering

Education Program (STEEP) which was held in June 2015. The following sections present a description of the STEEP program, results of the program evaluation, and lessons learned.

Program Overview

The CoE at UTK for the past decade has been hosting summer education programs for middle and high school students who have demonstrated interests in pursuing careers in engineering. The goal of the program is to provide students who show an interest in engineering studies an early exposure to and preparation for scientific study and research. Among several of the pre-college summer programs in the institution is eVOL9 which focuses on students who will enter the ninth grade in the ensuing academic year. In 2015, the CoE hosted its 3rd annual eVOL9 program which provides a one-week learning experience, at no major cost to students who are selected through the application process. In the program, students live within a residence hall on campus, engage in hands-on engineering fundamentals activities, receive ACT math preparation, compete in engineering challenges, and tour an engineering industrial plant. During the program, students work in teams to apply concepts and principles introduced in lecture or lab settings to work on an engineering project. Thirty-two students are selected each year to participate in the eVOL9 program, however, in 2015, two students dropped out. Faculty members and students at UTK serve as program instructors, mentors, and counselors. They provide guidance and assistance to the participants during the program. The program closes with an award ceremony where outstanding students are recognized.

Since the program's inception, engineering disciplines like structural and electrical engineering have had great involvement in the students' activities. Student activities related to transportation engineering were missing in previous eVOL9 programs. In light of this, the authors of this paper (transportation experts) consulted with the ODP, to organized the first ever Summer Transportation Engineering Education Program (STEEP) as part of the eVOL9 program. Programs such as eVOL9 offer the potential to address the education and workforce development challenges of the transportation industry. By incorporating experiential and active learning strategies in such programs, it will help develop and nurture the next generation of transportation professionals.

Purpose of STEEP

The primary purpose of STEEP was to alert, engage, motivate and excite students to some of the educational and career opportunities in transportation, as well as challenges tackled by transportation engineering professionals. Specifically, the program intended to

- Make students aware of the elements of transportation systems: infrastructure, vehicle, operations, policies, safety;
- Illustrate using real world transportation contexts applications of Science and Math concepts and principles.
- Challenge students to apply Science and Math concepts and principles (using analytical and experimental techniques) to work on simple day-to-day transportation problems.
- Promote personal growth and development via hands-on transportation related projects.
- Provide students with knowledge of career opportunities in the transportation industry.

Methodology

STEEP had two parts. The first part consisted of lecture sessions and the second part on hands-on engineering projects. The hands-on portion included students working in teams using computers to perform calculations based on the lectures, and also conducting experiments using scale models to verify and validate their calculations. The projects were designed first to introduce participants to aspects of transportation engineering, particularly on how human and vehicle factors impact the design and operation of roadways and secondly, to educate teenagers on why road safety should be of value and priority to them. The authors who served as subject matter experts for STEEP worked with other four counsellors (not subject experts) to provided general guidance and support to the students in carrying out their hands-on learning projects. The authors spent two to three hours each day between 9:00 am and 12:00 pm from Monday to Thursday with students, holding 30-45 minutes lectures and using the remaining time on hands-on project. In the evenings, for a couple of hours from 4:00 pm, the counselors helped the students complete portion of their assigned project works. Details of the two projects and their corresponding activities are described subsequently.

Project 1: Speed, Acceleration, Braking distance, and Time. So What?

Driving a motor vehicle is an integral part of daily life for most adults in the USA. A driver not only has to interact with the vehicle, but also with the roadways system elements (such as geometry, signs, signals, markings), other road users and vehicles, the environment, among other factors. Driving safely requires comprehending various stimuli and responding appropriately to them. Drivers make critical decisions such as when to slow down, stop or pass another vehicle on the roadway. Transportation engineers work to help drivers make better decisions as they travel along highways. Engineers design the geometry of roadways, and provide appropriate signage (posted speed limits signs, warning and guide signs) to make traveling pleasant, comfortable, and most importantly as safe as possible for motorists.

Activity 1

This project was to evaluate factors that affect stopping distances of vehicles in motion. In the lecture sessions, students were provided an overview of key factors related to vehicle speed, acceleration / braking, roadway gradient, driver reaction time, and distance travelled by a vehicle. They were introduced to key relationships between speed, distance, acceleration, and time and provided the governing equations that linked these key variables. They were asked to compute braking distances for several combinations of the roadway gradient. Next, they were required to experimentally measure key variables such as speeds, distances, and times travelled by vehicles (in a controlled, indoor setting using toy cars and wooden planks) as the gradient was varied. The longitudinal gradient of the roadway was characterized using the angle of the plank with respect to the horizontal plane. This angle was adjusted using a mechanical jack. The set-up for the experiment is shown in Figure 1.

Apparatus: Wooden plank, digital stop clock, tape measure, wooden block, toy vehicle

Experimental Set-up:

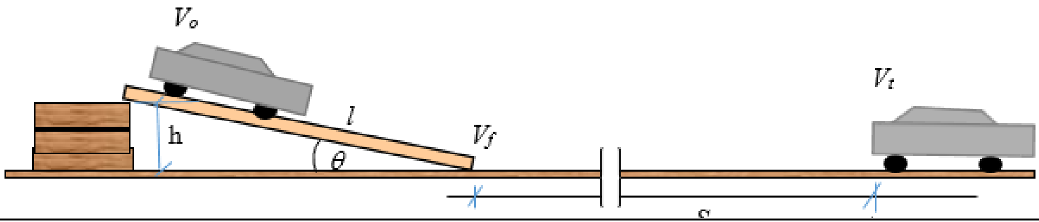

Figure 1: Experimental set-up for project 1

Key equations provided to the students:

Total stopping distance, SSD = $D_r + D_b$

$D_r = 1.47v \bullet t_r$

$$D_b = \frac{V^2}{30\left(\frac{a}{g} \pm G\right)}$$

$$SSD = 1.47\,V\,t_r + \frac{V^2}{30\left(\frac{a}{g} \pm G\right)}$$

D_b = braking distance (ft)

D_r =driver perception-reaction distance

a = deceleration rates (ft/s^2)

G = grade (percentage)

V = initial speed when brakes applied (mph)

t = reaction time

g= gravity (ft/s^2)

Students were required to work in teams and informed that this would be typical in professional life. The 30 students were assigned to 8 groups: three members each in two groups and four members each in the remaining six groups. Each team was tasked to use the set-up shown in Figure 1 to determine the relationships between vehicle speed, distance and time as a function of the roadway gradient. The teams were then asked to compare the results for the various scenarios and critique the differences in the results. Students submitted their results upon completing their experiments. The three teams that presented the best results were recognized at the end of the program. Illustrative results submitted by one of the student teams are shown in Figure 2.

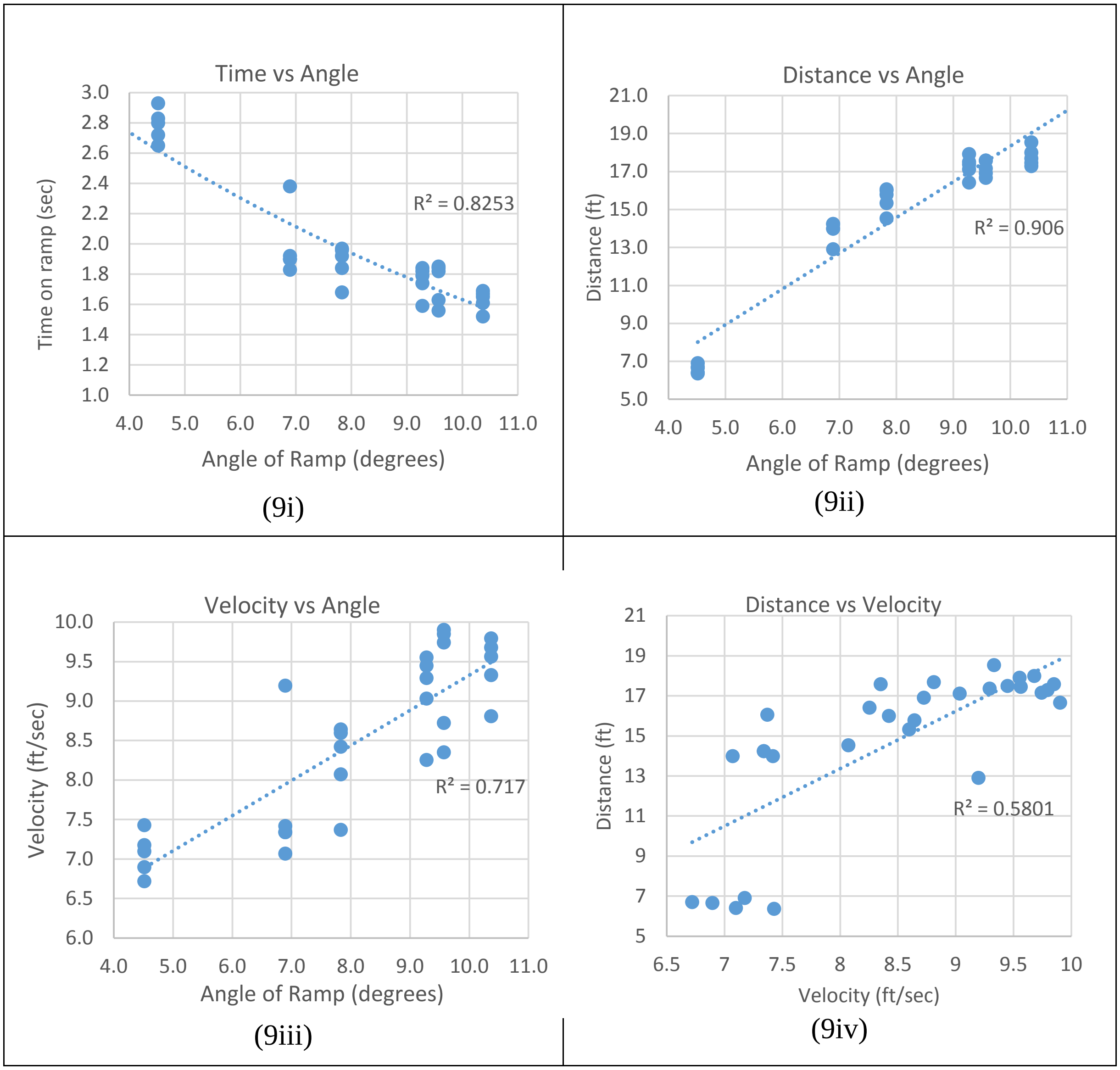

Figure 2. Project 1 results of one of the student teams.

Project 2: Volume, Mass, and Stresses: Implications for Vehicle and Pavement Design

Loads carried by vehicles and the number of tires affect the design of roadway pavement as well as vehicles. A vehicle's load in the form of stresses is transferred to the pavement through the contact between the tires and the road pavement as illustrated in Figure 3. Traffic volumes and the stress they impose on the pavement are considered as inputs in the design of road pavement. The objective of the second project was to introduce students to the concepts of road pavement design. The students were tasked to apply principles in geometry and science to estimate loads (weights) and corresponding vertical compressive stresses at the tire-pavement interface for various types of trucks and for different types of cargo (liquids or solids). They were asked to compare the results for the various situations and comment on the results.

Activity 2
In a lecture discussion, calculations of areas and volumes of various geometric figures were reviewed. Then, the student teams used a spreadsheet program to work on the problem. The procedure for this activity are outlined below:
Procedure:

1. Calculate the cross sectional areas and volumes of the tanker shapes given
2. Based on the densities of various solids and liquids, determine the weight of the solids and the liquids.

Densities of different liquids

Substance	**Temperature (°F)**	**Density (lb/ft^3)**
Water	70°F	62.4
Petroleum (refined for cars)		
Ammonia (aqueous)		
Ethanol		
Liquid Nitrogen		
Sulfuric Acid (95%, aqueous)		
Gravel		
Dirt Mixture		
Annomium Nitrate (fertilizer)		
Clinker cement		
Oak Wood		
Steel		

3. Calculate the gross weight (weight of empty truck + its content (load)) for all the scenarios presented in question 1.
4. Determine the tire-contact patch area
5. Calculate the compressive stress exerted by each tire on the pavement assuming each tire is carrying the same load. ***[Report all your answers in the excel sheet provided]***

Truck #	**Trailer Type**	**Content**	**Trailer Volume (ft^3)**	**Content Unit Weight (lbs/ft^3)**	**Content Weight (lbs)**	**Trailer Weight (empty) (lbs)**	**Total Weight (lbs)**	**Number of Tires**	**Load Per Tire (lbs/tire)**	**Tire Contact Patch (in^2)**	**Stress (lbs/in^2)**
1	Cylinder	Water									

6. a. Which truck trailer and its content will cause the ***maximum damage*** to the pavement?

   b. Which truck trailer and its content will cause the ***least damage*** to the pavement?

Key geometric concepts were reviewed. This focused on equations and strategies to calculate areas of cross section and volumes for various geometric shapes that were representative of the geometries of trucks. The students were also given information and sketches about truck trailer configurations (shapes, axle configuration, etc.) and weights.

Again, each team submitted their calculations. An examination of some of the student responses shows that their calculations were off by order of magnitude (factor of 10), and that they did not recognize this on their own. This is presented herein to illustrate the opportunity to help the students learn by reviewing their errors, using an iterative process, and the joy of discovery.

Program Evaluation

To assess the effectiveness of STEEP, evaluations were conducted before and after the program. The first evaluation was a before and after on-line survey and the second, a before and after in-class test. The survey completions were voluntary. Details of each of the evaluations follow.

Before and After Online-Survey Evaluation

On the day of arrival, prior to any interaction with the subject matter experts, the participants were asked to complete an online survey. The survey had two parts, the first part was to assess how comfortable the participants felt they were in performing basic math and science computations related to geometry, vehicle speed, acceleration, braking, time and roadway gradient relationships, and their awareness of pavement design concepts. The second part was a perception survey where participants were asked to indicate how strongly they agree with a series of statements related transportation engineering. The same survey was administered at the end of the program.

Figure 3 shows the results of the first part of the online survey. Summary of the results show that the STEEP program had a positive impact on the participants. From Figure 3, similar trends are observed for each of the six questions the participants responded. The participants' comfort levels in performing basic computations increased tremendously after the STEEP program as illustrated by a positive shift in response from "very uncomfortable" to "very comfortable". Responses to question 6 clearly show the program had helped a majority of the participants to become very aware of the concepts related to vehicle loads and pavement design.

With regard to students' perceptions of transportation engineering and its career prospects, a positive change was observed in the results as shown in Table 1. In Table 1, the highest frequency for each statement is indicated in bold text. Comparison of the before and after surveys showed that a majority of the participants agreed with most of the statements. Again, the participants' perception about transportation engineering after the STEEP program changed positively as illustrated by a shift in response from "strongly disagree" to "strongly agree". The only exception was the statement "It would be easy to get a job in transportation engineering". Even after the program, some students still doubt about job prospects for entering into the transportation engineering field of study. This suggests the need to conduct more educational outreach programs to inform youth on the varied transportation engineering career opportunities.

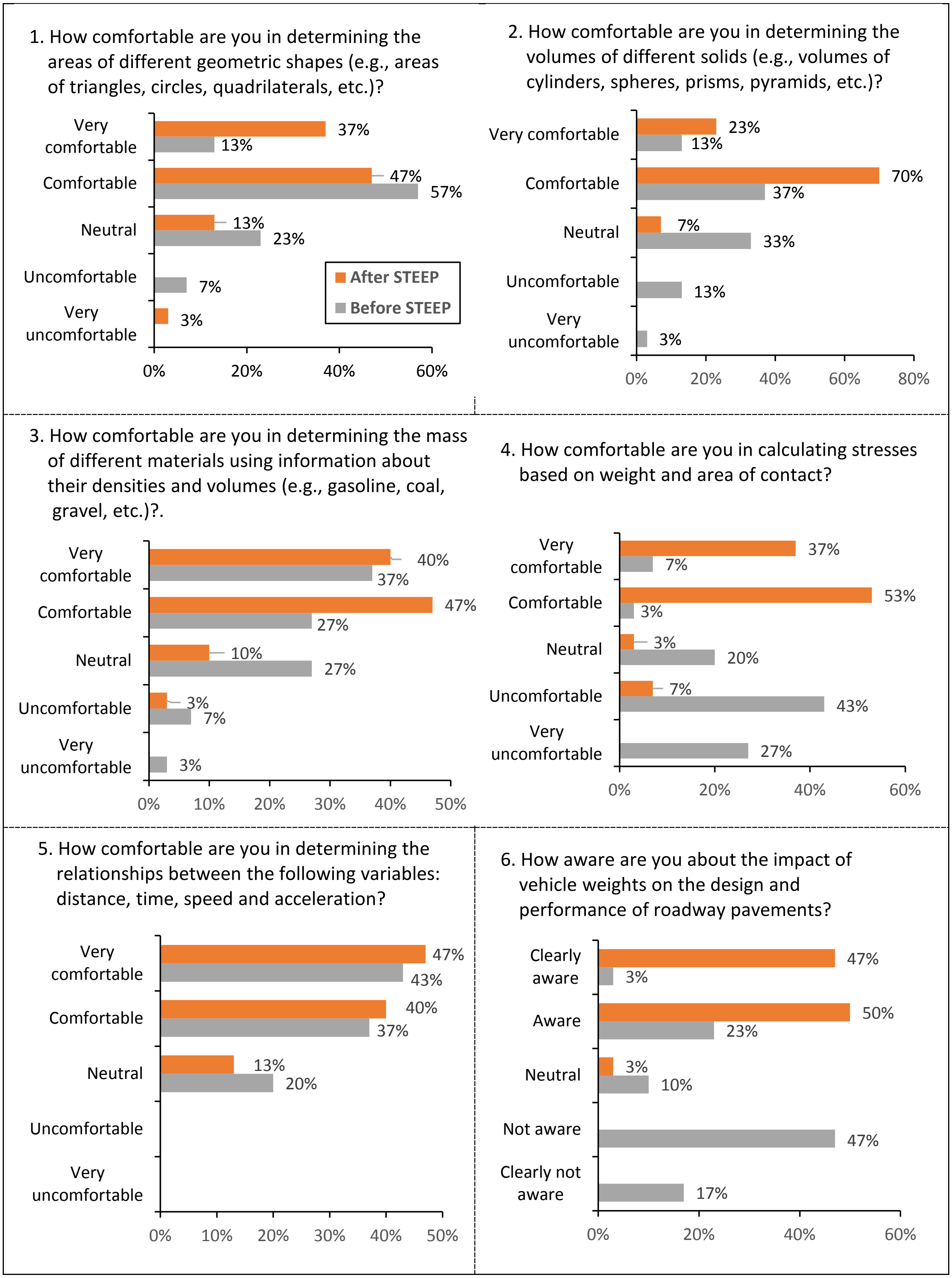

Figure 3 Participants' responses to on-line survey (part I)

Table 1 Online Perception Survey Results (Part II)

Statements about Transportation Engineering	Survey	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
It involves exploring, understanding, and predicting natural or social phenomena.	Before	20% (6)	**50% (15)**	23% (7)	3% (1)	3% (1)
	After	40% (12)	**47% (14)**	3% (1)	7% (2)	3% (1)
It involves machines, tools, and materials	Before	**50% (15)**	50% (15)	0% (0)	0% (0)	0% (0)
	After	**60% (18)**	33% (10)	7% (2)	0% (0)	0% (0)
It involves analyzing data to solve problems	Before	**60% (18)**	33% (10)	7% (2)	0% (0)	0% (0)
	After	**63% (19)**	37% (11)	0% (0)	0% (0)	0% (0)
A career in transportation engineering is prestigious	Before	7% (2)	20% (6)	**57% (17)**	17% (5)	0% (0)
	After	10% (3)	40% (12)	**50% (15)**	0% (0)	0% (0)
It would be easy to get a job in transportation engineering	Before	3% (1)	10% (3)	**47% (14)**	37% (11)	3% (1)
	After	3% (1)	20% (6)	**50% (15)**	20% (6)	7% (2)

Note: Boldface represents the highest frequency response for each statement

Before and After In-class Test Evaluation

To assess whether the students were able to grasp key concepts presented during the lecture sessions , a pre-test and a post-test were also administered in class before the first day of lectures and after the last day of lectures of the STEEP program. The content of the lectures were related to human and vehicle factors (including geometry and weight) that influence the planning, design, operation and maintenance of roadway infrastructures. Specifically, the discussions addressed how to calculate stopping sight distance and their applications in traffic and roadway design and operations. Additionally, the principles of the impact of vehicle loads in the form of stress on road pavement was also explained and demonstrated through science and math computations. The test was designed to evaluate the strengths and weaknesses of students in computing areas and volumes of solids with different shapes, as well as determining the relationships between speed, distance, time, and gradient. The entry test is shown in Figure 4. This same test was also administered as an exit test at the end of the program. The maximum possible score on the test was 15 points.

Entry Quiz **Date: June 15, 2015**

Last Name: ____________________First Name: _________________

Equations of potential interest:

$$speed(u) = \frac{distance(d)}{time(t)}; \quad density\ (\rho) = \frac{mass\ (m)}{volume\ (v)}; \quad Stress\ (\sigma) = \frac{Force\ (f)}{Area\ (A)}$$

$$Volume\ of\ prism\ (V) = Base\ area\ (A) \times height\ (h);$$

$$Volume\ of\ pyramid\ (V) = \frac{1}{3} \times Base\ area\ (A) \times height\ (h)$$

9. Jane drives at an average speed of 45 mph on a 135 miles long trip. How much time does the trip take?
10. Mark traveled from point A to point B on an interstate. The trip took 2 hours and 30 minutes and he traveled at an average speed of 60 mph. How many miles did Mark travel?
11. An attentive driver of a vehicle traveling at 40 mph had to apply brakes to slow the vehicle. If the distance traveled during her reaction time of 2 seconds is D. What will be the distance traveled if she was distracted and her reaction time were 4 seconds.
    b. 0.25D b. 0.5D c. 1.0D d. 2.0D e. 4.0D f. Other_________ (specify)
12. The time to accelerate constantly from 10 mph to 20 mph is "T". Then the time to accelerate constantly from 20 mph to 40 mph is _____________
    b. 0.25T b. 0.5T c. 1.0T d. 2.0T e. 4.0T f. Other_________ (specify)
13. If the braking distance (*ignoring the distance traveled during the reaction time*) required for a vehicle traveling at a speed of V is "X," all other factors remaining the same, then the braking distance required for a vehicle traveling at a speed of 2V is:
    a. 0.25X b. 0.5X c. 2X d) 4X e. √(X) f. Other_________ (specify)
14. An unknown liquid substance has a mass of 18.5g and occupies a volume of 20.0 ml (milliliter) in a cylinder. What is the density of the liquid in kg/m^3? [Hint: 1000g = 1 kg, 1000 liters = 1 m^3]
15. A load of 3000 pounds (lb) is acting on a square floor 6 by 6 inches (in) in length. Determine the compressive stress (lb/in^2) normal to the floor surface.
16. The solid below is made up of a cube (square prism) and a square pyramid. Determine its volume.

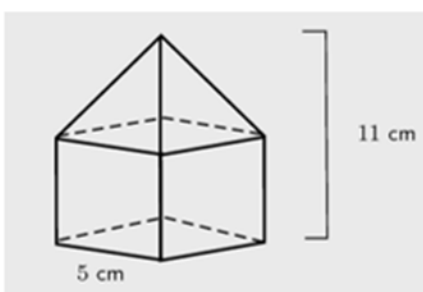

Figure 4. Entry test administered prior to STEEP.

The descriptive statistics of the scores for the entry- and exit-test are shown in Figure 5. This figure shows that the pre-test scores ranged from as low as 2 to a maximum of 14 points with a mean of 8.6 and a standard deviation of 3.6, whereas the post-test scores ranged from 5 to 14 points with a mean of 10.4 and standard deviation 2.6. The minimum, median and the average scores for the after STEEP increased substantially. None of the students made a score of the full 15 points. It should be noted that the solutions to the problems as well as access to the questions were not made available to the students until the end of the program.

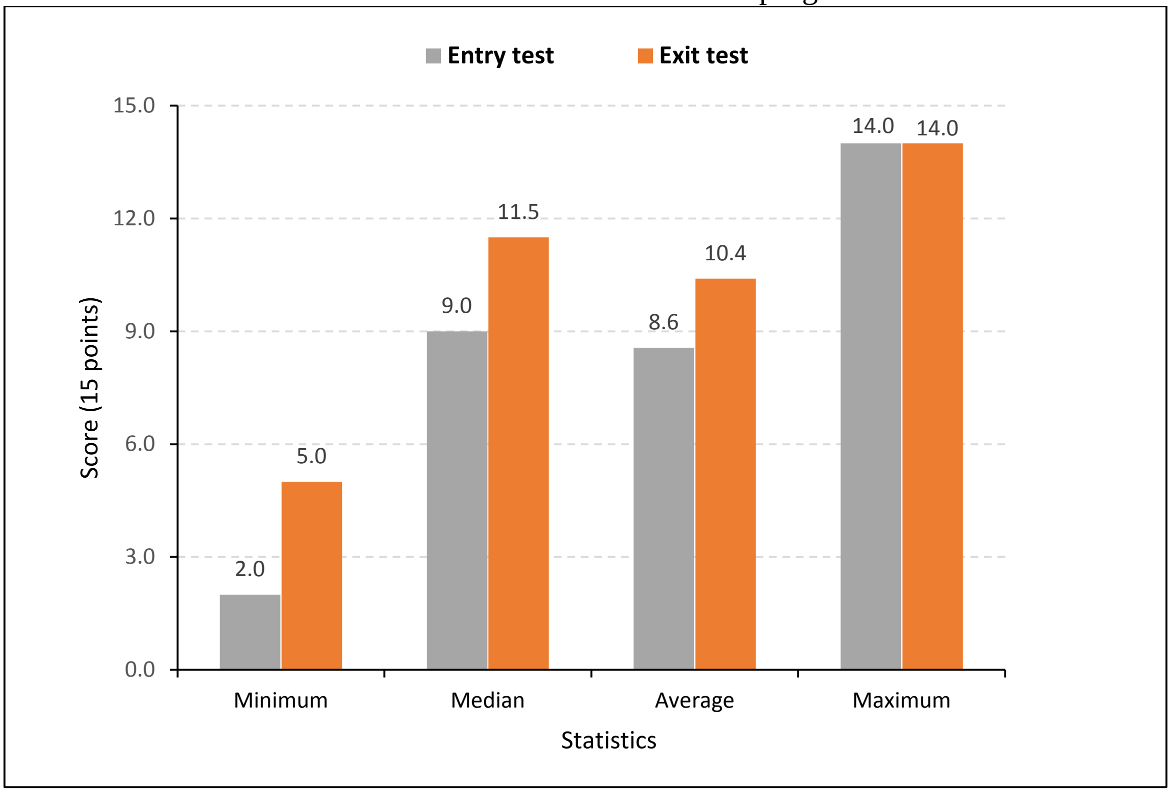

Figure 7. Descriptive statistics of the entry-test and exit-test.

A two-sample hypothesis test (t-test) was conducted to test the difference between the two means. The null and alternative hypotheses are:

H_o:$u_1 = u_2$, there is no difference between entry-test mean score and exit-test mean score
H_o:$u_1 > u_2$, there is a difference between entry-test mean score and exit-test mean score

The analysis was conducted at an alpha level 0.05 (corresponding to a 95 percent confidence level). Results of a one-tailed analysis yielded a t-value of 4.195 with a p-value less than 0.001. This indicates that the mean score of the exit-test was significantly greater than the entry-test mean score. This implies that the program had significant impact on the students' participation.

Lessons Learned from STEEP

In the near future, the transportation industry will experience recruitment challenges within specific work areas, in part due to a significant number of skilled personnel retiring coupled with the lack of interest of students entering fields important to transportation such as engineering, construction, and maintenance. STEEP has shown that organizing engineering career awareness and educational programs is a promising solution to address the future transportation workforce challenges. In this program, students were able to understand how human, roadway, and vehicle factors need to be considered in roadway planning, design, and operations, and in turn how they affect safety. Through hands-on projects the students gained an understanding of the role stopping sight distance play in the placement and posting of signs (speed limits, stop, guide and informational), operating intersection traffic signals and the design of other roadway infrastructures. Besides that, students engagement in using simple software (e.g. Excel) to perform basic science and math computations and their ability to apply concepts and principles in solving engineering problems is very promising. They were appreciative of the fact that STEM related programs are not merely abstract and theoretical concepts but that the subject matters define their everyday life activities which they can easily relate to. Comments from participants such as “This program was very educative”, “I didn’t know that science behind speed limit signs, now I know”, “I am applying for eVOL10 (the program for students at the next grade level) next year,” and many more indicated how STEEP positively impacted the students. The program served as an opportunity for not only attracting pre-collegiate students to consider STEM programs in their post-secondary education, but also, preparing them for future employment in the transportation industry.

Summary and conclusions

This paper summarized the efforts from STEEP, a transportation system based educational program for ninth graders in a week long summer program in June 2015 hosted by the College of Engineering at the University of Tennessee. The primary purpose of STEEP was to alert, engage, motivate and excite students to some of the educational and career opportunities in transportation, as well as challenges tackled by transportation engineering professionals. The program provided an avenue for students to learn about the different aspects of transportation through in-class presentations and hands-on traffic engineer projects. The students worked in teams on two hands-on learning experiences (projects) that helped illustrate the applications of math and science concepts and principles to the planning, design and operations of roadways. In-class evaluation in the form of tests, and administering a before-after on-line survey showed that the program had a positive impact on the 30 high school participants. One set of test results data were evaluated for statistical significance, and it clearly showed that the program had a significant positive impact to enhance the participants’ awareness and knowledge of key math and science principles and their applications in a transportation systems context. The program offers significant promise and can be replicated at other settings by carefully following the details presented in this paper.

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