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## **AC 2012-3909: USE OF A DRIVING SIMULATOR TO ENHANCE LEARNING EXPERIENCE OF UNDERGRADUATES IN HIGHWAY DESIGN**

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# Use of a Driving Simulator to Enhance the Learning Experience of Undergraduates in Highway Design

## Abstract

This paper presents an exploratory study that focuses on addressing the needs of the new generation for engaging and more active learning experiences. An undergraduate highway design project for civil engineers was complemented with the use of a driving simulator both before and after two major highway design stages, horizontal and vertical alignment. Students perceived the driving simulator as engaging as well as effective for testing and evaluating highway designs. Perceived engagement of the driving simulator increased significantly from the pre- to the post-phases of design activities. In addition, students' ability to evaluate the quality of the vertical alignment generated with the driving simulator increased significantly after they completed that part of the highway design project. As a result, including a driving simulator as a virtual reality tool for analyzing the quality of highway design can improve the way students perceive and engage in the highway design tasks. This was especially useful since the target students were part of mandatory courses not directly related to their major. Students' suggestions for expanding the use of the driving simulator to other parts of the course complemented the above findings.

## Motivation

The new generation of students identified as the "Net Generation"<sup>1</sup>, the "Millennials"<sup>2,3,4</sup> or "Me Generation"<sup>5,6</sup> have several characteristics that significantly impact how educational environments need to be shaped to stimulate their motivation and engagement. For example, high confidence and significant external-driven achievement are two predominant characteristics of this generation. To address the needs associated with these generational characteristics, instructors started to integrate in their courses technology-rich tools and associated instructional strategies. For example, one important role of technology was that of creating engaging and immersive learning contexts that promote personal achievement through peer and instructor-driven active learning. Another important role of technology was that of providing quick formative feedback that enhances students' confidence in their own learning.

While technology proves to be an important instructional tool, academic research, as is the case of transportation research in this study, often creates high-end technology tools with specific research-related functions. This technology typically provides tools for small groups of doctoral, master or senior undergraduate students engaged in research or experiential activities. However, its use does not extend to classroom-based undergraduate instruction. One such technology is represented by driving simulators, capable of producing rich immersive virtual experiences<sup>7</sup> that closely replicate the driving conditions on real highways<sup>8</sup> and allow a safe testing of various traffic parameters<sup>9,10,11</sup>.

However, this engaging technology is rarely used in relation to learning factors<sup>12</sup> or as an instructional tool for classroom-based activities<sup>13</sup> especially of undergraduate students. This paper presents the first steps in integrating a driving simulator in an introductory course in Transportation Engineering for civil engineers as a means to create a more stimulating context for learning highway design.

## **Instructional Context**

### Course Description and Goals

The context of this study is an introductory Transportation Engineering course. This is a mandatory course for undergraduate students enrolled in all civil engineering specializations. Therefore, the student body is quite heterogeneous with respect to learning characteristics. Due to the fact that most of the students do not view transportation as their major or career opportunity, engaging them in various course activities is often a demanding task for the instructor.

Even though the topics of the course cover a wide range of transportation engineering issues, the core element of the course is a semester-long team project that focuses on the redesign of an actual segment of a nearby highway. Addressing student engagement issues is even more stringent for design activities since design problems are and will be challenging in instruction because of their openness and complexity<sup>14</sup>. In previous classes, students found learning the horizontal and vertical design aspects of the course both vague and challenging, such that the instructor had difficulty fully engaging students in the design process<sup>15</sup>.

One potential detractor for students' engagement in the initial phases of the project appeared to be the lack of a concrete feeling of why a good highway design is important. That is, when designing the horizontal and vertical alignments, students seemed to focus on the equations and drawings rather than on the comfort and safety of driving on the designed highway. To address these issues, the instructor decided to expose students to a virtual experience of good and bad highway design through the use of a driving simulator typically used for transportation research.

### Driving Simulator

Driving simulators are used generally for research in the area of human factors, to monitor driver behavior, performance and attention. In the automobile industry they are also used to design and evaluate new technologies such as new advanced driver assistance systems or traffic control devices in different environments. A simulator's sophisticated computer programs can generate multiple driving scenarios populated with other vehicles. These scenarios are projected onto the screen of the simulator and can provide the driver with a front view of an on-road scene. In addition, the researchers can also use a range of cognitive and visual testing procedures which allow them to analyze abilities including visual acuity, contrast sensitivity, and motion perception.

The driving simulator<sup>10</sup> at Missouri University of Science and Technology (Missouri S&T) is typically used to analyze driver behavior under different roadway conditions. Figure 1 shows the driving simulator, which uses three LCD projectors, each having 3,000 lumens and controlled by a PC.



The driving cabin is instrumented with optical encoders for measuring the input of the steering wheel, the gas pedal, and the brake pedal. The virtual environment is displayed on a 6.5' by 25' screen. The driving simulator uses different software packages to create computer models for roads, buildings, cars, and traffic signs.

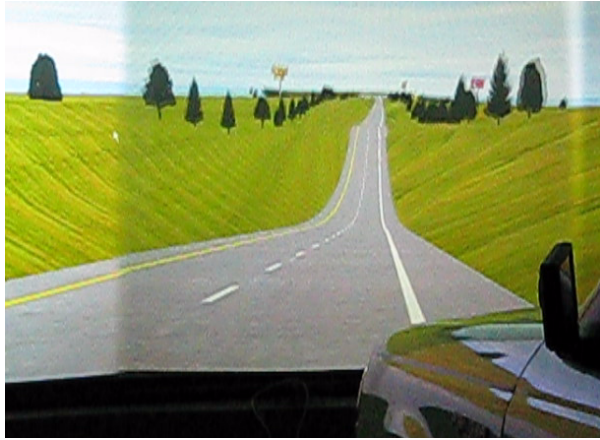
*Figure 1.* The Missouri S&T Driving Simulator

The combination of software and hardware used provides the driving simulator with the capability of collecting a diverse set of data, ranging from vehicle speed and acceleration rate to the driver's behavior based on the trajectory of the vehicle. The simulator is also capable of manipulating traffic conditions, such as the speed and density of traffic on the highway.

#### Structure of Student Activity using the Driving Simulator

For this study, the driving simulator served initially as a means to introduce a more realistic context for highway design activities that were the focus of the introductory undergraduate Transportation Engineering course for civil engineers. The goal was to help civil engineering students get a better understanding of the potential impact of a good and bad highway design on drivers' road experience and therefore motivate them to engage in the highway design project. Each of the students enrolled in this course had the opportunity to participate in a virtual driving that simulated several vertical and horizontal curves. Of these, two crests simulated a bad vertical design (Figure 2 a, b) while a third one simulated a decent vertical design. The worst vertical design had the steepest grades and the shortest length, while the decent design had a smoother departing grade and a longer curve length of the three.

After students completed the first drive using the driving simulator, they completed an entry survey related to both their experience and their perception of the activity. The structure of this entry survey will be detailed in the research methods part of this study. After the completion of the vertical alignment in the team-based highway design project, students were invited to participate a second time in the same virtual drive using the driving simulator. Following this second virtual driving, students completed an exit survey. In addition to the perception questions from the entry survey, the exit survey contained several assessment questions related to the design of the vertical alignment they drove in the virtual environment.



a)



b)



c)

*Figure 2. Simulated vertical designs with the driving simulator; a) sag curve, b) crest curve, and c) level road*

### Research Focus

Due to the exploratory nature of this study, the main research focus was twofold. First, the researchers were interested in students' perception related to the engagement and effectiveness of the driving simulator as a potential design tool both before and after they experienced the highway design project tasks associated with the vertical alignment. The second focus was on the ability of this activity to provide formative feedback regarding students' ability to recognize good and bad vertical design after the completion of the associated tasks in the highway design project.

## Research Methods

### Procedure and Instruments

With the goal of exposing students to a driving simulator and analyzing their overall perception about this activity, the instructor designed a small pilot test that was deployed in the fall semester of 2010. In this pilot study, the instructor divided students in two groups and each group tried either a virtual horizontal or a virtual vertical design on the driving simulator. Based on this small-scale implementation, the instructor decided to use only the vertical design because it produced a stronger impact on students' perception.

A second implementation of the driving simulator, which is the focus of this paper, took place in fall semester 2011. In this implementation, students used the virtual vertical design twice, first before they engaged in the highway design project and second after they completed the vertical design in their team project. The second exposure to the driving simulator served both as a reflective phase in the design project and as a feedback for the instructor on the effectiveness of the design project on students' learning of vertical alignment. In fall semester 2011, students answered both an entry and an exit survey related to the tasks completed during the driving simulator laboratory activity. The teaching assistants administered both surveys online, in the driving simulator laboratory, immediately after the completion of the task.

The entry survey started with an assessment question that asked students to rate the three curves in terms of the quality of their design using a three-level scale that included following options: "Bad design," "Decent design," and "Good design." An open-ended question followed this first assessment item and asked students to explain concisely the differences between the best and the worst designs they experienced on the virtual vertical alignment. The goal of this second question was to collect some qualitative data that reflected students' knowledge of highway design as derived from their day-to-day experience as drivers rather than from a highway design experience. Finally, the survey ended with a set of four questions targeting students' perceptions on the driving simulator as a learning and design tool. Students had to indicate their agreement on statements that proposed the driving simulator to be: a) an engaging highway design tool, b) a great tool for analyzing highway design, c) an effective tool for testing highway design, and d) a motivating tool for learning highway design. For these perception questions students used a Likert evaluation scale ranging from "1" for strongly disagree to "5" for strongly agree.

The exit survey included all of the questions from the entry survey as well as two additional, open-ended questions. The first additional, open-ended question was an assessment one, targeting students' knowledge of vertical design built during the highway design project. More specifically, students had to provide specific design suggestions to improve the design on the three vertical curves they experienced while using the driving simulator. The second additional, open-ended question asked students to provide suggestions regarding the use of the driving simulator as a laboratory activity in other parts of the course.

## Participants

Eighteen students, mostly juniors and some seniors, all enrolled in the mandatory introductory Transportation Engineering course, participated in both stages of this study. Participation was voluntary and rewarded with bonus points.

## **Data Analysis, Results and Interpretation**

### Students' Perceptions

Table 1 presents the basic statistics related to the four driving simulator perception questions for both entry and exit surveys.

Table 1. Basic statistics for perception questions

<b>The Driving Simulator <i>can be:</i></b> (1-strongly disagree...5-strongly agree)	<b>Entry Survey</b>		<b>Exit Survey</b>	
	<b>Mean</b>	<b>SD</b>	<b>Mean</b>	<b>SD</b>
... an engaging highway design tool	3.50	1.15	4.11	.47
... a great tool for analyzing highway design	3.56	1.25	4.06	.80
... an effective tool for testing highway design	3.44	1.29	4.00	.77
... a motivating tool for learning highway design	3.39	1.20	3.83	.92

The means presented in Table 1 show two major trends. First, the initial experience with the driving simulator was slightly above the mean of the evaluation scale for all perception items used in the entry survey. Second, the combination of the initial and final use of the simulator with the hands-on learning of vertical alignment in the lecture and team project improved students' perception of the driving simulator for all measured items.

When the driving simulator was included in the instructional process along with the lecture and the hands-on project, students perceived it as an engaging tool useful for analyzing and testing highway design. The highest gain occurred for the ability of the driving simulator to be an engaging design tool (17%), followed by the ability of this device to serve as an effective design-testing tool (16%). Of these, however, only the engagement item showed a statistically significant gain as measured by a paired samples t-Test,  $t(17) = -2.65$ ,  $p < .05$ . These results provide some support for the main goal of this implementation of the driving simulator: to create an engaging context for learning highway design.

The students, however, perceived the driving simulator activities to be less effective in motivating them to learn highway design. The ability of the driving simulator to serve as a motivator for learning highway design got both the lowest gain and the lowest evaluation scores among the four perception items (see Table 1). One possible explanation for this finding might be the fact that the instructor did not fully integrate the driving simulator in the highway design process but rather used it as a context-generating activity. Addressing this issue involves an exploration that goes beyond the scope of this study but can become a long-term goal for this course.

A synthetic presentation of these results along with the representation on gains in students' perception appears in Figure 3.

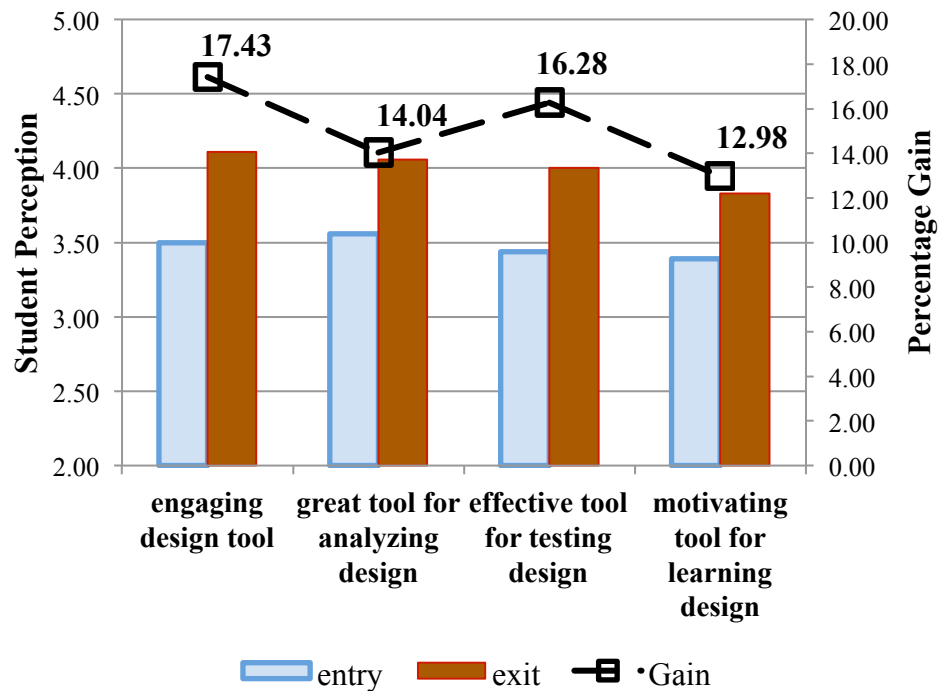


Figure 3. Means for the four perception items and percentage gain from entry to the exit survey

#### Student Performance in Evaluating the Quality of Vertical Designs

The researchers used both quantitative and qualitative assessment to analyze if students were able to evaluate the quality of the virtual vertical design. For the quantitative assessment, both the instructor and the teaching assistant of the course drove the simulator and evaluated the quality of the virtual vertical designs. Their evaluations were the base for the scoring scheme presented in Table 2.

Table 2. Scoring scheme for quality of simulated vertical curves

		Bad design	Decent design	Good design
Vertical curve/quality of design		Score		
<b>First curve</b>	(bad to decent design)	1	0.5	0
<b>Second curve</b>	(extremely bad design)	1	0	0
<b>Third curve</b>	(decent to good design)	0	1	0.5

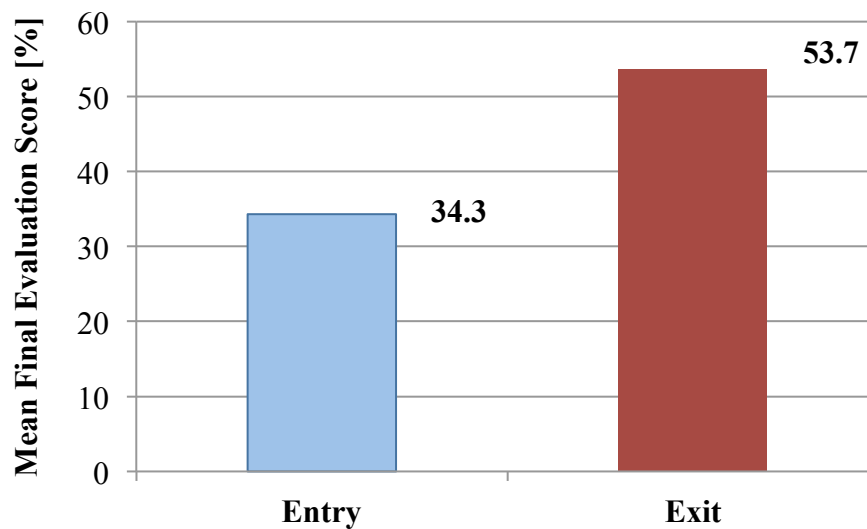
This scoring scheme reflects the range of acceptable evaluation for the quality of the vertical designs simulated with the driving simulator.



For each curve, students can earn a maximum score of one when their answer matches instructor's best evaluation of the quality for that vertical design. Using the proposed rubric, the researchers first summed the individual score for each of the three vertical curves to generate an absolute score. Then the final evaluation score resulted as the percentage of the absolute score to the maximum score possible, in this case three (3), the total number of crests evaluated.

The scoring scheme helped the researchers to generate a final evaluation score for both entry and exit surveys. The entry and exit final evaluation scores were compared to test if there was a statistically significant difference between their mean values.

The results of a paired samples t-Test showed that exit mean score was statistically significantly higher than the entry mean score,  $t(17) = -2.15$ ,  $p < .05$ . Figure 4 shows the means for the entry and exit evaluation scores, respectively.



*Figure 4.* Entry and exit means for students' final evaluation scores of quality of design

This significance of the increase of students' ability to evaluate the quality of the vertical designs is twofold. First, the increase proves that the instructional activities focused on the design of vertical alignments, both the lecture and the team project that took place between the entry and the exit survey, produced the expected impact on students' learning. Second, this finding suggests the possibility of integrating virtual simulation, such as the use of the driving simulator, to collect formative feedback after major steps in the highway design project. This type of feedback can, on one hand, help students understand if they need to focus more on specific design skills, and, on the other hand, help the instructor decide if additional measures to improve the learning process are needed.

In addition to the quantitative measures, students provided answers to several open-ended questions administered for both entry and exit surveys. These questions focused on the quality of the vertical alignments simulated in the entry and respective exit driving simulator activities. Students were also asked to provide suggestions for improvement and potential additional use of this instructional tool.

The open-ended answers related to the evaluation of the vertical curve quality provide additional support for the quantitative finding previously mentioned. Table 3 shows sample student answers related to the main differences between the best and the worst design.

Table 3. Student evaluation of the quality of the vertical design at the entry and exit activities

	Entry	Exit
Student 1	The curves were unsafe you could fly.	The first two seemed to take us to the sky and then drop us down. The last one is a better transition, and possibly safer.
Student 2	I felt the sight distances and grades were all very bad for interstates at least. However, the last curve was the best of the three and the first was the worst.	The first design just about made me lose my stomach even though I wasn't actually moving. I could totally see a distracted driver taking that hill and landing funny and flying off the road. The second was better, but still seemed way to steep, with bad sight distance. The third was ok, nothing special though, you still definitely know it is there.
Student 7	The best is rounder. The worst is parabolic & pointer	The first curve had a very steep drop off on the back side, the second curve had an abrupt drop off on the left and the third curve is relatively decent
Student 9	The better curves had more gradual increase and decrease in grade.	In the curve that was designed best, the truck did not leave the pavement. In the worst designed vertical curve, the tangents were too steep and the length of the curve was too short for that highway speed.
Student 16	The bad design of the first curve made it difficult to see what was ahead and frightening when travelling across it because it felt like I was flying, while the best curve was comfortable to travel.	The worst design was a bit frightening because I could not see what was ahead and the curve changed very rapidly. I went over the best design smoothly and could see ahead of me.

In addition to the more generic question that asked for the main differences between the best and the worst vertical designs, the exit survey also asked students to provide suggestions to improve these designs. Their answers included design elements associated with the vertical alignment design project, as shown in the sample answers presented below.

#### Student 7

The curve needs to be stretched out over *a greater horizontal distance*. And the second needs have some guard rail on the side.

#### Student 9

Increase the length of each of the curves and *decrease the entry and exit grades* for each curve.

#### Student 11

I would greatly *decrease the slopes* of all the curves. They have a sudden drop which could a hazardous. The *curve length could also be increased* which could be fixed by *adding more fill*.

**Student 16**

I would make the *length of the curve larger* for the second and third curve and *lower the grade of the first curve*.

Finally, in the exit survey, students also provided some suggestions on how to integrate the driving simulator in other course activities. As shown below, their suggestions ranged from generic statements related to the benefit of this tool, to specific additional tasks.

*Generic benefits for civil engineers*

**Student 3**

I think the driving simulator helps you see what some engineers use to make highway designs. It helps you physically see what the design will look like instead of just on paper.

**Student 8**

I think that the use of this simulator in one of the labs is a good way to introduce students to the driving simulator. It also gives a little variety to the lab, which can be quite nice.

*Expand the use of the driving simulator*

**Student 4**

Use it more often to demonstrate different aspects of highway design (vertical curves, horizontal curves, speed limit factors, etc.)

**Student 14**

Might be helpful to also test horizontal curves during the first half of the semester. Perhaps, a simulation with 12% super-elevation vs 2% might prove useful.

**Student 15**

I could see the simulator being used to evaluate speed design and horizontal curve design.

*Add more richness to the driving simulator activity*

**Student 7**

This is really only good for highways since there is not a large enough field of view for intersections or residential areas where kids can run out into the street.

**Student 12**

I think if it was easy enough it might be cool to design our highway from the project in the lab. This could show us how everything we calculated can be transformed into real life.

**Conclusions and Future Research**

Including a driving simulator as a virtual reality tool for analyzing the quality of highway design can increase students' perception of the engagement of highway design tasks.

This is especially useful when students are part of mandatory courses not directly related to their major, as in the case of the Transportation Engineering course analyzed in this study.

Along with the engagement, students also valued the driving simulator as an effective tool for testing and evaluating the quality of the highway design projects. Both students' direct answers to perception items and their open-ended answers regarding possibilities to expand the use of this tool for other highway design tasks provide support for this conclusion. In addition, if the instructor can use the driving simulator before and after major design tasks (e.g., the vertical alignment used in this study), these activities can provide formative assessment data that can help enhance students' learning experience.

For future research, the authors intend to analyze how a complete implementation of the driver simulator as a required task in the highway design project will enhance students' performance and learning experience.

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