Game-Aided Education for Transportation Engineering:

Design, Development, and Assessment

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ABSTRACT

Transportation engineering is a wide area that covers different topics including traffic planning, highway design, pavement design, traffic safety, and traffic control. Certain concepts in those topics are challenging and are hard to understand based on textbooks and lectures. In this work, I developed five web games targeting the five topics in transportation engineering education to improve students' understanding of those hard concepts. The games are hosted in a website server. Students can play these games online after register and login. The server stores the users' information and their gameplay data. We conducted a Before-and-After study to test the effectiveness of the games in terms of improving the learning outcomes of the students. The results showed that the games could increase the students' understanding of hard concepts significantly. The developed games can be used in transportation education. This game framework can serve as a reference for other education game developers.

I envision that more educational games will be developed by transportation and education communities in the recent future. There will be more than one game for the same topic. We need an approach to select games for different students group. I proposed a gravity model for evaluating the engagement of the students for the educational games. I found that different games have different properties in terms of attracting students' engagement. The proposed model can be used in the future for selecting educational games for specific students group.

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GENERAL AUDIENCE ABSTRACT

This thesis presents the effort of making computer games for education purpose. I developed five games corresponding to the five areas in transportation engineering courses. The objective of this work is to let the students understand the hard concepts in transportation engineering by playing the developed games. The students can play the games online, and their gameplay data will be recorded as they play. The effectiveness of this work was tested using before-and-after quizzes. We designed a set of quizzes that are within transportation engineering and can be solved using the knowledge learned in the games. We asked the students to do the quizzes and, without any feedback, do the same quizzes again after playing the games. The result showed that their scores improved in general, which means their understanding of transportation engineering was improved. Using the data collected from the gameplay, quizzes, and the students' course scores, I proposed a gravity model that describes how students were engaged in the games. I found that different games could attract different students.

Acknowledgements

I was enrolled into Virginia Tech as a direct Ph.D. student three years ago. The work presented here is independent from my Ph.D. work. Usually it takes a student one and a half to two years to get a master degree in my program. It took me longer but I think the whole story was not as complete as it could be until this year.

I would like to thank my advisor, Montasir Abbas. Thank him for finding me, for funding me, for training me, and for being there with me. If I draw comics about the conversations we had, it may beat the PhD comics.

I would like to thank my friend Robert, Patton Hall's housekeeping, who keeps my office clean. I would like to thank his weekly visit, checking me, and encourage me to "go and get it."

I would like to thank those who have been there with me, inspired me, and encouraged or discouraged me. I would like to thank those who witnessed my success or failure. I would like to thank you lovely people whose existence is the reason why I work so hard.

I would also like to thank Dr. C-T Lu and Dr. Tony Trani for serving in my committee. It's not easy to find an open time during the end of the semester, but I'm glad that we found a good time.

May the 4th (force) be with you.

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1. Introduction

1.1 Background and Motivation

The nature of transportation education requires students to observe, design, and interact with the transportation system. Transportation experiments require large-scale field experimentation and have safety concerns, so lab-work-based learning approaches are not achievable in some cases. Simulation software can be used to form a virtual lab that allows students to explore the transportation systems. However, learning the simulation software is as hard as, if not harder than, learning the concepts in transportation engineering itself. An intuitive interface between the simulation software and the students is needed. Customized developed games can be good interfaces to show the students enough but not too much information with pleasant learning experience.

We developed five simulation-based games that cover five topics in transportation engineering education. We envision that more educational games will be developed by transportation and education communities in the near future. There will be more than one game for the same topic. One concern raised by educators about using the games is that the student may get addicted to the games. We need an approach to select games for different students group so that the students' engagement with the games can be balanced.

1.2 Research Objectives

The objectives of this research are to 1) develop web games targeting the hard concepts in transportation engineering education, 2) evaluate the effectiveness of the games, and 3) find a metric to evaluate the developed games.

1.3 Thesis Contribution

This thesis presents five educational games developed by the author. The games cover five topics in transportation engineering, i.e., traffic planning, highway design, pavement design, traffic control, and traffic safety. This thesis can be used as a reference for transportation educators who want to use the games for their teaching. The developed games can serve as examples for those who want to develop educational games in different fields. The work presented provides information for education researchers who

want to adopt game-aided education to their own fields. In the future, multiple educational games for the same topics will come to the market. The proposed ranking and assessing model (gravity model) can be used to select the most suitable games for a certain population of students.

1.4 Thesis Organization

This thesis presents the research on Game-Aided Education for transportation engineering. Chapter 1 introduces the background and motivation, objectives, and contribution of this work. Chapter 2 discusses a case of how I designed an educational game for one topic in transportation engineering education. Chapter 3 presents the five developed educational games for transportation engineering education and experience I learned throughout this project. Chapter 4 compares and assesses the educational games using a proposed gravity model. Chapter 4 concludes this work.

2. Using Game Engines for Designing Traffic Control Educational Games[1]

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Abstract—Game-based education in transportation has been explored over the past 10 years. Previous research proved that game-based education is an effective way to deliver transportation engineering concepts. However, past research also found that effective education games are difficult to develop. In this work, we used a game engine to develop a multi-level 3D web game for teaching concepts in traffic signal control. We then tested the game using an experiment with student participants. The results showed that: the game engine was a suitable tool for developing educational games; the game significantly improved students' understanding of the target concepts; and students' understanding improved at different rates.

Keywords—Transportation Education; Game-based Education; Simulation-based Education; Game Engine

2.1. Introduction

Lecture-and-notes education can deliver informationmassive concepts to engineering students, but it can be difficult for students to digest some of these concepts. Traditional transportation engineering classes require students to go to the field to understand and apply the concepts taught in class. With the emergence of Intelligent Transportation Systems (ITS) technology, especially in signal control strategies, traffic engineering

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concepts have become more abstract. Students cannot necessarily observe the theories and understand the concepts behind the operation of modern devices.

In order to give students a better idea of how transportation engineers and ITS work, instructors have implemented new technologies such as animations, simulations, and games.

Chen and Levinson explored using a network growth simulator program (SONG), developed using Java, to teach the topic of transportation network growth [1]. They found that the program helped students develop an in-depth understanding of the network patterns' development and helped them develop some aspects of judgment, problem-solving, and decision-making skills.

Then SONG was integrated into the Simulating Transportation for Realistic Engineering Education and Training (STREET) research project. This project uses a suite of web-based simulations to improve instruction in the Introduction to Transportation Engineering course [2-4].

In addition to simulation, Huang and Levinson implemented a board game as a tool in graduate-level transportation planning and transportation economics classes [5]. In that work, students were asked to evaluate the effectiveness of the game and to write a self-reflective paper about their findings. The researchers found this approach was more effective for students who were moderately/highly visual, sensing, active, or sequential.

Our preliminary work includes creating a methodological framework for collecting data, creating a game prototype using vehicle trajectory data from Vissim simulation software [6], and creating conceptual design for the planning modules [7]. We also proposed an evaluation metric for game-based education [8].

Previous work focused on the game function and evaluation of the game. In this work, we focused on two questions:

1) How to design an educational game with an appealing user interface (UI)?

2) How does the game improve students' learning?

In the following sections, we will present the design of the web game, followed by description of an experiment involving students participants who used the game. Finally, the experiment results will be presented and analyzed.

2.2 Game Design

In this section, we describe the content of the course the game is intended to compliment to show how the two are related. Then the functional design of the game is discussed, followed by a description of the detailed engineering work required for game development.

2.2.1 Course contant

The course we chose is CEE 3604: Introduction to Transportation Engineering taught at Virginia Tech. The targeted concepts in the designed web game were Dilemma Zone protection in Intersection Signal Control. Delay was also introduced in this game.

2.2.2 Function Design

A Dilemma Zone (DZ) is an invisible zone where drivers face difficulty in choosing whether to continue or stop when approaching an intersection at the onset of yellow. A vehicle in the zone is in danger, because if the driver continues, the vehicle may still be in the intersection when the signal turns red, possibly placing it in conflict with vehicles coming from the another direction and possibly resulting in a right-angle collision. However, if the driver stops, the vehicle behind it may continue, possibly leading to a rear-end collision. In this work, a DZ's boundary is defined by a Time to Intersection (TTI) of between 2 s and 5.5 s. The number of vehicles in DZ is a common used measure of safety. The greater the number of vehicles caught in DZ, more dangerous the system is.

In signal control, safety is the highest priority objective. Without sacrificing safety, traffic engineers want the system to be as efficient as possible, meaning the system has as little delay as possible.

In real world, an actuated signal control system has vehicle detectors that characterize the traffic scenario. Then the system reacts to the detector data by switching the signal phase. In this game, we try to capture and convey the essence of the control process. Students

observe the traffic scenario in a 3D visualization environment, and students input a phase-switching decision regarding when to start and stop the subject phase. Then the game reacts to the input by switching the phase. Vehicles' TTI will be calculated to determine the relationship between the vehicles' current location and the DZ. Vehicles that already passed through the DZ will continue to cross the intersection, and vehicles that have not reached their DZ will slow down and finally stop behind their heading vehicles. The game will display those vehicles as green to show they are safe with respect to the DZ. All the vehicles caught in the DZ at the onset of yellow will be displayed as red, indicating they are in danger in the DZ. Of the vehicles in the DZ, some will stop and some will continue. The number of vehicles caught in the DZ and the intersection delay will be demonstrated in the Graphic User Interface (GUI). This entire game play process can be abstracted into DemonstrationControl-Feedback. The process is shown in Fig. 1.
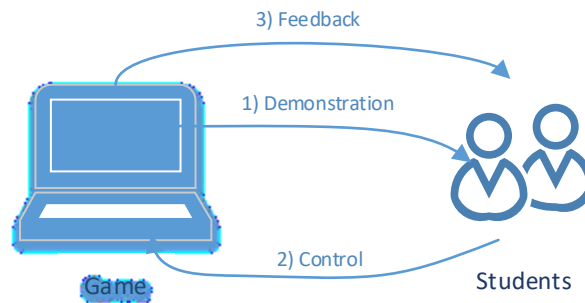

Fig. 1 Conceptual Process in Education Gameplay

The game was designed with multiple levels. Students can re-play multiple times in each level. In each play at one level, students will experience the Demonstration-Control-Feedback process. The feedback should increase student understanding of the concepts behind signal control; a comparison of feedback between plays can help students identify which control strategies work better and which work worse. In subsequent plays, students are expected to make better control decisions.

To make the game interesting and informative, each play is different from the others. At higher levels, the traffic scenario is more complex and students can gain a better understanding of the concepts. Table 1 shows the description of each level. The traffic

arrivals are determined by a Poisson process. The arrivals are random, so each play is unique.

Table 1 Description of Game Levels

Level	Description		
	Number of Directions of Traffic	Speed	Density
1	1	Low	Low
2	1	Low	High
3	1	High	Low
4	2	Low	Low
5	2	High	High

2.2.3 Game Development

The key obstacle associated with developing a game is finding a simple method for transportation educators to develop and apply game-based education. In order to simplify the game development process and to create vivid 3D scenarios, we used a game engine to develop the game. Game engines are typically development kits for game design. They have industry level, high-quality render, applied program interfaces (APIs), scene builders, etc. Some of the game engines also have the ability to edit mesh objects [9]. In this work, cross platform capabilities, render quality, economic factors, and APIs were main considerations, so we choose Unity 3D [10] as the tool to develop the game. It can be used to develop games with appealing UIs, because it has an efficient and industrial-quality render for the 3D scenarios.

The game is web-based and has two parts: a server part and a client part. The client part is simply presented by an internet browser and it can be accessed in a web page with no need to download the game file. The architecture of the game system is shown in Fig. 2.
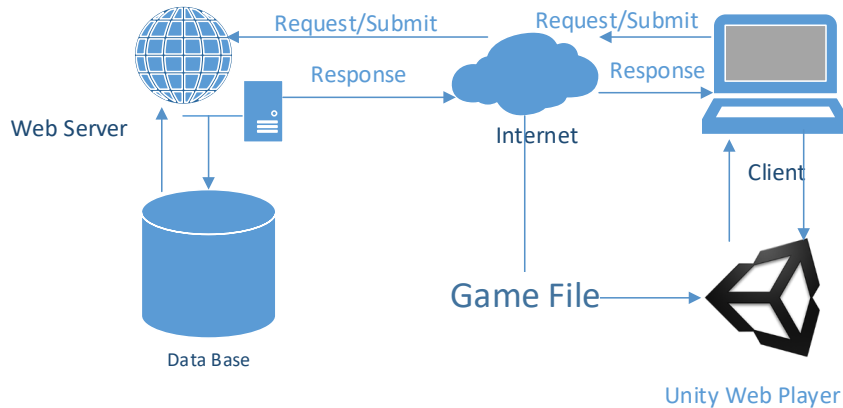
7

Fig. 2 Architecture of the Game System

The client sends a request for the game file to the server. The server responds by sending the game file back to the client. The game file includes the game resources (images, 3D models, sounds, etc.) and scripts. Unity Web Player reads and presents the game file by visualizing the scenario and explaining the scripts. Unity Web Player is a plugin for multiple web browsers (e.g., Internet Explorer, Firefox, Chrome, Safari, Opera). The 3D objects in the game were designed in 3D Max. The game records the scenario information and student's operations and scores. The recording process is achieved by sending HTTP requests to the server via the game. Using the same method, the game has User Registering/Login function (**Fig. 3**). The scripts in this game were written in C# and the game was embedded in the webpage using HTML and Javascript. The server part is implemented in ASP.NET with MS Access serving as the database. Key graphical user interfaces (GUIs) and screenshots of gameplay are shown in **Fig. 3** through **Fig. 8**.

The student needed to login to play the game so data for individuals could be distinguished in future analyses. The login screen is shown in **Fig. 3**. If a student did not have an account, he/she was required to register. During registration, a student needed to re-input the password to successfully complete the process. The login function was designed to track each individual's game play. The user name could be a nick name chosen by students participating in the experiment. Players not participating in the experiment could also register and play without reporting their user name and other information.
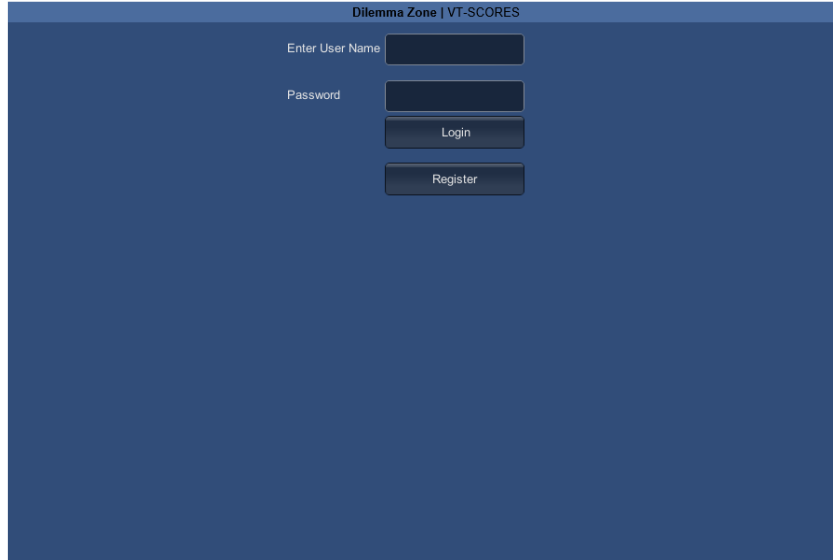
Fig. 3 Login User Interface

After login, a startup GUI was presented (shown in **Fig. 4**). The game scenario is a T intersection located in a desert. The panels on the screen are present through the game play life cycle. There are three groups of panels. The left panel shows messages guiding the student to finish the pre-settings and play the game. During game play, this panel shows key information regarding the current scenario (e.g., traffic volume). The middle top panel is the counter showing the time left to phase max-out. The right group of panels is the main control and feedback area. It shows the student's username, current level number, current level performance information (i.e., number of vehicles in the DZ and delay under current phase configuration), and the student's history of performance. It has a region that allows students to modify the minimum green time and maximum green time. It also has a control button to start a game or end a phase.

Fig. 4 Game Startup GUI

When the student clicks the start button, the game will start. A screenshot of the game starting is shown in Fig. 5. Initial queues exist for both directions of the road. All the vehicles are in yellow to show normal cars. The queues will start being discharged as the signal turns green. New vehicles will arrive before one queue or the two queues being fully discharged. The initial queues intend to prevent students stop the green at the very beginning so that they can always achieve zero vehicles in DZ. Students can navigate the scenario by using the arrow keys.

Fig. 5 Screenshot When Green Starts

When the student clicks the stop button to stop the green, the signal will turn yellow and then red. The vehicles in the DZ are displayed as red, and other vehicles are displayed in green. The right panel group updated and displayed data regarding the scenario's performance given the student's choice (i.e., update the number of vehicles in DZ and

delay and the history performance). The game let the student choose replay or go to the next level, up until the last level (i.e., level 5). A screenshot of the game when green ends is shown in **Fig. 6**.

Fig. 6 Screenshot When Green Ends

In each play, traffic was generated based on a random number generator with a different random seed, with the goal of making the game less boring by changing the scenario in each play. The random seed was recorded so researchers can retrieve the scenarios the students encountered.

2.3 Experiment

This experiment used volunteer student participants from CEE: 3604 Introduction to Transportation Engineering in the fall 2014 semester at Virginia Tech. Students were offered the opportunity to participant and received extra course credit for doing so. Data collection and analysis were approved by Virginia Tech's Institution Review Board (IRB).

The study had a pretest-posttest design. Student participants were asked to take a (pretest) quiz with 10 questions regarding the target concepts. Then they were asked to play the game and take the same (posttest) quiz again. The quizzes were untimed and students could play the game as many times as they wanted. The students did not get any feedback from the quizzes to prevent their answers to the pretest from affecting their responses to the posttest. This experiment was conducted during a weekend. Both the quiz and the game were administered online, so the location and timing of the quizzes and gameplay

were flexible. The quiz questions were multiple choice, so grading was objective and easy to manage. One example quiz question is shown in Fig. 7.

Fig. 7 One Example of the Quiz

2.4. Results and Analysis

A total of 45 students took the pretest quiz and 40 took the posttest quiz. The 40 valid students contributed 608 valid data points collected by the game's server. The students' final scores of the course were also taken into consideration to account for the students' individual characteristics.

The preliminary analysis from SAS JMP [11] show that gameplay significantly improved the quiz scores as a whole. In a matched pairs t-test, the mean difference is 0.95 at a 0.0051 significant level.

A further analysis to determine whether playing the game improved students' understanding of the target concepts was conducted using logistic regression. The output of the model was a function of the following factors: student performance in this class (the student's final course grade), baseline understanding level (the student's score on the pretest quiz), and number of gameplays. The analysis was conducted using R [12]. The coefficients for the logistic function are shown in Fig. 8. Using the logistic model to predict if students can improve with the whole data shows 70% correct rate.

```
> fit$coefficients
    (Intercept) classTotalScore   B_Final.Score          count
   -0.710818922     0.044927601    -0.579632755    -0.002164811
```

Fig. 8 Results of Logistic Regression

The results show that the number of gameplays (count) had a low coefficient and did not significantly affect student understanding of the subject concepts. The coefficient for students final score of the class (classTotalScore) was positive, indicating that higher performing students improved their scores on the second quiz more easily than lower performing students. The coefficient of the before-quiz score was negative, which make sense, because with a high baseline understanding, there was limited room for those students to improve.

2.5. Conclusion and Future work

For the previous analysis, we can reach the following conclusions:

- The game engine is an efficient tool to design an educational game with an appealing UI and high quality render.

- Gameplay can significantly improve student understanding.

- There is no need to play too many times, because doing so does not necessarily improve the understanding as a whole.

- Higher performing students improved their scores more easily.

- Weaker initial understanding of concepts can lead to greater overall improvement after playing the game.

Future work will include developing other game modules targeting other concepts in Introduction to Transportation Engineering. We also plan to integrate a face-to-face survey in future research, as well as more experiments and more detailed analyses. We will develop quizzes for each level to measure the different rates of improvement corresponding to the different game levels, instead of having students play as much, or as little, as they want between the quizzes.

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3. Game Suite for Transportation Education[2]

Abstract

Educational games have been proven to be effective tools to support transportation engineering education. Our group has been actively developing educational games for teaching transportation engineering classes. This work identified the key concepts in transportation engineering that can be gamified. Five games were developed targeting five areas in transportation. The developed games are Transporters for planning, Time-space Invaders for signal control, DZ-Man for safety, Angry Curves for highway design, and Road Crush pavement design. All the games can be played online after users' registration and logging-in. The users' gameplay data were uploaded to a server. A record of gameplay data include the user name, the game played, the level number in the game, the game parameters (e.g., the game scores), and the time that record was generated. We evaluated the effectiveness of the games by before and after studies. The students were asked to do quizzes after learning a certain concepts during the class. The quizzes were targeting the concepts taught in the class. Then they were asked to play a game targeting the same concepts and do the same quizzes again. We compared the quizzes scores before and after the gameplay to tell the effectiveness of the games. The games were evaluated in 2014 and 2015 during a transportation introductory class. The results showed that for all the tested games, the overall students' quizzes scores increased. T-tests were conducted for each evaluation and the results showed the increases were statistically significant. The results indicate that the games can improve students' learning outcomes significantly. This paper can be used to guide developers to build new games for transportation engineering education. This paper can also be useful for transportation educators who want to implement games in their teaching practice.

Keywords:

Game-Aided Pedagogy, Gravity Model, Learning Outcomes

3.1. Introduction

More and more educators agree that games can be used as effective tools for their education practice. Until now, most game-involved education practices are for K-12 group [1, 2]. At the same time, it's rare to find games being used for higher education. This phenomenon exists because the target knowledge for K-12 group can be more easily delivered through existing games, when compared to the target knowledge in higher education.

The nature of transportation education requires students to observe, design, and interact with the transportation system. Unlike chemical engineering, transportation experiments require large scale field experimentation and have human factor impacts, so lab-work-based learning approaches do not always work. Simulation software can be used to form a virtual lab that allows students to explore. However, learning the simulation software is as hard, if not harder, as learning the concepts in transportation engineering itself. An intuitive interface between the simulation software and the students is needed. Customized developed games can be a good interface to show the students enough but not too much information with pleasant learning experience.

Our Lab has been actively developing transportation education games. There are five games that have been developed in this game suite. These games target concepts in pavement design, highway design, traffic safety, traffic control, and traffic planning. Wang et al. developed the first game (DZ-Man) in this suite in 2014 [3]. A gravity model was proposed at the same time to describe the knowledge delivering dynamics and can be used to model the engagement of the students in such educational games [4]. The gravity model was further used to compare two different educational games developed by the group [5]. The five games were presented in Transportation Research Board annual meeting in 2017 [6]. The games were distributed among the transportation education community through the meeting.

At this stage of the project, the games can be accessed online. The games were updated based on the feedback from the users. This paper presents the updated educational game suite as well as the newly raised security issues and the solutions. This paper could serve as a guide to the educators who want to implement the developed games in their classes.

It could also serve as a reference for education researchers who want to conduct projects regarding game-aided engineering education.

3.2. The Games for Transportation Education

To build a transportation system in real word, there are certain processes that need to go through. We need to plan first to know where to allocate the buildings and how to connect them with roads. Then geometry design of the highways come to the stage. Before the actual road construction, pavement design should be conducted. When traffic is loaded to the road, proper traffic control strategies should satisfy the safety and efficiency requirements.

These processes cover certain topics in transportation education. These topics include traffic planning, highway design, pavement design, traffic safety, and traffic control. Corresponding to these topics, we designed five different web games, i.e., Transporters, Angry Curves, Road Crush, DZ-Man, and Time-Space Invaders. These games are hosted in a website server. Students can play these games online after register and login. The server stores the users' information and their gameplay data. A record of gameplay data include the user name, the game played, the level number in the game, the game parameters (e.g., the game scores), and the time that record was generated. In the rest of this section, we will present each of these five games.

3.2.1 Transporters

Transporters game is a game for traffic plan. The game UI has draggable tiles and a playground to which the players can drag tiles (as shown in Figure 1). The tiles represent road segments and trip zones. They players need to place the tiles in appropriate locations such that the traffic network will not be congested.

The Transporters game uses four step model (a conventional traffic forecasting model [7]) to evaluate the players design. The game gives the players visual feedback by

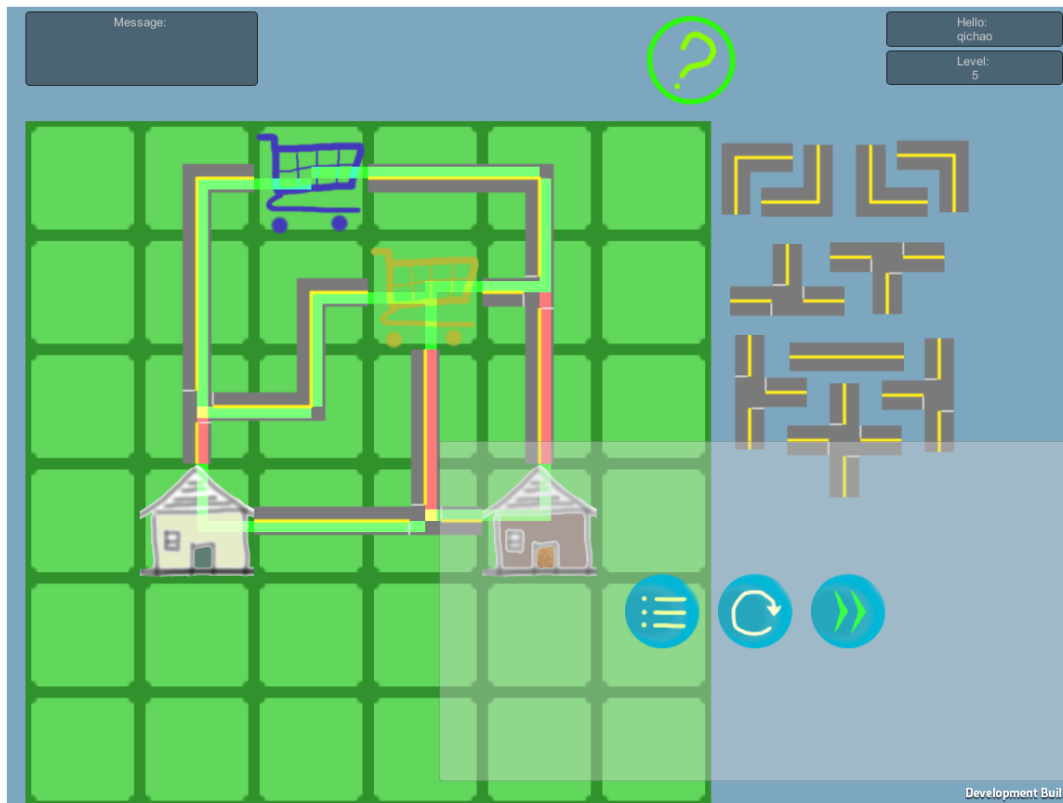highlighting the congested road segments with red color and the uncongested road with green color.

Figure 1. Game User Interface for Transporters

3.2.2 Angry Curves

Angry Curves game targets concepts in highway design. Players need to design the curvatures and super-elevations of the curves with given constrains. If the highway was designed properly, the game will show an animation of vehicles running on the designed highway nicely. If the design does not meet the safety requirement, the game will show an animation of vehicles been thrown away by the highway. A screenshot of the Angry Curves game is shown in Figure 2.

Figure 2. Game User Interface for Angry Curves

3.2.3 Road Crush

Road Crush is a game targeting concepts about pavement design. In pavement design, the typical design parameters are the material and the thickness of each layer. In this game, players need to design a segment of pavement by dragging the material tiles into proper layers and adjusting the thickness of each layer. Vehicles will stop moving and a crack will be shown in the pavement if the design does not meet the requirements, which means the road was crushed. If the design can handle the traffic on it, the game will show a check mark. A screenshot of the case where the design does not meet the requirement is shown in Figure 3.
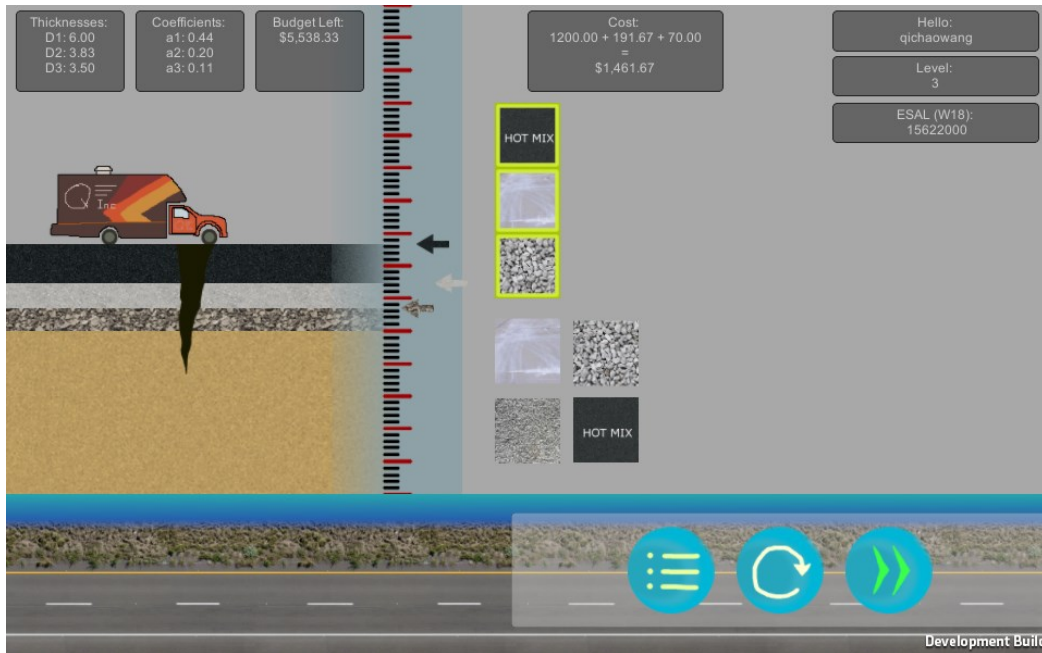
Figure 3. Game User Interface for Road Crush

3.2.4 DZ-Man

Dilemma Zone (DZ) is a zone where drivers cannot decide whether to stop or to go when approaching an intersection at the onset of yellow. In practice, various types of Green Extension Systems (GES) were used to protect DZ [8]. In this game, players need to mimic the GES to control the traffic light and decide when to stop the green. When a player stop the green, the vehicles in DZ will be in red and other vehicles will be in green. A screenshot of DZ-Man is shown in Figure 4.

Figure 4. Game User Interface for DZ-Man

3.2.5 Time-Space Invaders

Time-Space Invaders is a game targeting coordinated signal control concepts. It uses a GM model (a car following model [9]) to simulate the vehicles' movement. Players can adjust the offset of an intersection by dragging the arrow (as shown in Figure 5). The game shows time-space diagram as feedback. Delay is also shown in the game as costs.
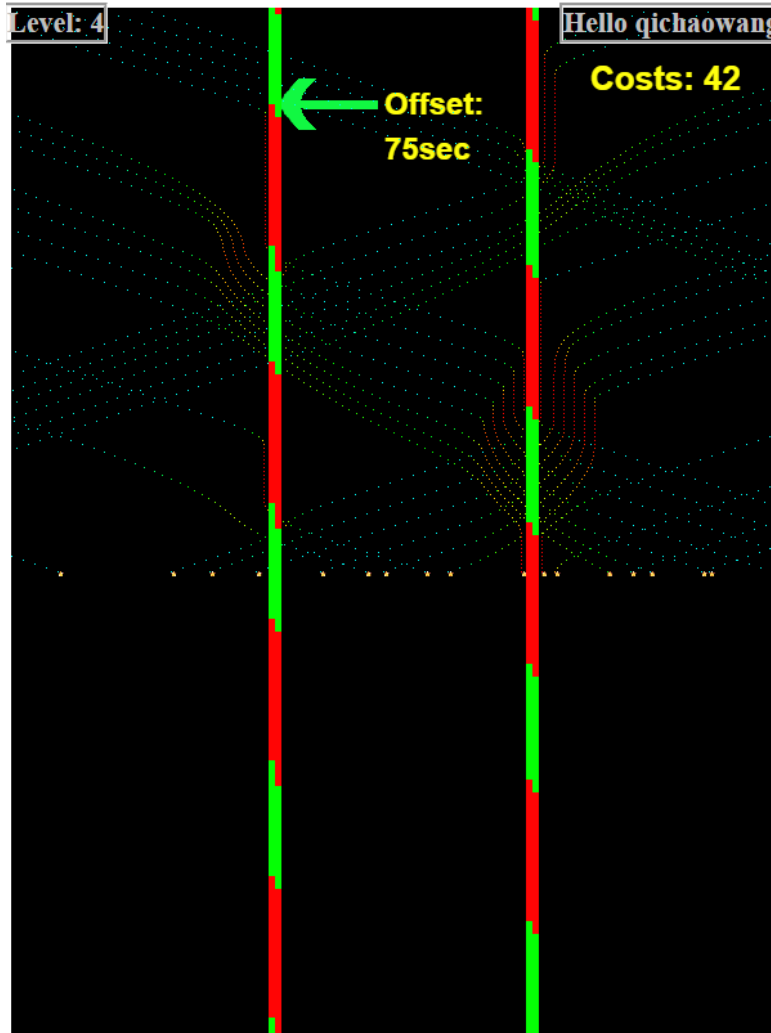
Figure 5. Game User Interface for Time-Space Invaders

3.3. Preliminary Tests and Results

We conducted a Before-and-After study to test the effectiveness of the games for improving students' understanding of the targeting concepts. The study process can be summarized as "lecture-quiz-game-quiz" processes. The students were given lectures on specific topics in the class of Introduction to Transportation. Introduction to Transportation is a class that covers all the five topics in transportation education. Then they were asked to finish a set of untimed quizzes related to a topic learned in the class. They were then asked to play a corresponding game. They can play the game as many time as they want. They were asked to do the same quizzes again after they finished the game play. No feedback was given to the students regarding their performance in the pre-

game quizzes. Therefore, the only factor that can affect their scores is the gameplay between the two sets of quizzes. The quizzes were designed as multiple choices, which avoid the effect of graders' subjective bias.

We conducted studies for DZ-Man in 2014 and 2015 and a study for Angry Curves in 2015. The experiments were approved by the Institution Review Board (IRB). There were 10 questions associated with the DZ-Man, and 7 questions associated with the Angry Curves. An example of the question is shown in Figure 6.

Post-Game Quiz

Table of Contents

Part 1 of 1 -

Question 3 of 10   1.0 Points
If the traffic volume increases and the number of vehicles caught in DZ increases:

⚪ A. This is expected because they are directly related
⚪ B. This is not expected because they are inversely related
⚪ C. This is not surprising since it is more likely to happen
⚪ D. This can never happen
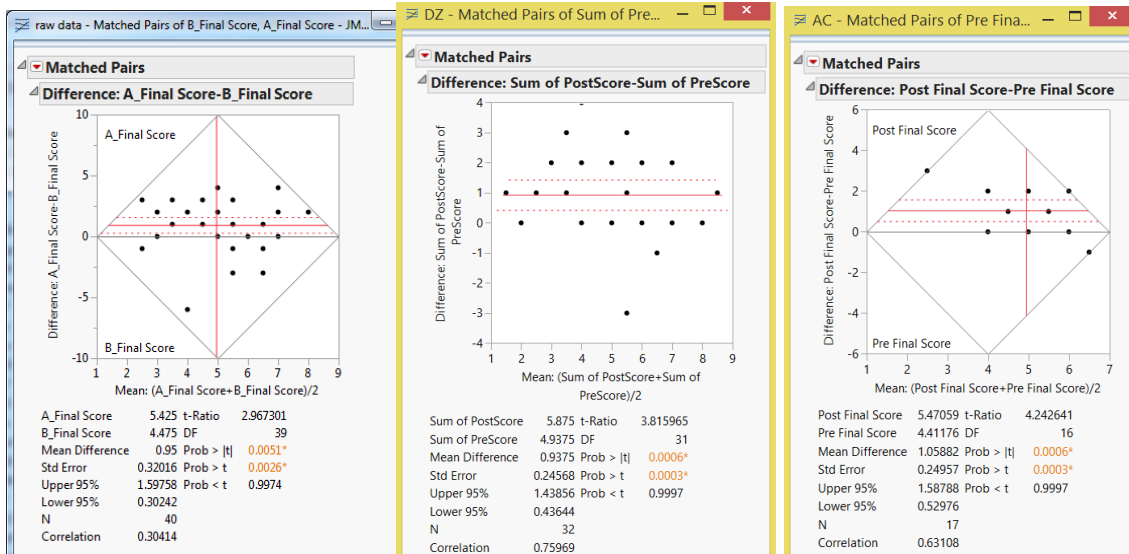Reset Selection

Previous   Next   Save   Exit

Figure 6. Screenshot of One Question

We conducted matched pairs T-Tests to compare the students' quizzes scores. The results are shown in Figure 7. From the results, it can be seen that the mean difference are all around 1. This means the students' average quiz score increased by 1 (out of 7 for Angry Curves game and 10 for DZ-Man game) in all the cases. The significance levels are 0.0051 for 2014 DZ-Man data, 0.0006 for 2015 DZ-Man data, and 0.0006 for 2015 Angry Curves data. This means the increases of students' understanding on the targeted concepts (reflected by the quiz scores) are statistically significant.

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a) 2014 DZ-Man data   b) 2015 DZ-Man data   c) 2015 Angry Curves data

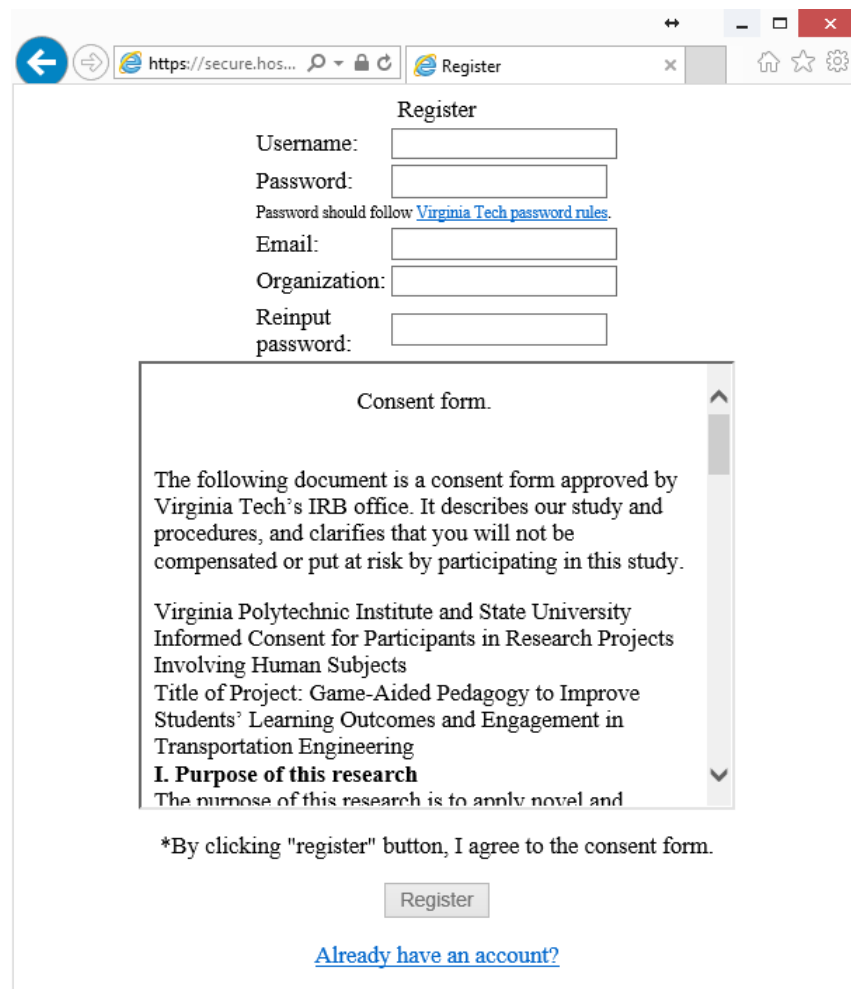**Figure 7. Matched Pairs T-Tests for Different Experiments Pre/Post Scores**

3.4. Beyond the Campus

At this stage of the project, we allow users from all over the world to have access to the games. This means the users of the games will no longer be limited within campus. The players' data will still be collected for further research purpose. The paper-based consent material cannot reach the users over the internet. The old online quiz system needs the team to add users manually to the system to allow their access. It is no longer practical to use the old online quiz system with potentially massive users. Double login (login to the game and login to the quiz system) should no longer be needed when the games and the quiz are hosted in one website. The way from which the students get to know the games is no longer limited to the assignments. The players may not be able to read the introduction of the games which was included in the description of the assignments. Those newly raised issues need to be solved.

3.4.1 Web-based IRB Protocol Updates

The user group need to be expanded to potentially anyone who meets the minimum requirement on the internet. In order to do so, we need to update the IRB protocol. To update the IRB protocol, we did the following tasks:

- Upgrade the website security. Several security risks have been fixed.

- Change the paper-based consent form into web consent form. The users need to agree to the web consent form to finish the registration. The registration webpage is shown in Figure 8.

Figure 8. User Register Page

3.4.2 Online Quiz System

In the studies where students were within Virginia Tech, students can take the quiz in Scholar quiz system (as shown in Figure 6). Scholar is an online learning management system. Only students added into a class in Scholar have access to the quizzes. This was convenient when the games were tested within campus. Now since the games is open to anyone on the internet, a new online quiz system is needed.

We updated the database structure to store the user-quiz information. Two data tables were used. One table stores the data indicating if the user finished the quizzes; another table stores users answers and scores. When a user goes to a game page, the server will check if this user have done the quiz for this game. If this user did the quiz before, the server will allow the user to play the game. If not, the server will redirect the webpage to the quiz page. After the user submit the quiz answers, the server will redirect the webpage to the game page. The quiz pages are in HTML form format. An example of the quiz webpage is shown in Figure 9.
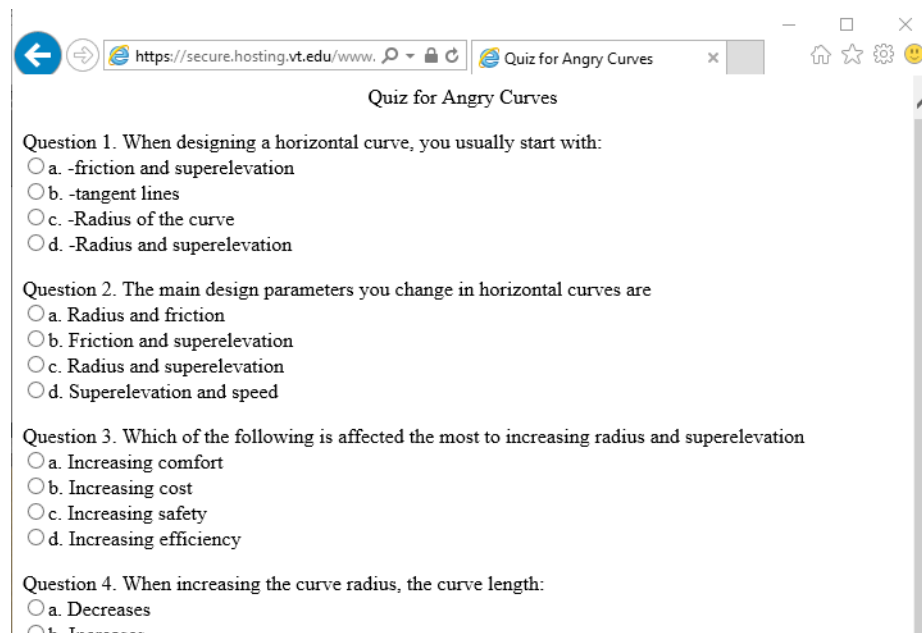

Figure 9. The Online Quiz Webpage

3.4.3 Unified Game Login Mechanism

We updated the games and website so that the players only need to login once to the website to play all the games and do the quizzes. A flow chart of login process is shown in Figure 10. After a user logging in successfully, the server will put the user ID information into a Session. A Session is where the data of one browser/server conversation can be stored temporally in a server. The server will then redirect the webpage to the homepage where the player can choose which game to play. After the player choose which game to play by clicking on a link, the server will query its database to see if the player has done the quiz at least once for this game. If has done the quiz, the player will be able to play the game directly. If not, the webpage will be redirected to the quiz webpage. Only after the player finishes the quiz, the game page can be shown. The quiz answer will be uploaded to the server with the user ID stored in Session. For Transporters, Angry Curves, Road Crush, and DZ-Man, they were developed in Unity. They cannot access the information in Session. However they can access the parameters in the URL that host them, so we put the user ID as a parameter in URL. To prevent faking identity, the webpage will check if the user ID in the URL parameters matches the user ID in Session. If they match, the page will stay and the game will be loaded. If they do not match, the page will redirect itself to a URL with the correct user ID in its parameters.
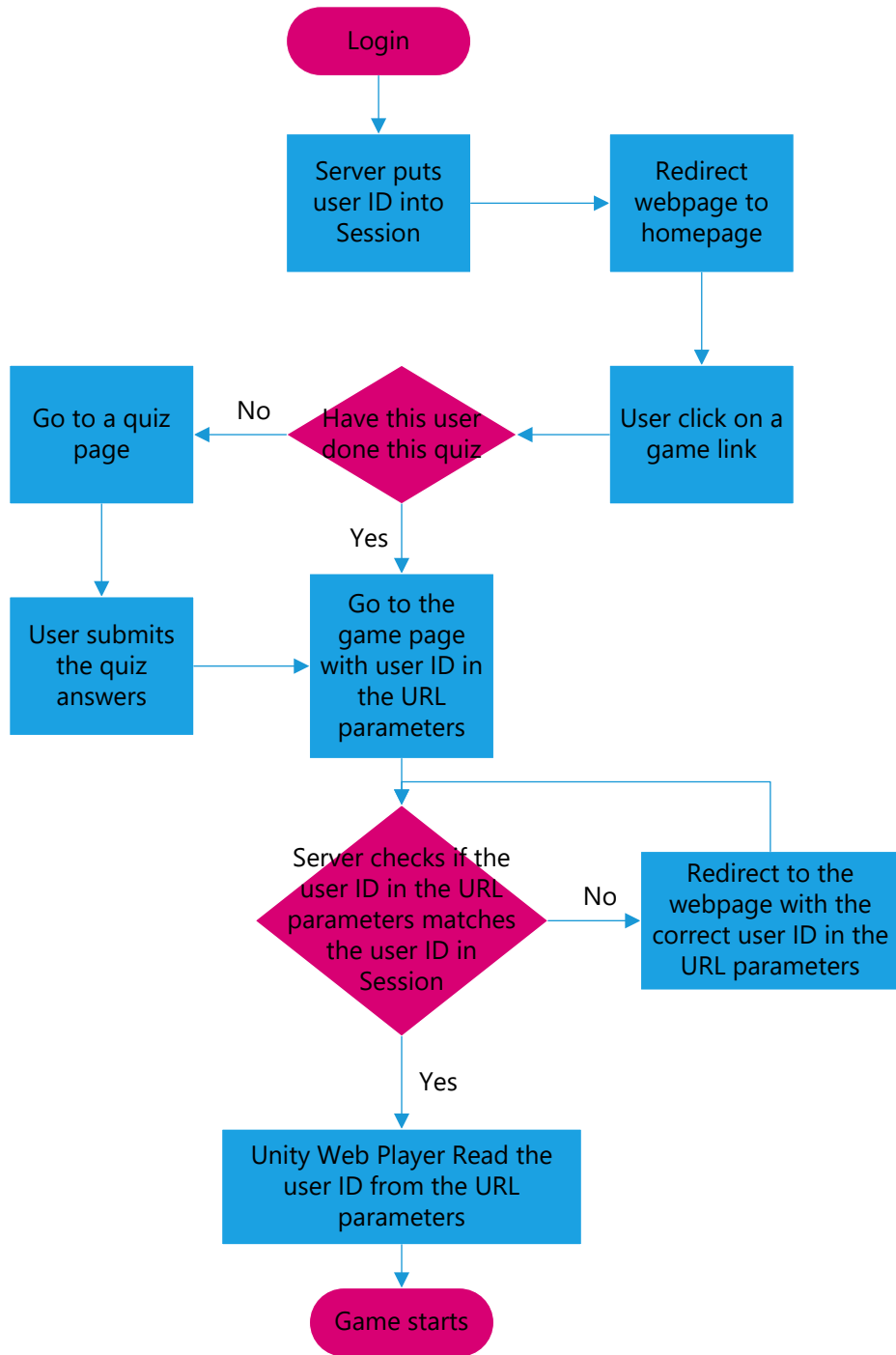
Figure 10. Unified Game Login Mechanism

3.4.4 Integrated Game Introduction

We updated the games such that they all have introduction scenes at the beginning of the games. The introduction tells the players what they should do in this game. The players

can skip the introduction if they do not need to see them, e.g., they have already seen the introduction. A screenshot of the introduction scene of DZ-Man is shown in Figure 11.

Figure 11. An Example of Integrated Game Introduction in DZ-Man

3.5. Conclusion and Future Work

In this project, five web games have been developed targeting five topics in transportation education. They are now available to the public. Before-and-after studies showed that the educational games can improve students' understanding of the targeted concepts significantly. Updates were made to encounter the issues faced when the games opened to larger scale of audiences.

For the future work, the team will keep collecting feedback for the games and make updates and revisions to meet the requirements from the broader user group.

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4. Using a Novel Gravity Model for Ranking and Assessment of Educational Games[3]

Abstract

Teaching introductory transportation engineering subjects can be very challenging. These courses usually include diverse topics and can involve students from different background and interest levels. Keeping students engaged and focused requires changes in traditional delivery methods. It also requires the design of exercises that are especially targeted to address certain concepts. Game-aided pedagogy has been proposed to stimulate students' interest and increase the efficiency of their learning. Our research team developed multiple games that were designed to target different concepts in the transportation fields. These games deliver appropriate amount of information density and accessibility, and utilize multimedia and hypermedia contents. We have developed a novel gravity model to relate students learning to information density, ability of students to absorb knowledge, and difficulty of delivery, and have previously demonstrated the model with one of the games.

In this paper, we expand and illustrate the use of the educational gravity model to assess and compare different games used in game-aided teaching. A description of two different games is included in this paper. Each game uses refined 3D vivid scenes to attract and stimulate students. Gameplay data collected include students' responses in each game level. Both games use client-server architecture to interact with students and store their gameplay data to assess the students' learning outcomes. We capture the effectiveness of each game by calibrating the gravity factor in each model. Each game has a naturally different gravity factor that could be associated with the game's appeal and capability to transfer knowledge. We attempt to shed more light into this concept and the potential for its use in ranking and evaluating newly developed games in terms of their pedagogical value.

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[3] This paper has been published in the proceeding of the 2016 ASEE Annual Conference & Exposition

4.1. Introduction

Studies from 1990s showed active learning is an effective way of teaching [1-4]. Active learning focuses on students' responsibility for learning more than instruction based delivery. One approach of active learning is to immerse students in the problem environment and let them explore and learn the concepts on their way while trying to solve the problem. The large-scale, costly and complex nature of transportation system does not lend itself to students' exploration of the real world. However, some concepts can only be appreciated and better understood in a large scale system. This usually calls for the use of simulation to reconstruct the reality and make it accessible for students [5-7].

Game-aided Pedagogy in transportation classes use simulation-based games to improve students' understanding of certain abstract concepts. Our past studies showed that educational games can significantly improve students' learning outcomes [8-11]. Compared to pure simulation-based teaching, games can stimulate students' engagement in learning and extend students' learning activities beyond the class boundaries. Wang et al. proposed a gravity model to describe the engagement of students in such educational game [9]. It was found that final scores (which serves as a surrogate measure of students' capabilities) and the level number in a multi-level games (which indicates the distance between the student and the game) can significant affect the students' engagement. However, the sample of this study was limited and only one game was evaluated. To show what kind of games can improve students' engagement, a comparison between games is needed. The concepts presented in this paper can be used to guide the development of future educational games and their implementation strategies.

The purpose of this work is therefore focused on the following research question: what kind of multi-level educational games can stimulate students' engagement more? Another related question is whether different levels of the same game can stimulate students' engagement differently.

To answer these questions, the following work has been done:

1. We developed two games targeting two different concepts groups. The games were developed using the same design framework (Unity 3D game engine). The games can be easily accessed by students and can store and report the students behavior to a central server.

2. We used the games in a class. The games were used in one class so that the students' properties can be measured under the same conditions.

3. We tested the students' understanding of the related concepts before and after the gameplay to validate the games' effects of improving students' learning outcomes.

4. We calibrated a gravity-based model[9] and compared the two games based on the model's parameters.

4.2. Method

This work adopted the gravity model and customized it into one model that describes the engagement level of the students. Two educational games were designed targeting two different topics in transportation. Two experiments were conducted using the two games to calibrate the model and evaluate the games, respectively. The customized gravity model was the evaluation metric used in the experiments. The games were the evaluation subjects and the tools to collect the students engagement measures.

4.2.1 The Gravity Model

In analogy to the gravity model in physics, we use a gravity model that describes the attraction between the knowledge source (i.e., the game) and each student. The attraction (engagement) is described in equation 1.

$$E = C_e \frac{P_{source} \times P_{student}}{D} \tag{1}$$

Where:

E $\qquad$ = student's engagement,

C_e $\qquad$ = engagement coefficient factor,

P_{source} $\qquad$ = properties of knowledge source,

$P_{student}$ $\qquad$ = properties of a student, and

D $\qquad$ = distance between knowledge source and the student, which is the new knowledge.

Since the goal is to evaluate and compare the different games, there is no need to have the coefficient factor separated from the P_{source}. Thus we combine and simplify the model into equation 2.

$$E = \frac{P_{source}^e \times P_{student}}{D} \tag{2}$$

Where:

P_{source}^e $\qquad$ = properties of knowledge source in terms of engagement

The equation can be linearized if we take all the factors as exponential function of corresponding underlining measures, i.e.:

$$\exp(e) = \exp(p_{source}^e) \times \exp(p_{student}) / \exp(d) \tag{3}$$

From equation 3, we can get:

$$e = p_{source}^s + p_{student} - d \qquad (4)$$

We make the assumption that all the terms in equation 4 can be a function of certain measurable parameters. In this case, we use students' final score to indicate the students' properties, level number to indicate the new knowledge, the number of gameplays to indicate the engagement, i.e.,

$$e = f_e(number\ of\ gameplays),$$

$$p_{student} = f_{ps}(student's\ final\ socre),$$

$$d = f_d(level\ number).$$

Another assumption is that the relationship between the terms in equation 4 and the measurable parameters are linear, which means

$$f_i(x) = a_i \times x + b_i$$

Where

i = function group indicator, could be e, ps, d, and

a_i, b_i = parameters for function $f_i(\cdot)$.

Then equation 4 can be written as:

$$f_e(number\ of\ gameplays)$$
$$= p_{source}^s + f_{ps}(student's\ final\ socre) - f_d(level\ number)$$

=>

$$a_e \times (number\ of\ gameplays)$$
$$= p_{source}^s + a_{sp} \times (student's\ final\ socre) - a_d \times (level\ number)$$
$$+ b_{sp} - b_e - b_d$$

Let $\theta_1^s = a_{sp}/a_e$, $\theta_2^s = a_d/a_e$, let the constant parameters be θ_3^s, we can get

$(number\ of\ gameplays)$
$$= p_{source}^{e}/a_e + \theta_1^e \times (student's\ final\ socre) - \theta_2^e \times (level\ number)$$
$$+ \theta_3^e$$

For comparison purposes, $p_{source}^{e}/a_e + \theta_3^e$ as a whole can be used to represent the game's properties, therefore we denote it as p_{game}^{e}. Then we get the customized model to describe the engagement shown in equation 5.

$(number\ of\ gameplays) = p_{game}^{e} + \theta_1^e \times (student's\ final\ socre) - \theta_2^e \times$
$(level\ number)$.

(5)

4.2.2 Game Design

The games should be easily accessible, user friendly, and have the ability to record and upload the users' gameplay data. To achieve these properties, Unity 3D game engine was selected as the developing tool associated with Microsoft Visual Studio. The games were designed in a form of web-games. Web-games are easier to deploy and maintain. The web-games published by Unity can be accessed by multiple internet browsers with a plugin from Unity. All the games were developed under a browser/server architecture. The architecture can be found in our past work [11].

Each game should target one specific topic. Since the games would be used by the same group of students, the difference in the topic between the two games should be maximized to eliminate the impact on the second experiment from the first game. So the selected topic were dilemma zone protection in traffic signal control and curve design in highway design.

4.2.2.1 DZ-man

Dilemma zone is a zone where the drivers are in a dilemma whether to continue or to stop at the onset of the yellow indication at a traffic signal. Drivers who decide to stop may

risk being rear-ended by the following drivers that might decide to continue. . Drivers who continue might risk running the red light. A common way of protecting dilemma zone in the real world is using green extension systems to extend the green of the subject approaches until no vehicle is present in dilemma zone.

A web-game named DZ-man was designed to mimic the control logic of the green extension system. The Graphic User Interface (GUI) is shown in Figure 4. After logging in, the player will see an intersection with a signal indicator. The player can start the game when they are ready by clicking the "start" button. After the game starts, vehicles in the queue before the intersection will start moving and new vehicles will arrive. Players can click the "stop" button to end the green after a minimum green duration. All the vehicles that passed their dilemma zone would continue and all the vehicles that haven't reached the dilemma zone would stop. For these vehicles, their color will turn green indicating they are out of dilemma zone and are therefore safe. For the vehicles within the dilemma zone, some of them would stop and the rest would continue. All the vehicles in dilemma zone will turn red as an indication of danger. Players strive to end the green without catching vehicles in dilemma zone. This game had 5 levels. Players can replay any level as many times as they want.
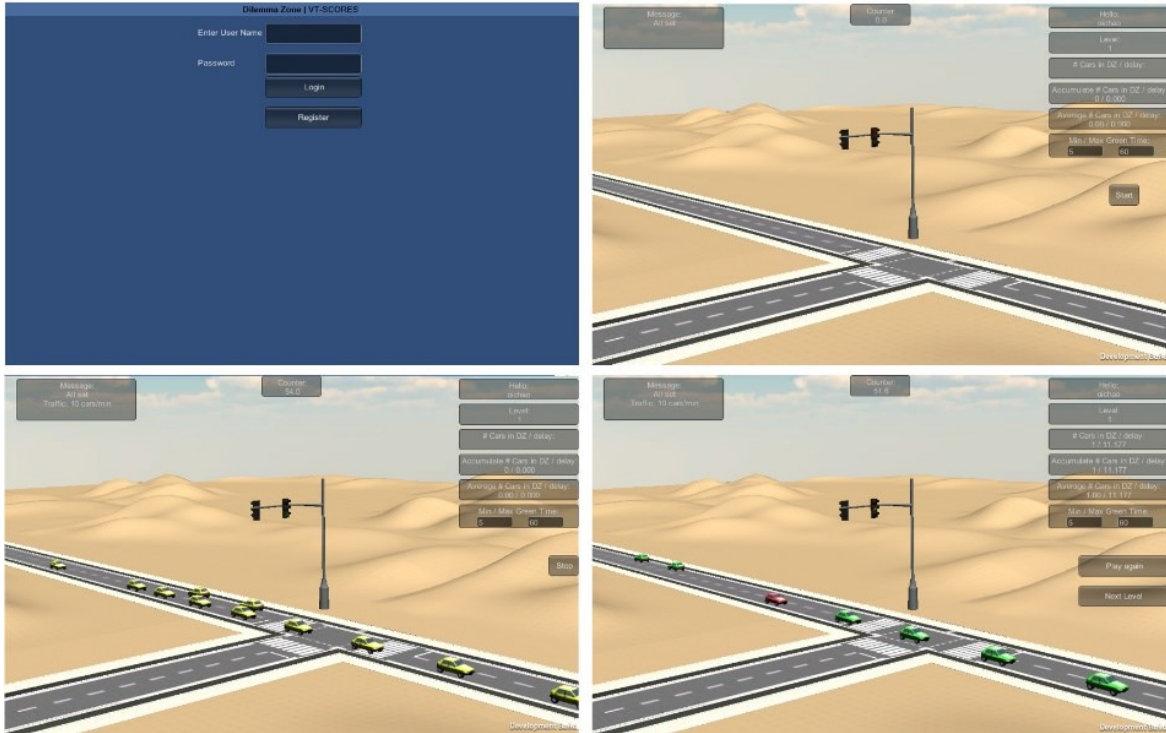
Figure 12. Game User Interface for DZ-man

4.2.2.2 Angry Curves

The design of curves can significantly affect the safety of a segment of highway. Engineers usually design the curves to connect given tangent lines representing the connected parts of the highway. Other relevant information includes the coefficient of side friction, designed speed, area map, and budget and space constraints. The design parameters are the curve radius and the super-elevation.

A web-game named Angry Curves was designed to illustrate the concepts in this module of a highway design class. The GUI of Angry Curves is shown in Figure 5. It has similar user control layout to DZ-man. In this game, the player is given a set amount of budget. Different design will have different costs. The objective is to design a safe curve (without making it angry) and minimize the cost. This game has two levels and an introduction

chapter. After user login, the game will go into the introduction sequence, provide the background information, and provide general guidance of how to play the game. In the introduction chapter, the coefficient of side friction, design speed and relationship between cost and design parameters are given. At the first level, players design the first curve without space constraints. If the design is safe, players can see the animation of vehicles passing the curves safely. If the design is not safe, players will see the curves shaking and when vehicles drive on the curve, the shaking curve will throw the vehicles away. Players can click the "switch camera" button to switch between first person view and third person view. Only a safe design in the first level can let the player go to the second level. In the second level, the focus of the camera will move to the location where a second curve would be designed. With other settings being the same, this time big trees are set nearby as design constraints. Each level can be replayed as many times as the players want.

Figure 13. Game User Interface for Angry Curves

4.2.3 Experiment

The games were given to students as assignments during the class of Introduction to Transportation in Fall 2015. The class was taught as flipped classroom and 49 students

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were formally enrolled. The experiment was approved by the Institution Review Board (IRB).

The games were wrapped into modules associated with corresponding chapters. One module included a prerecorded video lecture, class discussion (with Teaching Assistant and professor's help), a pre-quiz, the gameplay, and a post-quiz. Lecture and class discussion were the normal teaching content. The pre-quiz, gameplay, and post-quiz were the package of game-aided teaching. In this part, students took the pre/post-quiz in "scholar" (a website where the teaching materials and notices regarding the class were hosted). Students did not know their quiz scores before finishing the whole package. This was intentionally done so that the change in understanding level could only be affected by the gameplay in between the quizzes. The pre- and post- quiz were untimed.

,There were 10 questions associated with the DZ-man game, and 7 questions associated with the Angry Curves game. All the questions were designed in the forms of multiple choice so that the grading of the quiz would be objective. An example of the question is shown in Figure 6.

Post-Game Quiz

Table of Contents

Part 1 of 1 -

Question 4 of 10
The effect of the maxout timer in relationship to the number of vehicles caught in DZ:
- A. The longer the maxout setting, the more is the number of vehicles caught in DZ
- B. The shorter the maxout setting, the more is the number of vehicles caught in DZ
- C. A shorter maxout setting gives you a better opportunity to minimize the number of vehicles caught in DZ
- D. A longer maxout setting gives you a better opportunity to minimize the number of vehicles caught in DZ
Reset Selection

Figure 14. Screenshot of One Question

4.3. Results and Discussion

328 and 174 valid data points were collected from students' gameplays in DZ-man and Angry Curves, respectively. 32 students finished the full package of DZ-man, and 17 students finished the full package of Angry Curves. 12 students finished both packages. The gameplay data were processed to represent the number of gameplays in each level for each student. The scores from the gameplay were not taken into account because the game playing skills were not the focus of this research. The gameplay data was linked to the quiz data and the students' final grades for this class and reformatted for the analysis in SAS JMP software [12].

The first analysis needed to be done was to test the effect of the gameplay for improving the students' learning outcomes. Matched pairs t-tests were conducted for both gameplay experiments. Figure 7 shows the results for the tests. Figure 7 a) shows the mean difference between the scores of pre- and post- quiz for DZ-man is 0.9375 at 0.0006 significant level; Figure 7 b) shows the mean difference between the scores of pre- and post- quiz for Angry Curves is 1.05882 at 0.0006 significant level. The results show both games can improve the students' understanding of the related concepts significantly.
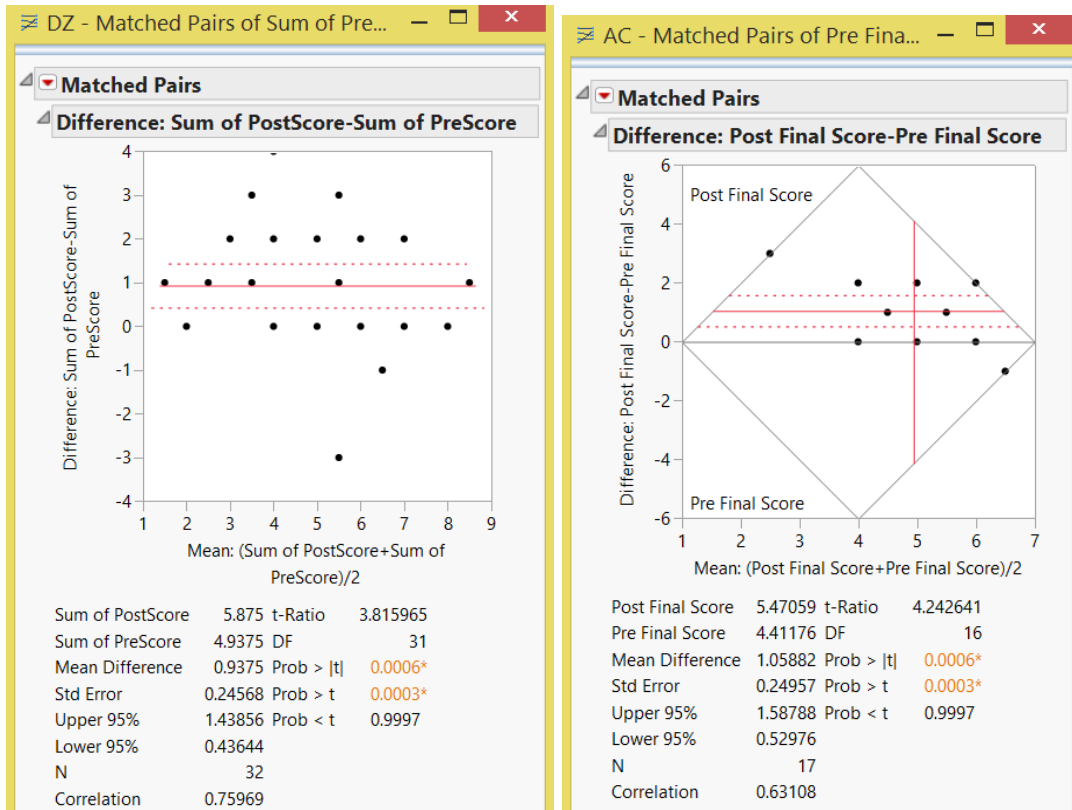
a)   b)

Figure 15. Matched Pairs T-Test for Both Games' Pre/Post Scores

Next, we looked at the features that can affect the students' engagement of the games. The number of gameplays were used as an indicator of engagement to show how interested the students were in each game. Figure 16 a) shows the average number of gameplays in each level. We can see a decreasing trend of engagement as the game level goes up, except for level 5. Then we look into how they are distributed in Figure 16 b). It can be clearly seen that there is an outlier in level 5 who played this level more than 25 times, so we excluded this data point. The revised number of gameplays in each level is shown in Figure 17. Now we can see a clearer trend of decreasing of number of gameplays in higher levels.
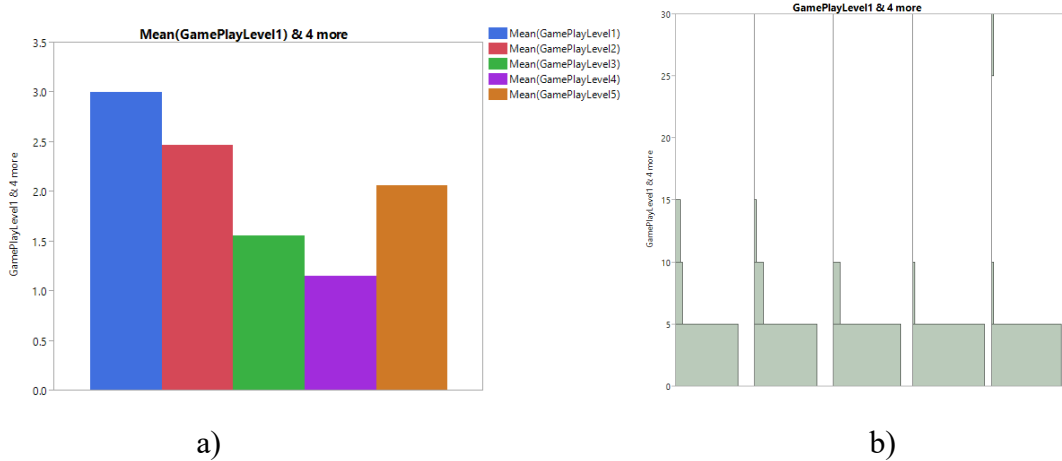
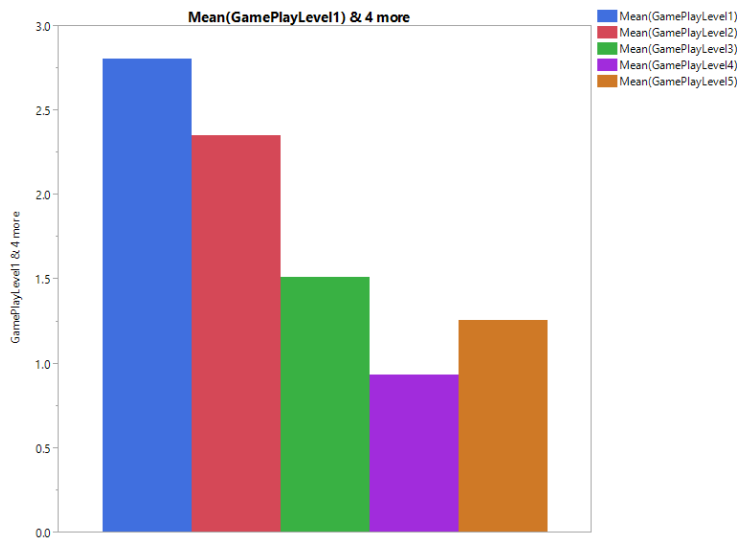Figure 16. Number of Gameplay v.s. Level Number in DZ-man

Figure 17. Number of Gameplay v.s. Level Number in DZ-man Excluding One Outlier

For the Angry Curves, there are only two levels, which provides us a more detailed way of visualizing it. Figure 18 shows each player's number of gameplays in each level. The horizontal axis shows the number of gameplays in level 1 and the vertical axis shows that in level 2. Each point shows one player's number of gameplays in each level. The red line indicates where the number of gameplays in level 1 equals to the one in level 2. It can be seen that most players play level 2 more than level 1. This is because comparing to DZ-man, Angry Curves is harder in term of understanding the gameplay (that is also the

reason why Angry Curves needs an introduction chapter to guide the players). The gap between players and the game is larger in the first level.
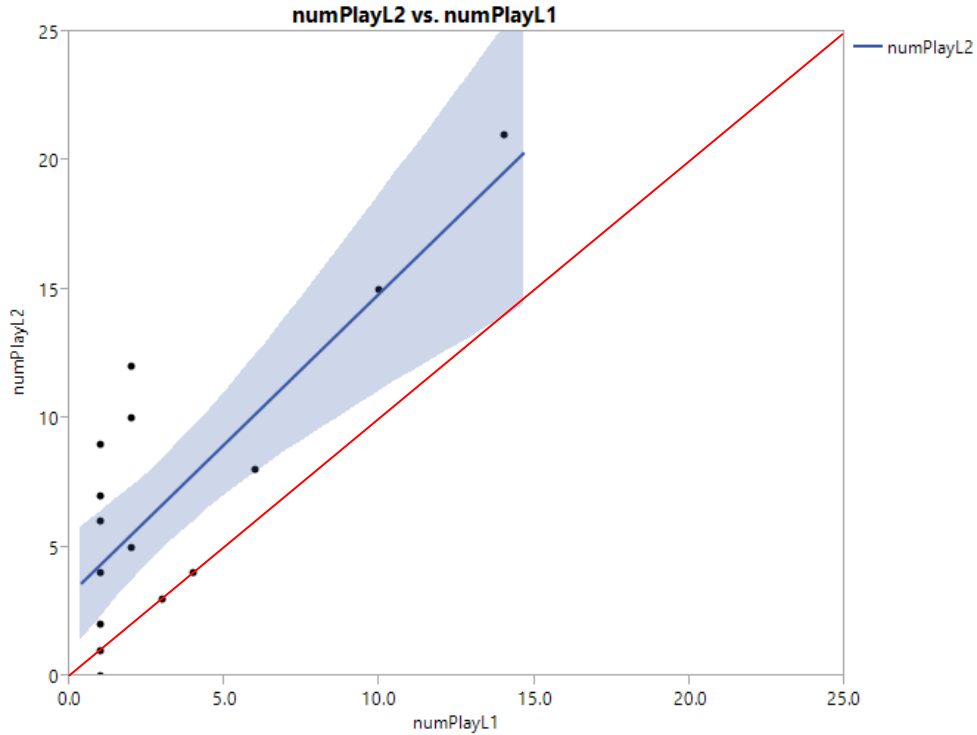

Figure 18. Number of Gameplays in Level 1 and 2 for Angry Curves

The engagement gravity model was calibrated with the formatted data. Figure 19 and Figure 20 show the results of the calibration. The intercept represent the p^e_{game} in equation 5. Because the purpose was to evaluate the games for comparison, the calibrated p^e_{game} should represent how an average student would engage in the game as a whole. So we shifted the final grade reference point to 85. Since the level number is a linear term, the parameters with the average of the numbers of the game should be able to represent the whole game's properties, so the level number was referenced to 3 and 1.5 for DZ-man and Angry Curves respectively. By doing so, the intercept, the p^e_{game} can represent the engagement to the game as a whole of a normal student with grade around 85.

Figure 19. Calibrated Model Parameters for DZ-man

Figure 20. Calibrated Model Parameters for Angry Curves

We can see that the students are more interested in the lower level of DZ-man. The sign of parameter for level is negative, which indicates in DZ-man, the higher level it is, the more new knowledge would be. While in Angry Curves, the sign of parameter for level is positive, which indicate the second level includes less information than level one. The reason is that in the first level, students need to get used to the gameplay and learn all the parameters for designing the curves, while in level two, only the constraint was added as a new information.

The different sign of the parameter for the final grade shows the difference of the fittest students group for the two different games. DZ-man can interest higher grade students more, while Angry Curves attracts lower grade students more.

Comparing the two games, Angry Curves has higher p_{game}^{e} than DZ-man. This means the design of the game Angry Curves is better than DZ-man in terms of students' engagement. The reason could be the better 3D modeling and more appealing UI in Angry Curves.

4.4. Conclusion and Future Work

In this work, two different games were designed and developed for two different topics within transportation engineering education. Two experiments were conducted with the two games. We also presented and customized a gravity model for evaluating the engagement of the students for the educational games. We found that different games have different properties in terms of attracting students' engagement. In this specific case, Angry Curves can attract students more than DZ-man. This also indicate that the UI design is an important factor in the educational game design—a point that should be paid more attention by the educators. Within the same game, it was found that students' engagement are different in different levels.

The significance of this work does not stop at comparing this two different games. It was found that the games can significantly improve the students' understanding of the targeting concepts. There should be more educational games developed for transportation education in the near future. With more development teams contributing to the educational game libraries, there will be more than one game designed for the same topic. This ranking and assessment framework can be used in education practice to select the most suitable game for the targeted group of students.

The future work needs more tests in a larger scale. Cross institutional collaboration and testing will be considered and pursued in the near future.

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5. Conclusion

In this work, I developed five web games targeting five topics in transportation engineering education. Before-and-after studies were conducted to test the effectiveness of the games in terms of improving the learning outcomes of the students. The results showed that the games could increase the students' understanding of hard concepts significantly. The developed games can be used in transportation education. This game framework can serve as a reference for other education game developers.

I also proposed a gravity model for evaluating the engagement of the students for the educational games. I found that different games have different properties in terms of attracting students' engagement. In a specific case, Angry Curves can attract students more than DZ-man. This also indicate that the UI design is an important factor in the educational game design—a point that should be paid more attention by the educators. The proposed model can be used in the future for "shopping" educational games for specific students group.

The work does not stop at the games. Web-games provide a potential to collect high-resolution data describing students' behavior. The state of students' understanding of the concepts can be better estimated by analyzing their gameplay data.

It should be noticed that the objective of the games was never to replace the traditional teaching approaches. An engineer should go through formal education and training to be able to serve the communities. A byproduct of this work is its contribution to the inclusive education. In an interdisciplinary work environment, the games can serve as a comfortable introduction to transportation engineering for the people outside of this field.