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A Knowledge-Delivery Gravity Model to Improve Game-Aided Pedagogy

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Dr. Abbas has wide experience as a practicing transportation engineer and a researcher. He was an Assistant Research Engineer and the Corridor Management Team Leader at Texas Transportation Institute (TTI), where he has worked for four years before joining Virginia Tech. Dr. Abbas conducted sponsored research of more than $720,000 as a principal investigator and more than $750,000 as a key researcher at TTI. After joining Virginia Tech, he has conducted over $2,400,000 worth of funded research, with a credit share of more than $1,750,000.

Dr. Abbas is an award recipient of $600,000 of the Federal Highway Administration Exploratory and Advanced Research (FHWA EAR). The objective of the FHWA EAR is to "research and develop projects that could lead to transformational changes and truly revolutionary advances in highway engineering and intermodal surface transportation in the United States." The award funded multidisciplinary research that utilizes traffic simulation and advanced artificial intelligence techniques. He has also conducted research for the National Cooperative Highway Research Program on developing "Traffic Control Strategies for Oversaturated conditions" and for the Virginia Transportation Research Council on "evaluation and recommendations for next generation control in Northern Virginia."

Dr. Abbas developed Purdue Real-Time Offset Transitioning Algorithm for Coordinating Traffic Signals (PRO-TRACTS) during his Ph.D. studies at Purdue University, bridging the gap between adaptive control systems and closed-loop systems. He has since developed and implemented several algorithms and systems in his areas of interest, including the Platoon Identification and Accommodation system (PIA), the Pattern Identification Logic for Offset Tuning (PILOT 05), the Supervisory Control Intelligent Adaptive Module (SCIAM), the Cabinet-in-the-loop (CabITL) simulation platform, the Intelligent Multi Objective Control Algorithms (I-MOCA), the Traffic Responsive Iterative Urban-Control Model for Pattern-matching and Hypercube Optimal Parameters Setup (TRIUMPH OPS), the Multi Attribute Decision-making Optimizer for Next-generation Network-upgrade and Assessment (MADONNA), and the Safety and Mobility Agent-based Reinforcement-learning Traffic Simulation Add-on Module (SMART SAM). He was also one of the key developers of the dilemma zone protection Detection Control System (D-CS) that was selected as one of the seven top research innovations and findings in the state of Texas for the year 2002.

Dr. Abbas served as the chair of the Institute of Transportation Engineers (ITE) traffic engineering council committee on "survey of the state of the practice on traffic responsive plan selection control." He is also a member of the Transportation Research Board (TRB) Traffic Signal Systems committee, Artificial Intelligence and Advanced Computing Applications committee, and the joint subcommittee on Intersection. In addition, he is currently a chair on a task group on Agent-based modeling and simulation as part of the TRB SimSub committee. He also serves as a CEE faculty senator at Virginia Tech.

Dr. Abbas is a recipient of the Oak Ridge National Lab Associated Universities (ORAU) Ralf E. Powe Junior Faculty Enhancement Award and the G. V. Loganathan Faculty Achievement Award for Excellence in Civil Engineering Education. He is also a recipient of the TTI/Trinity New Researcher Award for his significant contributions to the field of Intelligent Transportation Systems and Traffic Operations.

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A Knowledge-Delivery Gravity Model to Improve Game-Aided Pedagogy

Abstract

Teaching materials have evolved from mere text to multi- and hyper-media contents, leading to substantial growth in both information density and accessibility. One of the accompanying challenges with this evolution is the growing need to accurately quantify the degree of students' stimulation and engagement in this new environment. Game-aided pedagogy can stimulate students' interest and can complement their individual learning styles. It can also provide them with the appropriate amount of information density and accessibility, utilizing multimedia and hypermedia contents.

This paper introduces a gravity model to measure the level of students' engagement in game-aided pedagogy. The output of this model is the students' engagement. Information density, ability of students to absorb knowledge, and knowledge delivery are considered in this model as impact factors.

A multi-level web game was designed to enhance students' understanding of certain concepts in transportation engineering (driver behavior in dilemma zone) and is used as a platform for testing our proposed concept. Our objective is to increase the students' engagement and decrease the difficulty of knowledge-delivery. The game can simulate traffic operation scenarios and collect users' gameplay data using refined 3D scenes. Vivid scenes attract students and multi-level design increases the appeal of the game and thus can stimulate students. Gameplay data collected from users can monitor students' responses and gather their understanding of the delivered knowledge. This game has a "client" part and a "server" part. The client part interacts with students' operation and renders scenes, while the server part stores students' gameplay information and responds with different game levels accordingly. The client part was programmed with unity 3D and C# language together with HTML and Javascript. The server part was achieved by ASP.net and MS Access database. The output of this game can be used to assess the students' learning outcomes.

The result of this research can be used to quantify the students' engagement gravity model's parameters, which can in turn be used to guide the revision and development of the next generation game-aided pedagogy.

Keywords:
Game-Aided Pedagogy, Gravity Model, Learning Outcomes

1. Introduction

Teaching materials have evolved from word of mouth and mere text to multi- and hyper-media contents. The change behind the teaching materials is the increase of information density and accessibility. Recent decades' research in Game-Aided Pedagogy (GAP) also shows an increase of information density and accessibility of educational games compared to the other teaching media.

Simulations and computer educational games are treated as an efficient way for learning, at least since the 1970s[1]. Students' learning outcomes and engagement are both important. Our experience teaching several transportation classes suggest that students need significant out-of-classroom activities (e.g., simulation, games, tutorials) in order to grasp the disparate transportation subjects. However, if the students were not engaged/interested enough in these activities, they would complain and/or lose interest in pursuing transportation research. It is therefore very important to measure both the effectiveness and engagement level of activities.

We hypothesize that there is a relationship between the level of student engagement, the degree by which a game can be challenging, the student capacity, and the game content. For example, we hypothesize that an excellent student might be more intrigued by a more challenging game from which they can extract some new concepts. The objective of this research is to test this hypothesis and to quantify the relationship between the students' engagement and contributing factors. This relationship can then be used to guide the game design for GAP and examine the games' effectiveness for students' engagement and learning outcomes. In order to achieve this objective, we proposed a hypothesis and conducted an experiment to test and revise the hypothesis if needed. The hypothesized relationship is described in part 2.1. The design and implementation of the game used in the experiment can be found in part 2.2. The experiment is presented in part 2.3. The results and analysis are shown in part 3. Finally, the conclusion and future work are addressed in part 4.

2. Method

The methodology in this research focuses on three parts: (1) hypothesis of the relationship between the contributing parameters and students' engagement, (2) design of game in GAP, and (3) experiment. For the hypothesis, we propose a model contributes to students engagement with three parameters: student's learning capacity (using class score as a surrogate measure), knowledge encapsulated in the game (using the increase in students quiz score as a surrogate measure), and the game difficulty level. To test this hypothesis, a multi-level web game was designed to improve students' learning outcomes. In this case, the students' engagement was measured by the amount of time a student repeatedly played each game level. In the experiment, 40 undergraduate students volunteered to participate for extra credit. Their incremental increase in subject knowledge was measured by their performance in an un-timed quiz they took online both before and after playing the game. Their scores of the quiz and data uploaded by the web game were used to validate the model.

2.1 Knowledge-Delivery Gravity Model

The concept of gravity model was first addressed in physics to describe the gravitational force of planets. Then analogy of gravity model was used in economics and land use studies [2-4]. In transportation planning, the same philosophy was used to measure the attraction of one area to another area[4]. In general, gravity model could describe the impact from one object to another object. The original gravity model in physics is

$$F_{a,b} = G\frac{M_a \times M_b}{D_{a,b}^2} \qquad (1)$$

Where,

$F_{a,b}$ = gravitational force between object a and object b,

G = coefficient,

M_a = mass of object a,

M_b = mass of object b, and

$D_{a,b}$ = distance between object a and object b.

In the context of student's learning process, there are two objects that can have an impact on one another: knowledge source (educators, reading materials, game for GAP, etc.) and student. The attraction between these two objects would result in the interest or level of engagement. The amount of new knowledge that need to be delivered to the student is the distance between the two objects. We hypothesize that we can use this modeling framework to predict the level of students' engagement. The proposed relationship is shown in equation (2) below.

Based on the discussion above, we introduced the knowledge-delivery gravity model which is

$$E = C\frac{P_{source} \oplus P_{student}}{\mathrm{D}} \quad (2)$$

where

E = student's engagement,
C = coefficient factor,
P_{source} = properties of knowledge source,
$P_{student}$ = properties of a student, and
D = new knowledge.

The output of this model is the level of engagement. Properties of knowledge source, properties of a student, and new knowledge are considered in this model as impact factors. In this case, we take information density (game level), ability of students to absorb knowledge (students grades), and the amount of new knowledge (increase in quiz score) as the representatives of properties of knowledge source, properties of a student, and new knowledge, respectively. It should be noted that the relationship between these factors is not necessarily in the form of multiplication, but is left for the model to determine.

2.2 Game Design

A. Function Design

Dilemma zone and delay are two important concepts in traffic signal control. Dilemma zone is a zone before signalized intersections where drivers have difficulty deciding whether to continue passing the intersection or stop when the signal turns yellow. There is a dilemma because if the driver misjudges the safety of going through the intersection during the available yellow duration, he/she run the red-light and might have a side collision with vehicle from the conflicting directions. If the driver stops, the following car might continue and end up with a rear-end collision. Delay is extra time vehicles experience due to the existence of the traffic signal compared to free flow driving. Dilemma zones represent a safety issue while delay represents efficiency issue. In the real world, intelligent signal controllers are designed to allocate green times for each phase to minimize the number of vehicles caught in dilemma zone as well as minimizing total delay. A player trying to mimic the operation of an intelligent controller would have to end the green time (in our game, by pressing on a button) just at the right time in order to minimize catching vehicles in dilemma zone. Avoiding catching vehicles in dilemma zone entails ending the green when vehicles are either too far (leading to a definite stop) or too close (leading to definite pass). The duration of green time at each signal phase results in different amount of total delay at the intersection. A phase that gets more green than other phases typically gets less delay.

To illustrate these concepts, reproduce the scenario, and get students involved in the control process, we designed a multi-level web game for GAP. Considering the student engagement gravity model, the game was designed as a multi-level 3D game to increase students' interest and make the scenario easier to understand. Naturally, people learn by interacting with environment[5]. In the design of this game, we created a virtual environment which can be explored by students and provide them with feedback. Specifically, this game demonstrates a scenario of a signalized intersection as shown in Figure 1.

Figure 1. Game User Interface

The GUI includes three groups. The left panel shows the current scenario settings state. It gives players instructions to configure maximum and minimum green times and inform players about the traffic level in the current level. The middle panel shows a counter that shows the time left to max out of green. It starts from maximum green time and counts down to 0. The right panel group shows the name of player, current level of the game, current level feedback (number of vehicles caught in dilemma zone and delay), historical scores (accumulated and average number of vehicles caught in dilemma zone and delay in the current level), configuration of the controller (maximum green time, minimum green time), and control button (stop, re-play current level, next level).

Students can change the configuration of the controller, stop green, and can navigate the scene. Students can only stop green between the minimum and maximum green times. When the green time is less than the minimum green time, the stop button is deactivated. When green time reaches the maximum green time, the counter shows 0, and the phase changing procedure will be activated. In the phase changing procedure, the green stops, and the signal light would change to yellow and then red; most vehicles would slow down except for the vehicles which have already passed the dilemma zone; the vehicles caught in dilemma zone will change their main color to red while others will change to green; and the control panel shows the number of vehicles caught in dilemma zone and the total delay for the current signal timing. Green vehicles represent safe vehicles in terms of dilemma zone issue. Students can adjust the camera and navigate the scene to get a better view so that they can make a better decision. For a better understanding of the gameplay operation, the control flow chart is shown in Figure 2.

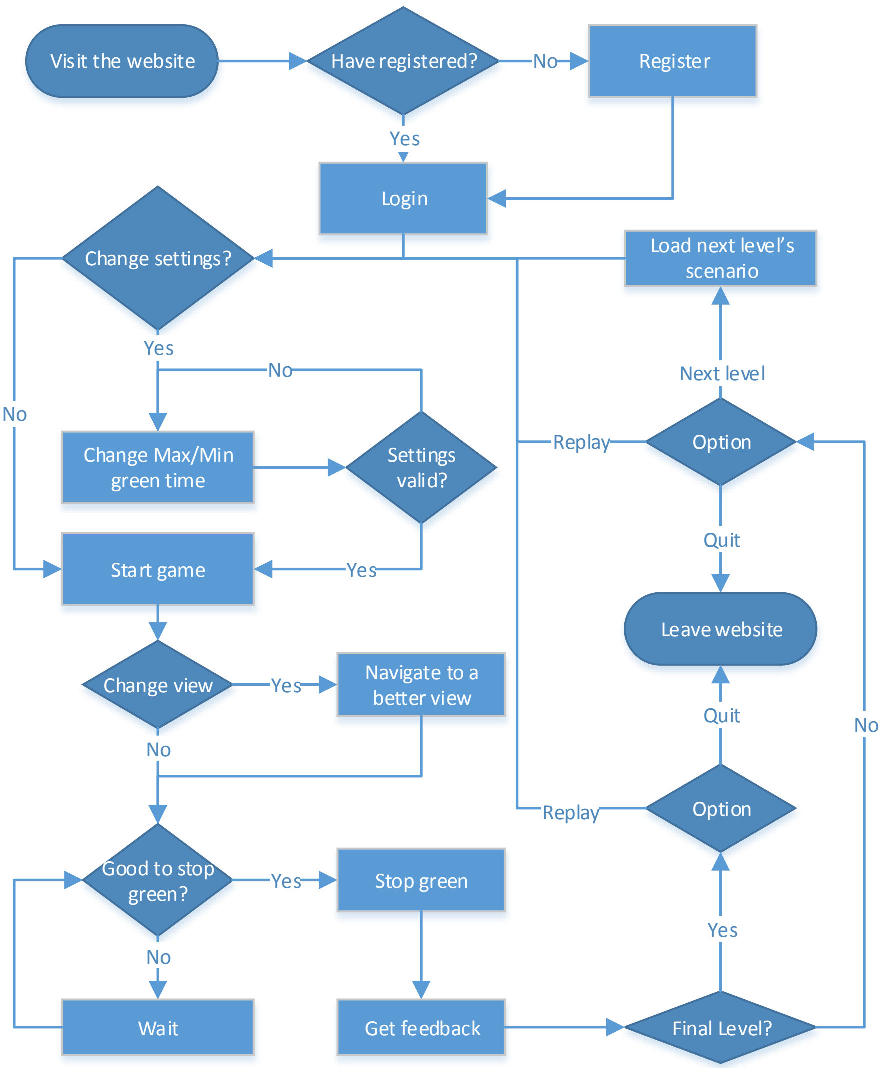

Figure 2. Game Control Flow Chart

In addition, researchers are able to get the game data of students. The game data include scenarios that every student player experienced, the play and settings data, and their score for each trial. With these data, statistical analysis can be conducted.

B. Implementation

To achieve the functionality of the game, we built a "fat client" system (where most of the process is implemented at the client side). The architecture of the game system is shown in Figure 3.

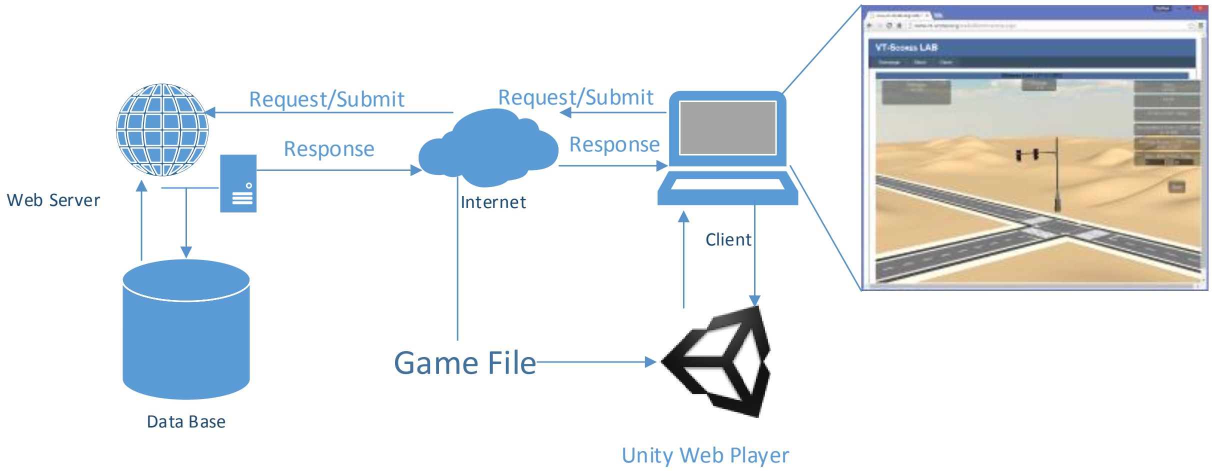

Figure 3. Architecture of the Game System

The game is embedded in the web page, but all the functions and visualization of the game is achieved by the Unity Web Player. The Unity Web Player is a plugin of browser that is suitable for multiple browser (e.g., Internet Explorer, Firefox, Chrome, Safari, Opera). The client requests the game file from the web server. After the game file is cached from the server, the Unity Web Player will interpret the file and run the game. In the client part, we use HTML and javascript to host the web page and introduce the Unity Web Player. The Unity Web Player renders the scene, reacts to the operation of players, and communicates with the web server. The client part of the game is programmed with C#, but the game file is compounded with C# script, 3D models, and textures etc. The web server part is implemented in ASP.net together with MS Access as database. It responds to requests from the client and stores data if necessary (e.g., register data, gameplay data).

In order to prevent boring students, the scenario is different each time the student plays. This is achieved by random arrivals of vehicles. The arrivals of vehicles follow Poisson distribution with the parameter of traffic flow. The random number seeds of each level is uploaded and stored in the database so that the scenario can be regenerated by the researcher.

To mimic a real scenario, we put a queue before the intersection at the beginning of green and use a car-following model to simulate the driving behavior. When the green starts, vehicles start accelerating one by one. The arriving vehicle will slow down if the queue has not been discharged.

Two tables are used to store data in web server (shown in Table 1, Table 2). The user information table is used to store registered user's login information. When a student registers for playing game, a record will be inserted and would be used to verify students' identity when they try to login. The gameplay table is used to record all the gameplay data for each play. From this table, students' effective operations and performances can be observed.

Table 1. User Information Table

Field	Data Type	Meaning
ID	AutoNumber	key
UserID	Short Text	Player's user name
psw	Short Text	Player's password

Table 2. Gameplay Table

Field	Data Type	Meaning
no	AutoNumber	key
UserID	Short Text	Player's user name
_level	Number	Level of this record
_DZ	Number	Number of vehicles caught in dilemma zone
_delay	Number	Total delay in the current signal timing
_logTime	Date/Time	Time of uploading this record
_seed1	Number	Seed of random number for lane 1
_seed2	Number	Seed of random number for lane 2
_timeleft	Number	Time left before max out
max_time	Number	Maximum green time
_angle	Number	User's camera angle
_zoom	Number	User's field of view

2.3 Experiment

The sample of this experiment consists of 40 undergraduate engineering students enrolled in the class of Introduction to Transportation Engineering. The experiment was approved by the Institution Review Board (IRB). The students taking the experiment were given extra credit regardless of how well they did.

The students were asked to take an untimed quiz of 10 questions before the game (two questions related to each level of the game), played the game, and took the same quiz again. Students were not able to see their scores in the quiz. This was done intentionally so that we could safely attribute the improvement in quiz scores to game play. The quiz was designed by the research team with questions that are related to the concepts that students need to learn from different levels of the game. The experiment was conducted at a weekend before the end of semester. All of the experiment was conducted online. The chosen location and time to participate in the experiment was flexible. Each student was given enough time to explore and play the game. The questions are in the form of multiple choice which is objective and easy to manage. An example of a question is shown in Figure 4.

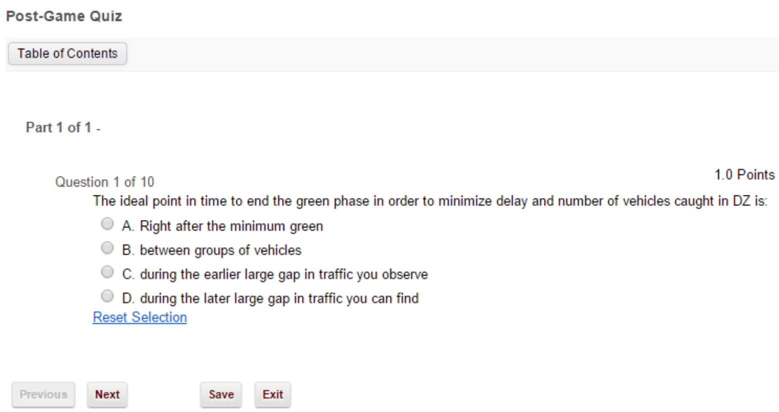

Figure 4. Screenshot of One Question

3. Result and Discussion

608 data points were collected from the game server, showing 608 trials by different students. This data was combined with the quiz data and formatted for analysis in SAS JMP software [6]. The first analysis we conducted is shown in Figure 5, where a matched pairs t-test was used to test the significance of playing the game using repeated measures analysis. The mean difference shown in the figure is 0.95, which is significant at the 0.0051 level. This result shows that playing the game significantly improved the quiz scores as a whole.

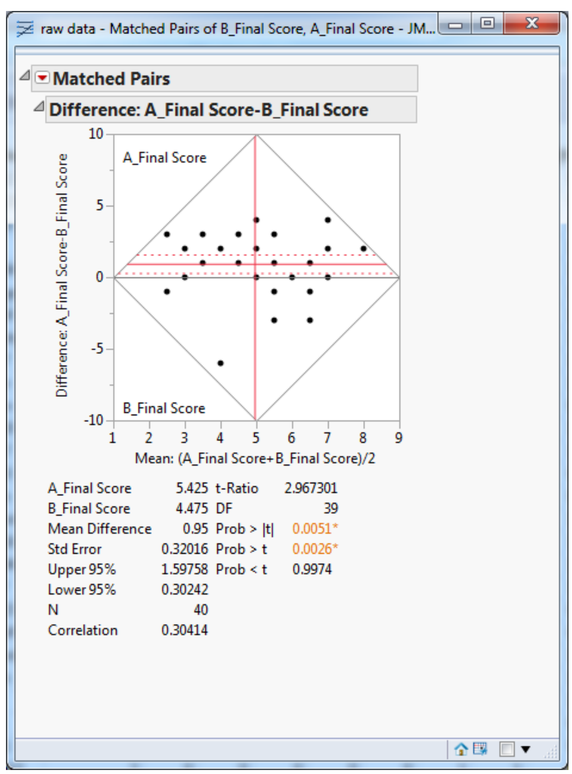

Figure 5. Matched Pairs Analysis

Next, we conducted a screening analysis to determine the correlation between each factor. A visual display of the number of times a student played (surrogate for engagement), student's final score in the class (surrogate for their learning capacity), and game level (surrogate for information intensity) is shown in Figure 6. It can be observed in the figure that the engagement of students with a final score of less than 80 (C students) had a different pattern from students who have a final score that surpassed 80 (A and B students). This is one preliminary finding of this research and could be interpreted as that less prepared students (e.g., C students) found equivalent stimulation in all levels of the game, whereas better prepared students could only be stimulated by levels of the game that provided information they did not already know. It should also be noted that different students were more stimulated by different levels, which can be interpreted as that different students needed better clarifications of different concepts. For the following analysis, we focus on the right cluster of the data in Figure 6 to further examine the proposed gravity model.

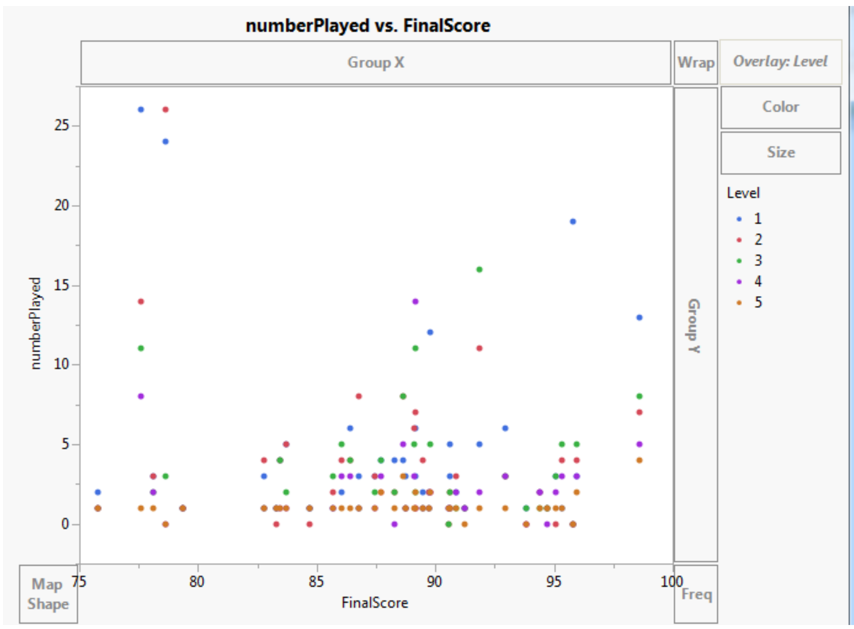

Figure 6. Screening Analysis with Scatter Plot

Figure 7 and Figure 8 show the leverage plot and significance statistics, respectively. Both figures show that the proposed model with numberPlayed as a dependent variable, and finalScore, level, and scoreIncrease as input variables is significant at the 0.0006 level. Next, we repeated the analysis after removing all insignificant factors and interactions and keeping the three input variables only. The results shown in Figure 9 indicate that the student finalScore and Level were significant. The scoreIncrease, variable measuring the amount of new knowledge was not significant. This might be due to the limited amount of quiz data and should be tested in future research.

Whole Model

Actual by Predicted Plot

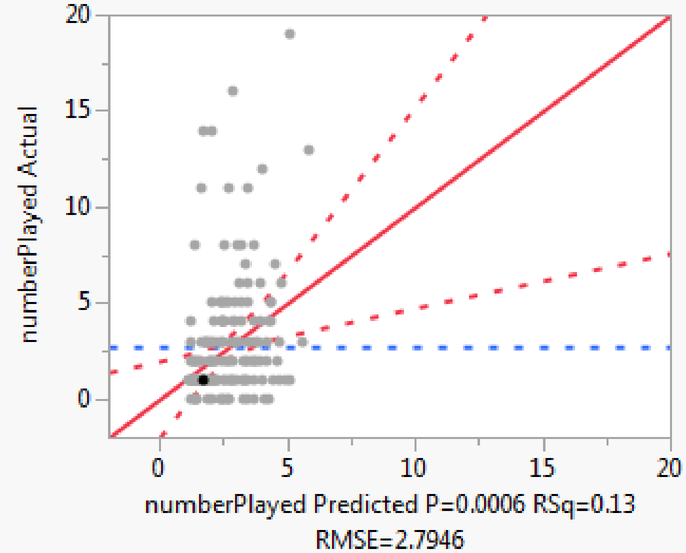

Figure 7. Leverage Plot

Summary of Fit

RSquare	0.130248
RSquare Adj	0.099186
Root Mean Square Error	2.794619
Mean of Response	2.702857
Observations (or Sum Wgts)	175

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	6	196.4861	32.7477	4.1931
Error	168	1312.0625	7.8099	Prob > F
C. Total	174	1508.5486		0.0006*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-3.585963	4.797159	-0.75	0.4558
FinalScore	0.0924476	0.053153	1.74	0.0838
Level	-0.678338	0.149428	-4.54	<.0001*
ScoreIncrease	0.1164844	0.246916	0.47	0.6377
(FinalScore-89.7853)*(Level-3)	-0.04173	0.038332	-1.09	0.2779
(FinalScore-89.7853)*(ScoreIncrease-0.19429)	0.0139849	0.064211	0.22	0.8279
(Level-3)*(ScoreIncrease-0.19429)	-0.020415	0.181312	-0.11	0.9105

Figure 8. Significance Testing

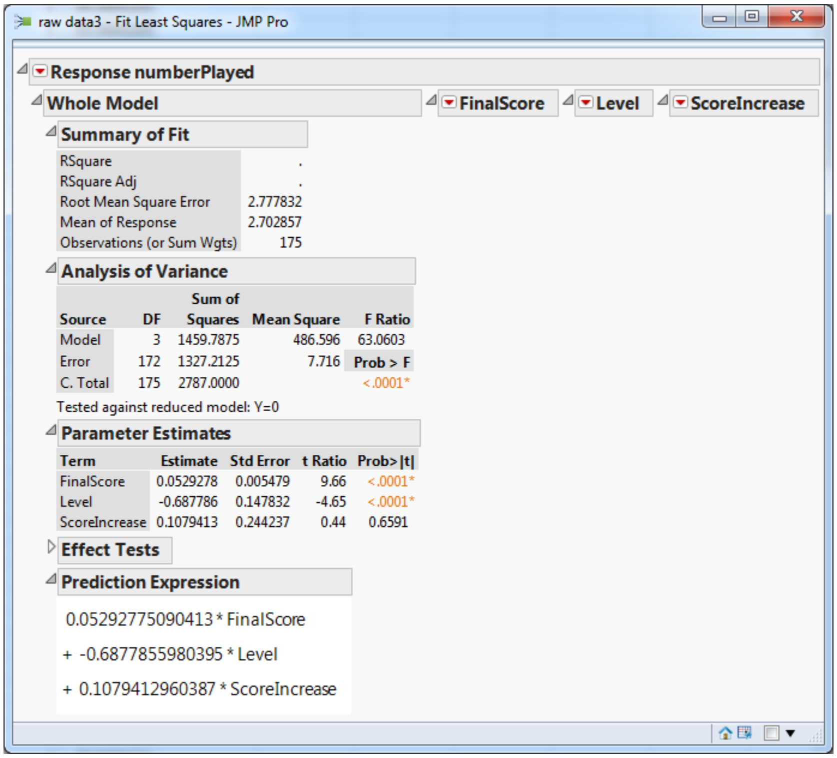

Figure 9. Model Parameters

Figure 9 also shows the prediction expression of the proposed gravity model for the selected sample. The positive sign associated with the final score indicates that the better the student the more they are likely to show more interest and engagement. The negative sign in game level shows that less incremental interesting information was provided in each further level. The positive sign associated with the scoreIncrease suggests that the more information density available in the game, the more interest and students' engagement it triggers.

4. Conclusion and Future Work

In this paper, we introduced a student's engagement gravity model to improve GAP. In the guidance of this model, a multi-level web game was designed, developed and deployed. Then we conducted an experiment to examine the effectiveness of this game. The results showed that:

1- The game was effective in improving students learning
2- C students were equally stimulated by all levels of the game
3- A and B students were stimulated by levels of the game that provided information they did not already know.
4- Different students were stimulated differently by different levels
5- The proposed gravity model was found significant
6- Students learning capacity and game level were found significant

The next step of this research is to examine the impact of more microscopic behaviors of students in GAP. A wider range of experiments need to be conducted to achieve a better calibration of the proposed gravity model.

Acknowledgement

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