AC 2009-2145: USING GAMING AND MOTION SIMULATION TO ENHANCE VEHICLE-DYNAMICS EDUCATION

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Abstract

Engineering educators are faced with an ongoing challenge of creating engaging, student-centered learning situations in post-secondary education. With the broad availability of visually engaging and fast-paced games, contemporary students can find traditional classroom methods of lecture and guided laboratory experiments limiting. This paper presents a novel methodology that incorporates driving simulation, motion simulation, and educational practices into an engaging, gaming-inspired simulation framework for a vehicle dynamics curriculum. The research places students into a gaming scenario where learning occurs during game play, rather than using a formally structured learning approach to vehicle dynamics. The application of the methodology is demonstrated in the context of an advanced vehicle dynamics course. This paper reports on work done under National Science Foundation grant DUE-0633596 in the Course, Curriculum, and Laboratory Improvement program.

Introduction

Engineering education focuses on helping students to learn about the mechanisms that underlie phenomena and try to use that knowledge to improve our condition in life. One of the most difficult tasks in engineering education is developing student understanding of the relationship between real-world phenomena and analytical models of the underlying theory. Using abstractions (e.g., equations and graphs) can help students advance their knowledge, but do not provide a concrete relationship between theory and application. A significant focus of a student's education is learning how to work in a world of equations and graphs while applying the results to real-world products and systems. The President's Information Technology Advisory Council (PITAC) addressed this challenge by recommending the development of technologies for education and training that use simulation, visualization, and gaming to actively engage students in the learning experience.[1] In the same report, PITAC also recommended the development of educational experiences that provide learners with access to world-class facilities and experiences using either actual or simulated devices.

The traditional view of engineering classrooms does not take advantage of advances in visualization and gaming, with the instructor in the front of the room, lecturing at students, providing information while the students take notes.[2] This approach does not actively engage students in the learning process by challenging their conceptions and requiring them to develop creative solutions to problems. The Accreditation Board for Engineering and Technology (ABET) has adjusted their accreditation to include that students learn communication and teamwork as a part of their engineering studies.[3] The gaming-based approach presented in this paper builds on a simulation framework for vehicle dynamics education that was developed as an innovative means of incorporating items from the ABET criteria to assist in the development of educational experiences that will translate well to industrial application. The research presented also uses guidance from the National Survey of Student Engagement (NSEE) to develop an engaging learning environment.[4] A point common to both the ABET criteria and the NSEE is that students should both study the theoretical basis for phenomena and practice the application of their knowledge in an active manner that is similar to what they will experience after college.

As suggested by PITAC, simulation can be used to actively engage learners. The working definition used in this work is that simulation is “the process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behavior of the system or evaluating various strategies for the operation of the system”. Simulation enables a designer to explore the merits of alternative designs without physically building the system, reducing development cost and the risk associated with some forms of physical testing. In engineering education, simulation can be used as an engaging tool to teach students important concepts as well as demonstrate the potential application of industrial simulation in product development.

This paper presents the development and evaluation of a learning environment that provides a game-based context for vehicle dynamics education. Driving-game based approaches have been developed for research applications (mental health, driver workload, and rehabilitation applications, gaming-based contexts have not been used in vehicle dynamics education. The presented work describes an innovative methodology for coupling gaming, motion simulation, and educational practices together in a cohesive pedagogical approach. The approach is designed to enhance learning about road vehicle dynamics through active student participation in authentic engineering experiences for learning about dynamic systems.

The most engaging environment for vehicle dynamics education would have students driving real vehicles, performing specific driving maneuvers, and collecting performance data using instrumentation. After modifying the vehicle, students could collect additional data and investigate the changes in its characteristics. Concerns about cost, time, space, safety and weather make this impractical at most schools. However, many students have already experienced controlling a sophisticated driving simulation environment in the form of a driving game (e.g.,Gran Turismo 4[5] or Race Pro[6]). Students do not typically associate the gaming environment with the models equations that engineers use in designing a vehicle because they view game play and learning as mutually exclusive activities.

Rather than focus on guided inquiry to educate students about vehicle dynamics, the research effort presented here focuses on creating a situated learning environment, where new educational material is presented in an authentic context, and social interaction and collaboration are required for learning to occur. Students use a gaming-inspired application of a vehicle simulation framework to discover the impact that design decisions have on a dynamic system. The methodology is evaluated using a custom-developed gaming implementation that can also be adapted in the future to incorporate higher fidelity visualization and analysis engines.

Simulation Framework

The gaming scenarios are based on a framework developed to couple motion simulation, large scale visualization, and realistic vehicle dynamics into an integrated environment[7]. Figure 1 shows the driving simulation facility used in this work. The vehicle cabin is mounted on a motion platform, and students control the game from inside the vehicle. Each gaming scenario is configured from a control booth that is also used to monitor student performance in real time. The motion platform converts incoming messages, resulting from student input, into commands for the actuators that move the top of the platform. The motion of the vehicle cabin is coupled with the display of a virtual world on a large screen in front of the driver. Example scenes from these virtual worlds are shown in Figure 2. Example scenarios include a skidpad for guided inquiry exercises, a section of local roads for sample test drives, to a racetrack for aggressive gaming situations. Each scenario has a different educational goal that is incorporated into the game score.

Figure 1. Driving Simulation Facility

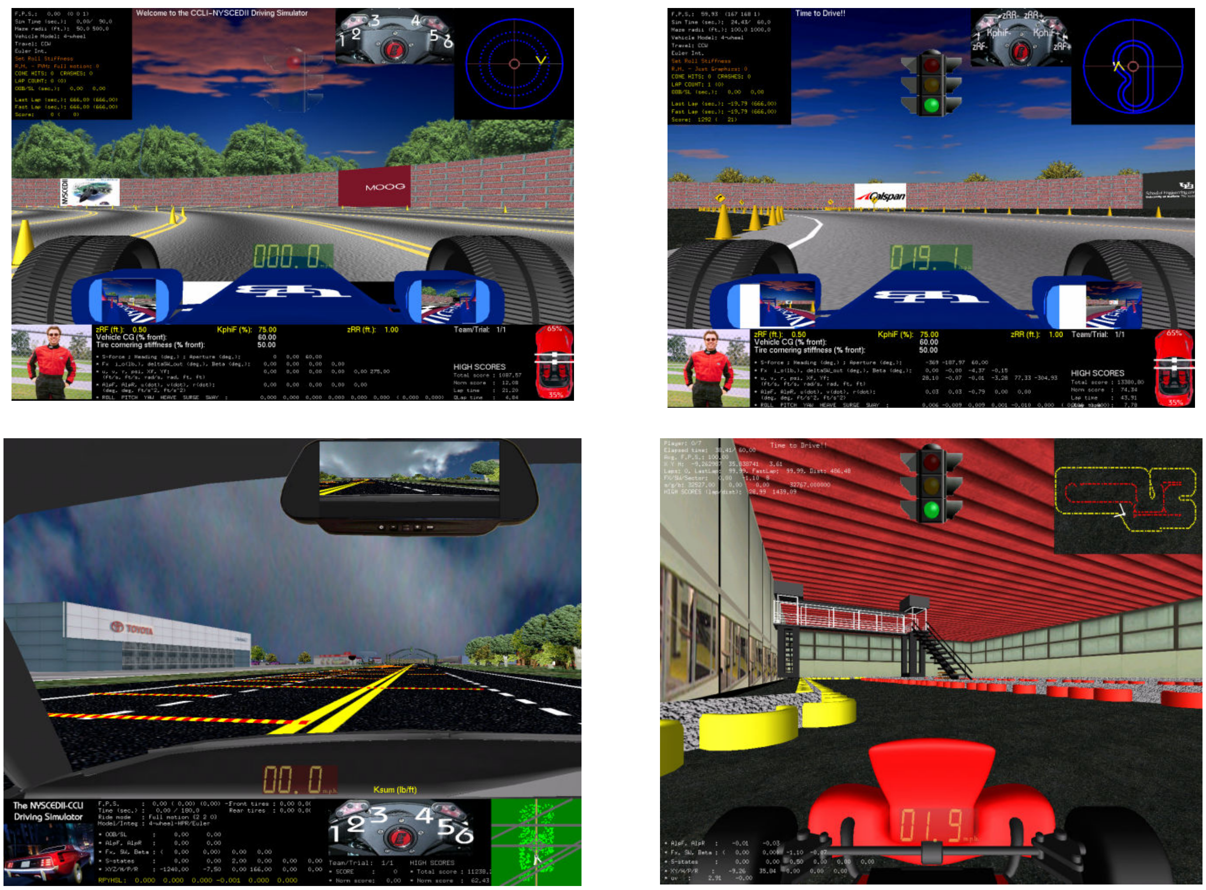

Figure 2. Screen captures from Serious Game driving simulation scenarios (Clockwise, from Top Left: Experiment 1 (“Skid Pad”), Experiment 2 (“Tri-Radii”), Experiment 3 (“Millersport”), and Future Work (“Networked Karting”)

High-fidelity driving games (e.g., Gran Turismo[5]) may seem well suited to direct incorporation into a course. These games are commercially available at low cost, require minimal hardware, and using gaming interfaces that many students are familiar with from their leisure time. In order to make games more accessible, often vehicle parameters are lumped into terms like "responsiveness". These terms make it easier for players to use the game, but can create difficulties in relating theoretical background to direct application, information is literally lost in the translation. As a result, the incorporation of these games would require significant adaptation of the content being taught in the course. There is clearly a need for a pedagogically sound learning environment that allows for the creation of custom learning scenarios that are designed to focus student's attention on the system dynamics, rather than the outcome of a particular race. This work develops an engaging simulation game that focuses on the differences between different simulation models (i.e., physics engines), to enable students to develop a better understanding of the information available as engineers make decisions at different stages of a vehicle design project.

The simulation framework is incorporated into a two-course sequence of technical electives on automobile vehicle dynamics, "Road Vehicle Dynamics 1 and 2" (RVD 1 and 2). Open to both undergraduate and graduate students, RVD 1 has a typical enrollment of approximately 70 students and RVD 2 has a typical enrollment of over 40 students. The incorporation of the framework into RVD 1, an introductory course on the basics of automobile motion, stability and control, was discussed in a previous paper.[7] This work focused on the incorporation of the framework as a guided inquiry tool for learning. Learning modules included tire performance and modeling, exploration of the elementary "Bicycle Model" of vehicle dynamics, and the vehicle dynamics associated with the more detailed "Four Wheel Model".[8]

Exploring advanced techniques such as quasi-static vehicle analysis, RVD 2 builds on RVD 1. The course emphasizes the impacts of suspension design, including ride comfort and handling. Students investigate the oscillations of the sprung and unsprung masses. Taught in a more open-ended format than RVD 1, the course incorporates independent student learning, with several paper reviews, in-class presentations and projects throughout the semester. Dr. Kasprzak taught this course in Spring 2007, Spring 2008, and is adapting the material for a System Dynamics course in Spring 2009.

High-Fidelity Simulation, Advanced Gaming Setting

The scenarios incorporated into RVD 2 provided a more advanced context for student learning. Each scenario gave the student specific tasks to accomplish during gameplay to achieve a high score. While attempting to get a high score, students would experience vehicle performance changes resulting from changes in vehicle parameters. For the gaming experiment, two changes were made to the vehicle model to increase the fidelity of the dynamics model. In the gaming sessions, rather than use a linear tire model the vehicle used a nonlinear and load sensitive model.[9] Based on tire data collected at the Calspan Tire Research Facility[10] for the FSAE Tire Test Consortium[11], this model provides students with more realistic tire behavior. The nondimensional tire model represents tire lateral force as a function of vehicle slip angle and normal load. In addition, the tire "friction-ellipse" effect seen in real tires is incorporated as well. The second modification is the use of a different vehicle dynamics model. The guided inquiry experiments in RVD 1 used a simple Bicycle Model of the vehicle. The gaming model used a realistic four-wheel vehicle model, including lateral and longitudinal load transfer based on vehicle lateral and longitudinal accelerations[9]. This model is coupled with the load sensitive tire model to provide a much higher fidelity vehicle dynamics model. Vehicle suspension characteristics could be changed by adjusting the roll stiffness distribution and front/rear roll center heights. The resulting vehicle model has moderate complexity when compared to comprehensive vehicle simulations, but provides sufficient complexity for a learning tool without overwhelming students with information.

The first scenario brings students back to the skidpad they experiences as part of RVD 1. This scenario provides students with an opportunity to focus on familiarizing themselves with the new vehicle model. Each student drives a baseline vehicle at ever increasing speeds up to the limit, all the while being conscious of how much steering is required to stay on the circular skidpad. Then, one of the parameters (roll stiffness distribution, front roll center height or rear roll center height) is set to a new parameter and the student is asked to describe the effect of this change. Figure 3 shows a typical understeer gradient plot from this task. In this figure the ends are noticeably curved, reflecting the effect of the nonlinear tire model. Students universally commented on how much more realistic this model felt compared against the bicycle model with its linear tire model.

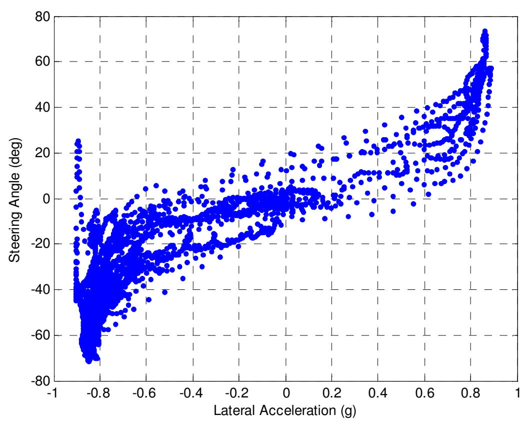

Figure 3. Plot for determining understeer gradient.

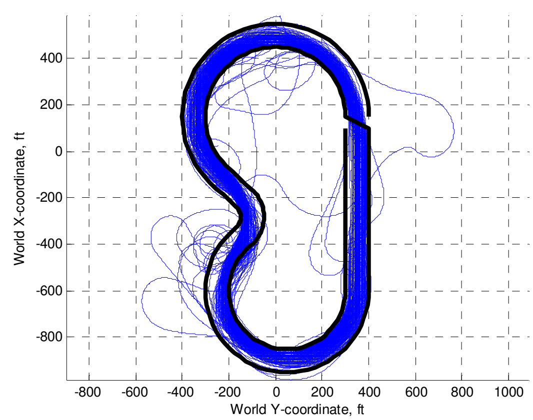

Figure 4. Student vehicle paths plotted on the Tri-Radial Speedway

As they completed the first scenario, students also could change the values of the vehicle parameters while driving. Using three thumb-activated buttons on each side of the steering wheel, roll stiffness distribution, front roll center height and rear roll center height could be adjusted. Pressing a right side button increased the value, and pressing a left side button decreased the value. For each session, students were allowed to adjust one parameter (each group of students explored all three parameters). Once the student had completed the understeer gradient part of the first scenario, they were asked to adjust the parameter to experience its effects on vehicle handling, and then to determine an optimum parameter to achieve the highest score (based on speed) on the skidpad. This proved to be a very instructive tool, as students quickly learned how a change in a vehicle parameter resulted in a change in vehicle performance, in what direction and in what magnitude.

The second and third scenarios introduced students to a racetrack, the "Tri-Radial Speedway". This track has three corners, each with a different radius, and a long straightaway. Each scenario challenged the students to complete the track circuit in the least time possible as they would experience in a regular driving game. The paths students took are plotted on Figure 4, including when students left the course. Students drive around the course in a counterclockwise direction.

Task 2 focused on acclimating students to the vehicle performance and learning how to drive around a racetrack. The car students were provided with in Task 2 did not allow any adjustments, providing a baseline challenge based on student driving skills. As students played this game, they learned how to navigate the track, including developing reference points for braking and driving lines through the curves..The large number of off-course excursions at the right hand corner indicate that students had to learn how to drive around the track for the fastest time. Almost every driver overshot the right hand turn on their first lap. After completing a few circuits, most students could successfully drive the course. More practice was required to improve lap times. Students adapted to the simulation very quickly, apparently due to their experience playing video games

While students were learning to navigate the track, students also had the opportunity to familiarize themselves with the vehicle performance. Instead of driving at a constant speed, as they would on a skidpad, on the course students were constantly changing speed and direction. With the more advanced vehicle model, a load transfer occurs to the front of the vehicle under braking, which can destabilize the vehicle. As students entered the first turn too quickly (at the top of Figure 4), some applied too much braking and spun out. Though at the time they may not have been able to use the exact terminology to describe the phenomenon, students also experienced lateral force rolloff, the reduction in lateral force that results from large tractive or braking forces. Students applying too much throttle entering the straightaway found the rear of the vehicle difficult to control. The motion platform also provided students with the feeling of driving around the course as it responded to simulate the vehicle's roll and pitch as the students drove around the track.

The second challenge at the "Tri-Radial Speedway" provided students with the capability of adjusting a vehicle parameter while driving to get a better time than they could with the original vehicle. This activity forced students to perform a trade-off in setting up and driving the vehicle around the track. Rather than listen to a lecture, to achieve the fastest time, students had to trade steady-state cornering with stability in a turn. Students also learned that though some settings may theoretically give the best performance with a perfect driver, those settings did not provide enough margin for error when they drove around the course. This experience provided insight that the ability of the driver must also be considered when designing a vehicle.

After students finished driving the course in Task 3, they performed analysis on the resulting data in the same way they would if they had driven an actual car. Figure 5 shows a g-g diagram for a smooth driver over four laps on the course.[8] This plot of planar vehicle accelerations illustrates how much time the vehicle spends at the lateral acceleration limits for this vehicle (appx. 0.9 g). Figure 6 presents a CN-AY diagram for the same driver.[8] This diagram presents yaw acceleration vs. lateral acceleration, and a smooth driver will have very small values on the y-axis.

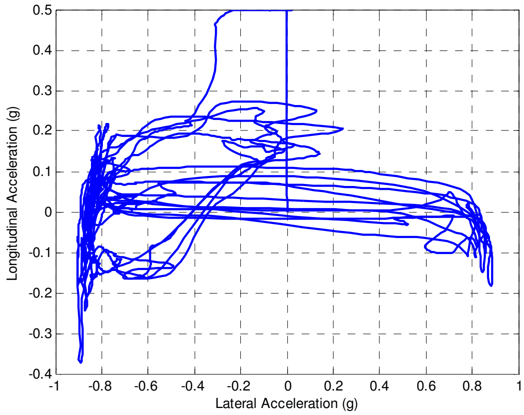

Figure 5. g-g diagram for a smooth driver over four laps

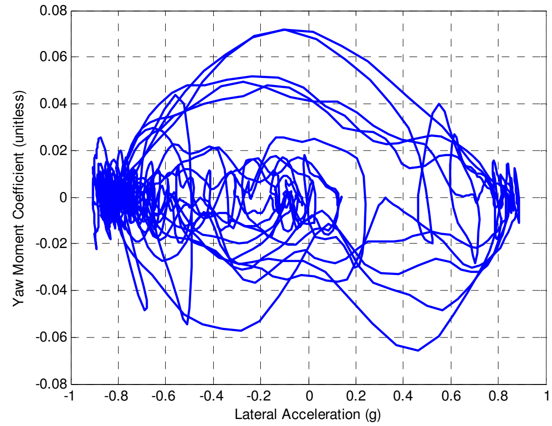

Figure 6. CN-AY diagram for a smooth driver

Figures 7 and 8 show similar figures for a driver who is not as precise over the course of four laps. This data includes one spinout. Compared with the previous driver there is no distinct pattern in these plots. The first driver's data is more in line with what a professional proving ground driver or race driver would produce from in-car measurements.

After the experiment, the students were able to analyze data from their own driving and the driving of the other students in their group. Students developed correlations between their comments while performing the experiment with the measured data. After completing the scenarios, students had learned about roll stiffness distribution, roll center heights, friction ellipse effects, weight transfer, dropped-throttle oversteer, g-g diagrams, and moment method (CN-AY) diagrams. Rather than learn by listening to a lecture, students actively participated in the process, conducting the experiments and a post-processing of the data they generated in the same way they would in industry.

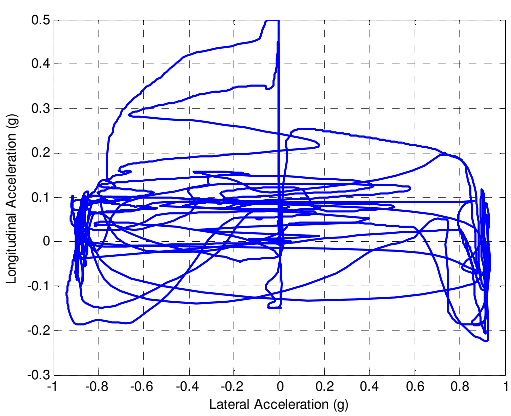

Figure 7. g-g diagram for a less-smooth driver

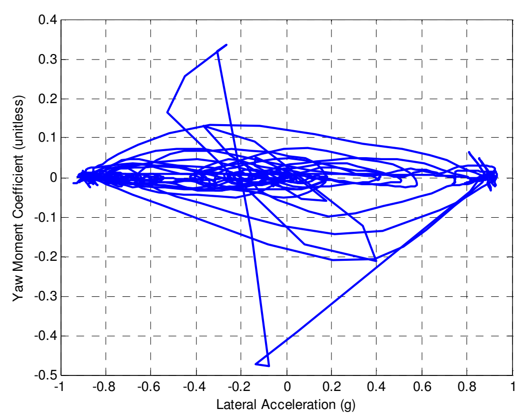

Figure 8. CN-AY for a less-smooth driver

Assessment

A total of 41 students participated in the experiments, separated into 8 groups. Each group spent an hour with the motion simulation system performing the three specific driving tasks. At the end of the experiment each group received a copy of the data collected during all the runs for their analysis. The assessment phase for this experiment focused on how well the students learned the key concepts in each experiment and how their gaming experiences impacted their education and learning opportunities.

A comprehensive survey was given at the end of the RVD 2 class. The survey results shown in Table 1 reflect the mean of the responses of the 41 students who completed the course (2 students resigned the course). The items in Table 1 capture the responses that are most relevant to the gaming laboratory experience. Omitted items relate more to teaching methodology employed in the course. The questions were on a 5-point Likert scale with 1 representing strongly disagree and 5 representing strongly agree. An ANOVA was run for each item, and statistical significance between means, was found for all of the survey items. These responses provide evidence that students perceived the RVD 2 course (and RVD 1 course), including the laboratory gaming component, to be of significant value in their engineering education.

Table 1. RVD Ratings Survey Results

	RVD 1 & RVD 2 have…	Other engineering courses have…
exposed me to genuine engineering problems**	4.439	3.195
allowed for hands-on learning experiences**	4.512	2.902
prepared me for the workplace**	3.951	3.097
allowed me to use the types of technology and facilities that engineers use in today's workforce**	3.878	2.951
offered me a chance to identify and formulate engineering problems**	4.220	3.610
provided engaging learning opportunities**	4.537	3.293
made use of problems and situations similar to those that I expect to face in the workplace**	3.854	3.049
helped me be more familiar with what a practicing engineer does**	3.829	3.073
given me opportunities to perform experiments in engineering**	4.268	3.244
given me opportunities to analyze engineering data**	4.732	3.537
given me opportunities to interpret engineering data**	4.707	3.463
presented new ideas and material in a realistic context**	4.463	3.341

**$p < .001$

In addition, the survey also included open-ended items, one of which asked them why they had enrolled in RVD 2. All 41 students responded to this item, some with multiple responses. They are categorized and compiled in Figure 9. Note that the fifth most popular response was one that mentioned specifically the motion simulation gaming environment. The most frequent responses mention their positive experiences in RVD 1 which could certainly include the gaming experiences that were part of the class.

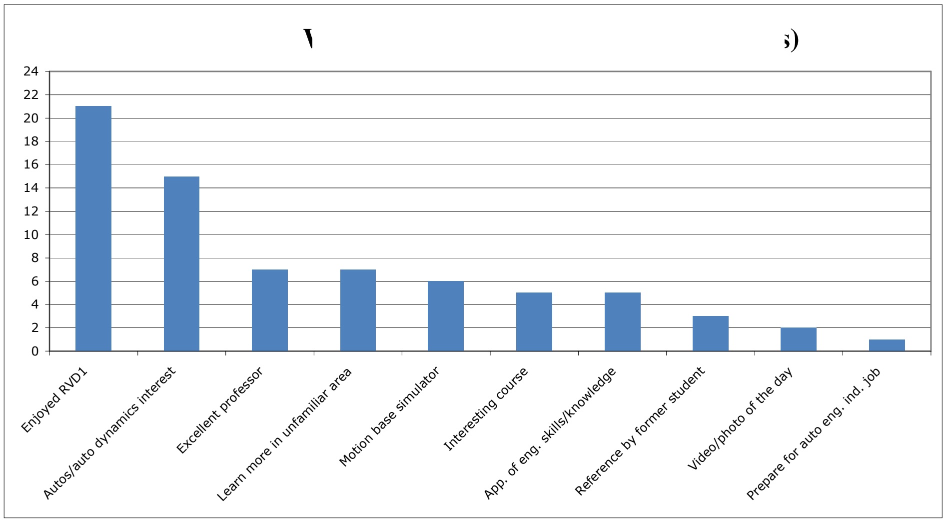

Figure 9. Responses to the Question "Why did you take RVD 2?"

Another item on the survey asked the RVD 2 students if they would recommend either RVD 1 or RVD 2 to other students. All 41 RVD 2 students responded affirmatively. Figure 10 displays the reasons that were given for this recommendation. Note that the second most popular response articulates the hand-on gaming experience in both classes.

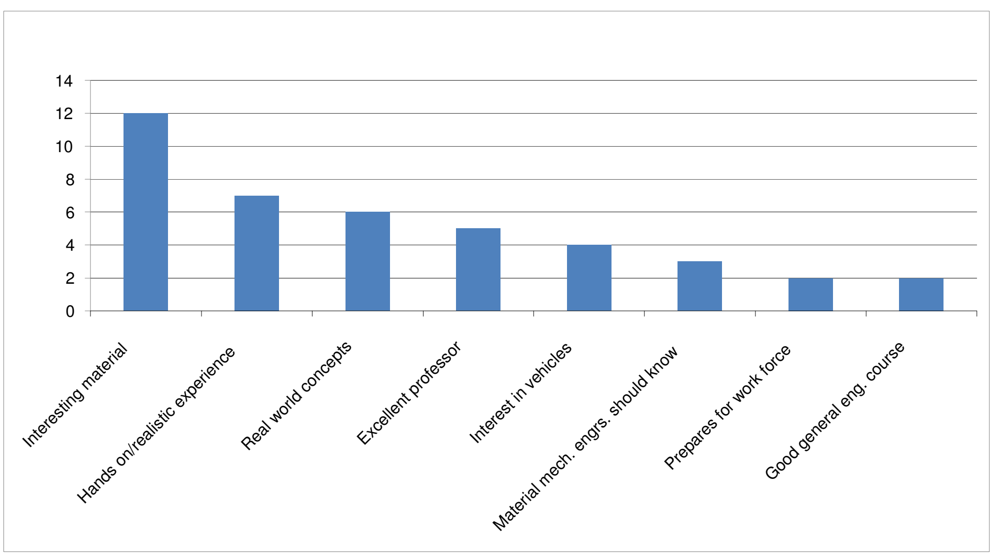

Figure 10. Reasons to recommend RVD 1 and RVD 2

The next section addresses some overall insights and conclusions from the collective set of experiments. It also presents some ideas towards future re-designs of the experiments, based on the collected feedback.

General Insights and Conclusions

This paper presents a method of using a simulation game to present students with an authentic vehicle testing scenario. The driving simulation environment is used to augment two standard road vehicle dynamics course offerings. In all, 73 students participated the low-end gaming tasks and 41 of these students continued with the second course and participated in the high-end gaming tasks. Based on the experimental results from performing these tasks, from in-laboratory observations (before, during, and after the experiments), and based on the student surveys (before and after the laboratory experiments), numerous conclusions can be drawn.

- The game scenarios were successful in attaining their primary goal – to serve as a forum for experiential, inquiry-based learning within an educational setting that had previously been instructed exclusively by way of traditional, lecture-based classroom approaches. Students would first see and experience the dynamics of a vehicle using the motion simulator, and this exposure was followed by traditional instruction (i.e. representative mathematical theory and governing dynamics equations) in the classroom setting.

- The instructor noted significant differences between the students who engaged in the gaming experiments and those from previous non-gaming offerings of the courses with respect to the learning objectives of each experiment. He noted substantial and identifiable progress in the students with respect to their comprehension of theoretical concepts and application of these concepts to practical vehicle design issues. In previous years, a few in-class computer simulations with plots of output variables were used to illustrate different vehicle behaviors. With the use of the motion simulation experiment the connection between theory and reality was easier to make since the students had experienced the various vehicle behaviors. Interestingly, because of the realistic context that the experiments provided, the instructor also noted a pronounced familiarity with the technical vocabulary of the course after the experiments were conducted.

- For each of the laboratory groups, the laboratory instructors could easily detect the progression of knowledge and lesson comprehension during the experiments. With the first driver, there would always be a considerable amount of apprehension and guesswork, as the student would serve as the first person to complete the exercise. Based on that student's successes and shortcomings, the second and third drivers would conquer the exercises much more quickly and confidently, and generally speaking, improved driver performance in each session reflected this trend.

- With 114 students in 19 groups across two semesters, almost 200 experimental setups were performed. Using a physical vehicle and test track or road course, the setup time would have dominated the experimental process, limiting the students' ability to explore the impact changes in configuration has on vehicle dynamics.

- The results from the course surveys show that the course has a considerable impact on how students felt about their engineering education and their perceived experiences in their educational process. The use of experiential learning in the vehicle dynamics curriculum increased students' opinions of their opportunity to have hands on experiences, use modern engineering tools, and solve problems that were similar to what they expect to see in the workplace. This outcome shows that using simulation to provide authentic learning environments provides educators with a means of following the guidance provided by ABET and the National Survey of Student Engagement, with the ultimate goal of educating engineers that are better prepared for the workforce.

- Students universally commented on how much more realistic the model from the high-end gaming experiment felt compared to the bicycle model in the initial experience. The ability to change the values of the vehicle parameters also proved to be a very instructive tool, as students quickly learned the impact a change in a vehicle parameter had on vehicle performance.

Further development and study will include more experiments aimed at using gaming environments to learn key technical concepts including fundamental vehicle dynamics, driver-vehicle interactions, and driver-to-driver interactions in networked simulations. The networking feature will allow multiple drivers to interact with one another within the same driving environment. In addition, future plans include developing a computing toolkit to allow other researchers and educators interested in vehicle and motion simulation gaming applications to efficiently develop environments and experiments. This toolkit could also be applied to desktop version of driving simulation environments, allowing for greater dissemination and study.

Acknowledgements

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