Game-based Experiential Learning in Dynamics Education Using Motion Simulation

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ABSTRACT

In education, relating theoretical and analytical results to real-world phenomena is a difficult task. While equations and graphs are an efficient means of presenting large amounts of information, such representations are abstractions of reality. A significant portion of a student's learning process is learning how to transform these abstractions into knowledge that will allow them to apply their understanding to real-world systems. Many students have experienced controlling a vehicle simulation with gaming platforms such as PS3 or Xbox, however, they do not necessarily associate the gaming environment with the models, equations, and system dynamics that define a road vehicle, aircraft, or sea vessel. Consequently, we propose a novel approach to leverage Serious Gaming environments to advance learning and instruction of vehicle dynamics. Specifically, we propose the development of courseware-based materials for a motion simulation-based framework that will provide authentic experiences for instruction of dynamic systems concepts, and will serve as an adaptable and immersive learning environment for vehicle dynamics (ground, air, and sea) education. For example, the effect of center-of-gravity location on the stability of a vehicle is "just an equation" if presented mathematically, but its true meaning is much more apparent if experienced on a motion simulator, where coupling between output motions (e.g. yaw, pitch, roll) becomes obvious. When combined with in-course theory, this blended learning solution will be used by students to discover the impact that design decisions have on a dynamic system, while gaining inquiry-based exposure operating vehicle simulations. Significant pedagogical advancements (e.g. hardware/software developments, learning materials and novel teaching strategies) are a significant element to our work. Furthermore, qualitative and quantitative assessment of our framework experiments will demonstrate the collective impact on learners' perceptions about their comprehension of key principles, and on instructors' teaching strategies.

ABOUT THE AUTHORS

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INTRODUCTION

Engineering education often focuses on helping students to better understand the relationship between real-world phenomena and analytical models of the underlying theory. Using conventional abstractions (e.g., equations/graphs) can help students advance their knowledge, but these mechanisms often do not provide a concrete relationship between theory and application.

As suggested by The President's Information Technology Advisory Council (PITAC, 2001), simulation enables a designer to explore the merits of alternative designs without physically building the system, reducing development cost and the risk often associated with physical testing and experimentation. In engineering education, simulation can be used as an engaging tool to teach students vital concepts.

However, the use of simulation does not ensure student engagement. In order to provide an engaging experience for students to learn, the simulation must be developed with student engagement in mind. Different types of simulators can be effective in teaching, training, or demonstrating design concepts to students. Computer graphics-based simulators that display the simulated system, provide the user with a meaningful understanding of the system's behavior. Physical simulation tools, such as motion simulators, augment the display of graphical information with physical motion, providing learners with immediate feedback when designing dynamic systems and the opportunity to both see and experience the impact of their decisions first hand. A successful pedagogy will couple authentic experiences for a student along with support from an instructor to promote lasting learning.

This paper presents the development and evaluation of a blended learning solution for vehicle dynamics education. The approach integrates serious gaming, motion simulation, and educational practices that improve the capability to learn Science, Technology, Engineering and Math (STEM). In this immersive learning environment, material is presented in an authentic context, and students use a vehicle simulation framework to interactively discover the impact that design parameters have on a dynamic system.

The custom-developed framework described here can be developed into educational courseware involving the dynamics of various classes of moving vehicles, civilian and military, including: road, flight, and marine, all of which are presently in various stages of development and implementation. Furthermore, the architecture can be adapted to incorporate higher fidelity visualization and analysis engines.

BACKGROUND

Most adults have a pre-existing comprehension of vehicle dynamics; most have been a passenger in an automobile, airplane, and/or a sea vessel. Thus, vehicle motions are inherently familiar to those who are concerned with understanding their dynamics. Educators and engineers are increasingly turning to Virtual Reality (VR), simulation and virtual prototyping, rather than physical prototyping, to allow learners to better bridge the gap between theory and "real world".

The ideally authentic experience would be to have learners control real automobiles, airplanes, or marine vessels, and perform specific maneuvers. Cost, time, safety, and weather are obvious constraints that often deem this option impractical. An alternative solution is to make use of an authentic, simulated vehicle environment. By enabling learners to interact directly with a model of a vehicle, simulations allow students to understand a system's dynamics using multiple senses (i.e. visual, haptic, and aural).

Video gaming systems have increasingly been found in training, education, and simulation contexts (e.g., Lane, 2005; Zyda, 2005), designed to apply subject matter to the real world (Prensky, 2001). Additionally, physical simulation tools (e.g., motion simulators) provide learners with immediate feedback, and provide the opportunity to both see/experience the impact of decisions firsthand. A successful educational pedagogy couples authentic learning experiences with conventional instruction/instructor support to promote retention. Demonstration of this blended learning environment is the primary purpose of this paper.

BROADER IMPACTS

The proposed educational framework has a wide range of novel applications. In addition to the road vehicle applications emphasized here, one can envision using the technology to develop an undersea application to train ocean engineers and undersea vehicle operators. Similarly, one can envision using the technology to develop an airborne application to monitor volcanic activity in remote regions. Note also that these applications and others have the added capability to inform the future design of the ground, air, and undersea vehicles integrating empathic and ergonomic feedback from the user and various types of sensors.

To develop such technology, partnerships with other scientists in engineering, communications, architecture, psychology, and medicine would be needed to create allied research teams to tackle large, complex global, social, environmental, and technical issues through motion simulation. This kind of interdisciplinary research team can rarely be assimilated in a single company. Therefore, partnerships with leading research institutions with relevant expertise are vital.

Motion simulation hardware, similar to that leveraged in the present work, could be constructed for anywhere from $50-200K US. However, extension to desktop, laptop, and other mobile computing platforms is where truly significant impact could occur. Mobile computing users could be networked to a motion simulator for remote access and instant feedback. Leveraging the emerging network of dispersed motion simulators, remote users could conceivably control a fleet of road, air, or sea vehicles. Mobile computing interfaces could be developed for the desktop at a cost geared more towards the consumer market.

VEHICLE DYNAMICS – THEORETICAL BACKGROUND AND KEY CONCEPTS

In this section, the basic theory is discussed for each of the three types of models encompassed by the vehicle

dynamics education framework. Note that although the three models vary in complexity, the principles employed to arrive at each model are identical. The extensibility of the proposed framework from one model type to the next is one of its primary advantages.

Road Vehicle Dynamics

The simplest road vehicle model is the classic "Bicycle Model" of the automobile (Milliken and Milliken, 1995), which treats the pair of tires at each end of the vehicle as a single tire, as shown in Figure 1. Inputs to the model are steering wheel angle and tire longitudinal force (i.e. throttle and brake), and outputs include vehicle velocities, accelerations, and tire forces.
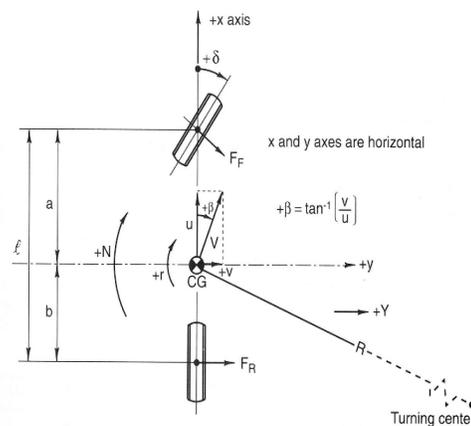

Figure 1. The Bicycle Model of the Automobile

In the Bicycle model, understeer gradient is a measure of how fast the front and rear "slip angles" increase. When the front slip angle increases faster than the rear, the car is said to be "understeer". This is the condition designed into all passenger cars, as it results in a car that is comfortable to drive. The concept of yaw moment balance is also examined in this model. At steady-state conditions, the total yaw moment on the vehicle is zero. This yaw moment is generated by the front and rear tire lateral forces, acting ahead of and behind the center of gravity (CG).

In essence, the front tires make the car want to turn ("control"), while the rear tires try to keep the car from rotating ("stability"). The implications of yaw moment are most apparent when the tires reach their breakaway slip angle. Assuming the front and rear tires saturate at the same force level, if the front tire slip angles are growing faster than the rear, the front tire will saturate first. This is called "limit understeer", and is very stable, but not controllable. The opposite case, where the rear tire saturates first, is "limit oversteer", and is unstable; the car spins. Race cars attempt to utilize as much of the front and rear tire lateral force as possible,

so they try for "neutral steer", a condition intermediate to limit understeer and limit oversteer.

A more realistic model of the automobile, also implemented in this study, is the "Four-wheel Model". The Four-Wheel Model has a fully non-linear and load-sensitive tire model. Unlike the Bicycle Model, the amount of load that each of the four tires is carrying has a significant effect on the lateral force that each tire can produce. These loads change while driving in response to lateral load transfer. The Four Wheel Model thus allows students to experience how changes in roll stiffness distribution and roll center heights affect the understeer gradient and limit behavior.

Flight Dynamics

The dynamic behavior of an aircraft is shaped significantly by its stability and control properties, which in turn relate to its aerodynamic characteristics. Static stability analysis enables the control displacement and force characteristics to be determined for both steady and maneuvering flight conditions, while dynamic stability analysis enables the temporal response to controls and to atmospheric disturbances to be determined for various flight conditions.

The mathematical model governing the motion of an aircraft consists of six non-linear coupled differential equations. Reduced-order linear models can be derived from the complete equations of motion to study the dynamic motion about nominal flight conditions. In this paper, we concentrate on longitudinal motion of an airplane, characterized by two oscillatory modes, phugoid and short-period; refer to Figure 2.
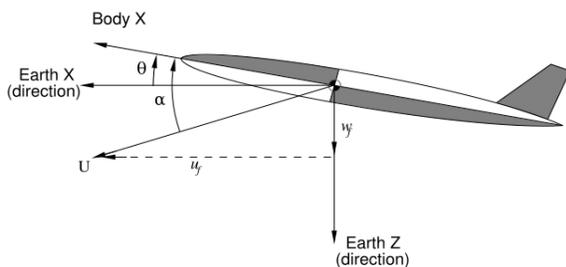

Figure 2. Aircraft model: coordinate system

1. *Phugoid Mode*: Phugoid mode is generally a long-period mode and can be regarded as a gradual interchange of kinetic and potential energy about the nominal altitude and airspeed.

2. *Short-Period Mode:* As the name suggests, short-period mode refers to a high frequency mode and can be obtained by eliminating the force equation in the

longitudinal direction of motion, and altering the forward speed to be zero.

Sea Dynamics

Similar to ground and air vehicles, there are inertial/global and a body/vehicle reference frames used to described vessel translation and orientation. See Figure 3.
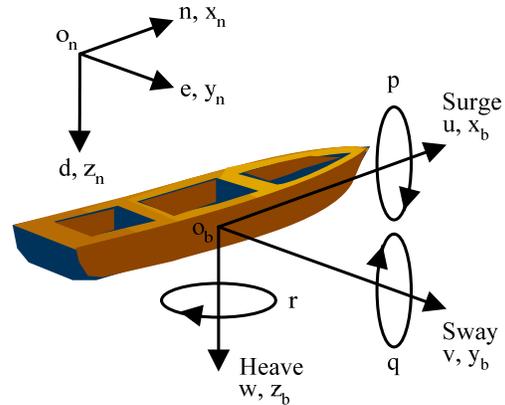

Figure 3: Ship Motion and Sign Conventions

Following the notation of (Fossen, 1994), the generalized vessel position vector is represented by: $\boldsymbol{\eta} = [\textbf{n, e, d, φ, θ, ψ}]^{\textbf{T}}$, and the generalized velocity vector is represented by: $\textbf{v = [u, v, w, p, q, r]}^{\textbf{T}}$. As shown by (Ross et al., 2007), a vessel's motion can be represented by the Lagrangian model, as:

$$M\dot{v} + C(v)v + D(v)v + g(\eta) = \tau \qquad [1]$$

Where **M** is the rigid body mass matrix, **C** is a matrix of forces due to Coriolis and centripetal effects on the rigid body, and **D** is a matrix of damping terms, which are due to the energy carried away by the waves generated by the vessel and viscous effects. (Fossen, 2005; Perez, 2005). **g(η)** are restoring forces due to gravity and buoyancy, and **τ** are the sum of the environmental and control forces on the vessel.

EXPERIMENTAL DESIGN
FOR DYNAMICS MODULES

This section discusses the design details for each learning module for the three classifications of vehicle dynamics (road, air, and sea). All modules leverage University of Buffalo's (UB's) motion simulator, which consists of a six degree-of-freedom motion platform. Two passengers are accommodated in a vehicle cabin. Additional simulation hardware includes a four-screen hexagonally arranged

visualization system and a 2.1 channel stereo sound system. Figure 4 is an image of the exterior of the vehicle cabin and frontward simulation screens.

Figure 4: Motion Simulator (side)

1. Road Vehicle Dynamics Modules
Experiment #1.1 – Skid Pad

This experiment is based on a simple circular test track known as a "skidpad". Skidpad testing is a typical automotive proving ground activity dating back to the 1930's (Milliken and Whitcomb, 1956). Two walls define the edges of the virtual environment, with an inner radius of 50 feet an outer radius of 500 feet. Centered between the inner and outer walls is a 60 ft. wide circular strip of drivable track bounded by cones.

Students are asked to drive vehicles with different configurations at gradually increasing speeds around the skidpad. A variety of vehicle configurations are driven, varying center-of-gravity (CG) locations and tire cornering stiffness distributions. Prior to the experiment, the students are exposed to terminology, but they will not have yet been exposed to implications of the relationship between these vehicle parameters. Through the experiment, students are expected to conclude that the front CG location must exceed the front cornering stiffness distribution to achieve a stable vehicle. The opposite relationship produces unstable vehicles and, when they are equal, a neutrally stable car results. Students are also expected to note that the unstable car can be successfully driven at low speeds, but it becomes much more difficult as speeds increase. This is a result of the yaw damping effect; critical, even in the simplest vehicle dynamics models.

Experiment #1.2 – Tri-Radial Speedway

The second experiment makes use of the Tri-Radial Speedway, whose dimensions are double the size of the skidpad. Walls bound the world with an inner radius of 100 feet, and an outer radius of 1000 feet. The course consists of a large constant-radius left turn shortly after the starting line, followed by a tight constant-radius right turn, followed by a second large left turn that leads into the final straightway. Figure 5 shows a portion of this speedway. Note the top view of the track geometry in the lower-central portion of the viewport. The goal of this experiment is to investigate the new parameters in the Four Wheel Model. Here, the CG location and tire models are held constant, with the tires instead being represented by the Four Wheel Model's nonlinear tire model representation.

Figure 5 – Tri-radial Speedway: Experiment #2

Each trial run is conducted with a different roll stiffness distribution, front roll center height or rear roll center height. Students are expected to conclude that increasing the front roll stiffness distribution, increasing the front roll center height or decreasing the rear roll center height all increase the understeer of the vehicle. On the Speedway, students experience how front and rear drive behave differently when tractive effort is applied (as it reduces the lateral force on that end of the vehicle), and also experience the destabilizing effect of heavy deceleration.

While time constraints in the course do not allow the students to validate these virtual models against the "real world", a rigorous data analysis is conducted after each experiment. Static data is known regarding the vehicle (CG location, wheelbase, track, mass, etc.) At every time step, dynamic data is collected for the vehicle excursion, including vehicle position, orientation, velocity, and acceleration, tire forces, etc. Subsequent to the experiment, students make use of this simulation data to perform engineering calculations just as they might with data collected on a physical vehicle. Exercises include: calculation of "understeer gradient", computation of Ackermann Steer angle (i.e., the steering angle required to achieve a circular path at a constant speed) (Milliken and Milliken, 1995), and estimation of vehicle weight.

2. Flight Dynamics Modules
Experiment #2. 1 – Static and Dynamic Stability

Generally, phugoid mode occurs so slowly that the pilot can negate the disturbances by applying appropriate control actions. However, an airplane can be difficult to control if the short-period mode is lightly damped and has a relatively low frequency. Furthermore, as the static stability derivative is directly proportional to the aircraft CG-position, the frequency of short-period mode decreases, and eventually the aircraft becomes unstable as the CG is moved aft. Figure 6 illustrates the effect of varying the CG-position on the phugoid and short-period mode responses. Certainly, a graph of the increase in longitudinal stability of an aircraft as the CG moves forward can illustrate the trend, but the concept becomes much more apparent when experienced first-hand aboard a simulator.
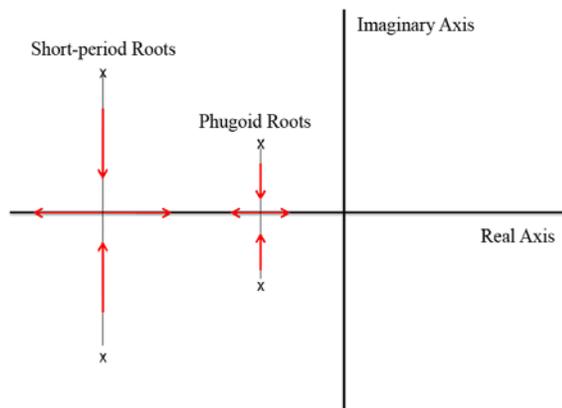

Figure 6 – Effect of CG-position

With the proposed framework, students can adjust an aircraft's geometric and aerodynamic characteristics, and accordingly, will discover many of these critical parametric relationships. Animations and pre-configured simulations are provided to allow a student to discover how each key concept relates to fly an aircraft. Restricted degrees of freedom (DOF) aircraft motion will be considered to enhance the understanding of baseline flight dynamics concepts. This allows the students to gain experience with the mathematical representation and physical comprehension of aircraft response before multiple DOF scenarios are attempted. For example, a test case in which the aircraft's CG is constrained to move in a straight line at a constant speed but the aircraft is free to pitch (about the CG) would enhance understanding of the longitudinal motion of an aircraft.

The students is shown an animation of an aircraft's pitching motion with varying degrees of static and dynamic stability and experiences the motion in the flight simulator. Later, students will be asked to control the pitching motion for different scenarios and will be provided with a series of challenges to allow them to discover the relationship of design parameters to airplane handling characteristics.

3. Sea Dynamics Modules
Experiment #3. 1 – Ride Control

Similar to road and air vehicles, specific experiments using simulated marine vessels are used to guide the student to make insightful discoveries concerning the basic dynamics of marine vehicles. Because of the complexity of marine vessel dynamics, preliminary experiments are kept simple so the students can readily experience specifically-guided aspects. For example, in the visual portion of our simulation, the seas are designed flat, and there is no wind or current present. This keeps the focus of the essence of the experiment on the student, and it also makes for simpler real-time rendering for the developing team. In this experiment, students are asked to navigate a boat on a lake, bounded by a slightly irregular coastline. Buoys are placed in the lake to mark an intended travel path. A typical view of such a simulation is shown in Figure 7.

Figure 7 – Typical marine dynamics scene graph

The "course" consists of one long straightaway, two 180° turns, and one long slalom section, where the students are expected to navigate around a series of buoys in a "zig-zagging" fashion. Several scenarios are executed, each demonstrating different aspects of marine vessel ride quality. They include:

- Varying CG height
- Varying CG fore-aft placement
- Varying propeller depth placement
- Varying craft length/width

For each scenario, the different configurations can be selected in real-time WITH programmable buttons AND on-board Human Interface Device (HID) for basic steering/controlling. Analogous to lessons learned in the previous educational exercises, students are expected to conclude that: a rising CG tends to

make the vessel unstable, a forward CG makes it more difficult to get the vessel to plane, changing propeller depth alters planing characteristics, and longer/wider vessels, become more difficult to control. Using a simulation-based hardware/software arrangement, these characteristics are seen/experienced first-hand.

SIMULATION IMPLEMENTATION

Hardware/software developments

The vehicle dynamics framework, developed in-house using Microsoft's Visual C++, is illustrated in Figure 8. The driver sitting inside the vehicle adjusts the HID controls, and these inputs are sent to the Simulation Computer (SC). The SC then updates the parameters of the vehicle model accordingly (e.g. position, velocity, yaw rate/angle, etc.). Model changes manifest themselves in required updates to: the scene graphics state, the motion platform state, and the audio state of the simulation.
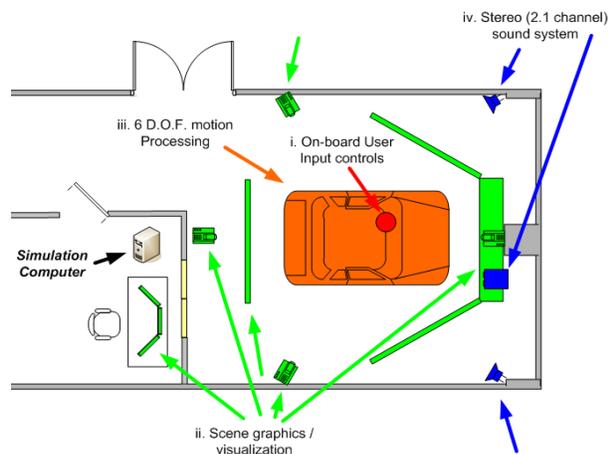

Figure 8 – Vehicle Simulation Framework

User (control) Inputs
User input commands are captured from the HID using Microsoft's DirectInput protocol (Microsoft, 2008), a subcomponent of the DirectX library. DirectInput allows the programmer to specify an input device, and the state of the input device can be polled in real-time, with minimal latency. With updated user input states, the vehicle model is updated.

Motion Outputs
The vehicle states are computed, and must be converted into degrees-of-freedom (DOF's) - roll, pitch, yaw, heave, surge, and sway. Due to the finite stroke length of each of the platform actuators, this conversion involves scaling, limiting, and tilt coordination (Romano, 2003); sub-processes of a methodology commonly known as washout filtering

(e.g., Bowles et al., 1975). The updated DOF's are delivered by the simulation computer to the computer on-board the motion platform. Once received, the state of the platform is updated, and the platform continues to send datagram packets to the simulation computer (and vice-versa) for the duration of the simulation.

Graphics Outputs
The simulation graphics have been developed using OpenGL. The virtual workspace, shown in Figure 9, is 3840 pixels wide x 2028 pixels high (using Nvidia's "Vertical Span" feature), as we have a grid of two 3x1280 pixel wide Viewports, each 1024 pixels high. The top row of the grid displays our forward Left, Center, and Right views, respectively, and the bottom row displays the rearward three views.

Figure 9 – Six channel Virtual Workspace

Audio Outputs
The framework uses OpenAL for adding sound events into the simulation, including: vehicle ignition, engine tone (which varies according to the speed/RPM's), squealing tires (which vary in accordance with the calculated slip angles), hazard/danger cues (e.g., a "thump" sound when a cone is struck; a police siren when the speed limit is surpassed), crash cues (e.g., a spinout when the sideslip angle exceeds its allowable limit, or a rollover when the lateral tire normal loads exceed their limits), and vehicle shutdown.

RESULTS AND DISCUSSION

Results from the implementation of the vehicle dynamics educational framework have been collected over the last three years, primarily by way of UB's Road Vehicle Dynamics (RVD) course, MAE 454/554, an elective undergraduate/graduate course in the Mechanical and Aerospace Engineering Department, Systems Analysis (MAE 340 – undergraduate), Independent Study (MAE 499 – undergraduate), and the sequel course to RVD, Special Topics: Road Vehicle Dynamics II (MAE 400/500 –

undergraduate/graduate). Results are decomposed into major categories: learning materials/teaching strategies, and assessment methods (qualitative and quantitative).

Learning materials and novel teaching strategies

Leveraging the ever-present digital lifestyles of today's engineering students has allowed our research team to have significant and sustained impact across broad educational objectives, student groups, and academic environments. The educational innovation described in this paper is a state-of-the-art, hands-on, context-building, interactive laboratory experience developed specifically for engineering courses and topics that have been historically context-light. Without the necessary technological relevance and the social, global, and/or environmental contextual anchors, students routinely find themselves wondering why they are learning all this "science" using outdated laboratory equipment and methods. The educational framework described here has leveraged motion simulation hardware and software developments along with contextual anchors from numerous transportation infrastructures to create unique experiential learning modules. Input from leading transportation companies such as General Motors, Ford, and Milliken Research Associates has also helped frame the technology and learning materials from a corporate perspective.

Assessment Methods and Results

Included here is a sampling of the assessment results for the "skidpad" and "tri-radial speedway" experiments defined previously. Note that the results are both quantitative and qualitative in nature, and include a control group analysis, adding further statistical significance to the results attained.

Quantitative Assessment sample
Table 1 illustrates the pre-test and post-test items and related statistics for the skidpad experiment. Through this experiment, students were expected to understand the fundamental concept that the front weight distribution (CG location) must exceed the front cornering stiffness distribution to achieve a stable vehicle. The opposite relationship produces unstable vehicles and, when they are equal, a neutrally stable car results. They were also expected to understand that the unstable car could be successfully driven at low speeds, but became much more difficult as speeds increased.

Items 1 and 2 in Table 1 were graded with a partial credit rubric: 2 points for a correct answer, 1 point for a partially correct answer, and 0 points for an incorrect answer. Items 3 and 4 were scored as 1 for correct and 0 for incorrect. The pre-test was administered to 44

students who were in attendance on that particular class. The post-test was administered to 51 students immediately following the small group laboratory experience. With the exception of the laboratory experience, no other intervening instruction occurred between administrations of the pretest and posttest. Clearly, the results are favorable towards the simulation experiments, as post-test results increase for all 4 questions, especially the first two, where the "effect size" (both > 2.0) is more substantial. This may be largely due to the fact that with only 2 possible answers (i.e. no partial credit), the 3rd and 4th questions were prone to more "correct guesses" during the pre-test, so the true margin of improvement (to post-test) appears to be somewhat falsely skewed.

Table 1. Results: Skidpad experiment

Test Questions	Pretest Mean (SD)	Posttest Mean (SD)	Effect Size
1. Identify an <u>unstable</u> combination of: (cornering stiffness / weight distribution)	0.133 (0.457)	1.577 (0.750)	2.324
2. Identify a <u>stable</u> combination of: (cornering stiffness / weight distribution)	0.133 (0.457)	1.615 (0.718)	2.456
3. Which vehicle parameter contributes <u>most</u> to the stability of a car? Explain.	0.556 (0.503)	0.923 (0.269)	.912
4. If a car is unstable, will you notice at low speeds? Explain.	0.522 (0.503)	0.827 (0.382)	.416

Qualitative Assessment sample
The first qualitative question was given as: "How well did this experience prepare you to answer items 1-4? Explain your answer." For this question, 101 out of the 104 responses across both experiments (skidpad and tri-radial speedway) thought that the simulator experience was helpful; 3 people left the question blank. The most frequent responses to the "Explain your answer" portion were:

- "Helped me understand concepts/relationships"
- "Hands-on experience is helpful, allowed me to feel what was happening, able to feel the concepts"
- "Tied theoretical knowledge to practical work"
- "Interactive process helped me learn, dynamic experience better than lecture"
- "Gave me experimental (objective) information, able to learn from the data"

The second qualitative question was: "Given a choice, would you prefer to learn the concepts covered during the experience using the motion base simulator or through a classroom lecture? Explain your answer." For this question, 89 out of the 104 students selected the simulator experience as their preferred method to learn the concepts, 10 said that they would prefer both, and 5 responses were blank or illegible. The most frequent responses to the "Explain your answer" portion were:

- "Hands-on learning experience, tactile feedback important, able to feel the concept"
- "Easier to visualize what is happening, able to see how things interact"
- "Learn from modifications, able to see how model reacted under certain conditions"
- "More likely to remember, easier to remember what you experience, more memorable"
- "Helps unite theory and practice, see how concepts from classroom are put to use"

From the data, it is clear that the students not only enjoyed the experience and found it to be beneficial, but they scored significantly higher on questions testing fundamental principles after the experience.

Mixed Control Group Study
In June of 2010, the RVD course was offered during the Summer Session at UB. With a total of 16 students for this session, a new approach was attempted, in the form of two 1-hour long experiments. The class was divided into 2 portions. Group #1 spent the first hour on the motion simulator to conduct the Skidpad experiment, and then spent the second hour in an adjacent Laboratory, where they first read a notes sheet on course theory pertinent to the Skidpad experiment, and then viewed a video that demonstrated principles that were key to the experiment. Group #2 received the same material, but in the opposite order: i.e., notes /video first, then motion experiments second. In both cases, this was the students' first formal exposure to this course material.

Three surveys were issued: one at the beginning, and one each at the end of the first and second hours. Each survey had the same 4 questions (see Table 1), and the third survey had an additional 5th question:

5. Consider all that you learned today, and assign percentages to the portions of the class (Study Notes, Video, Motion Base) according to how much each portion impacted your learning.

Figures 10 (Questions 1 and 2) and 11 (Questions 3 and 4) are a summary of the average scores for the data collected. Note that Questions #1-2 have a maximum possible score of 2, while Questions 3-4 have a maximum score of 1. Figures 12-13 display results for Question #5, which list percentages for the **video (V), study notes (SN), and motion base (MB).**
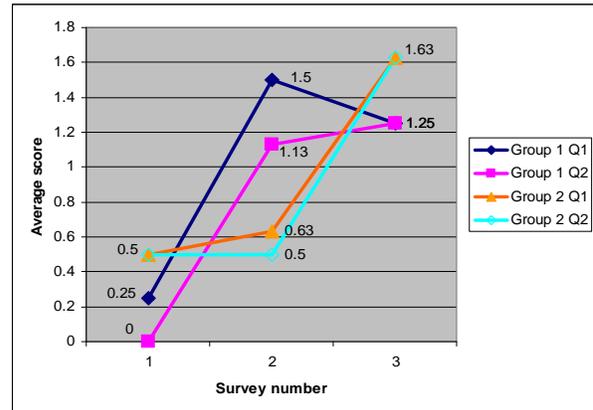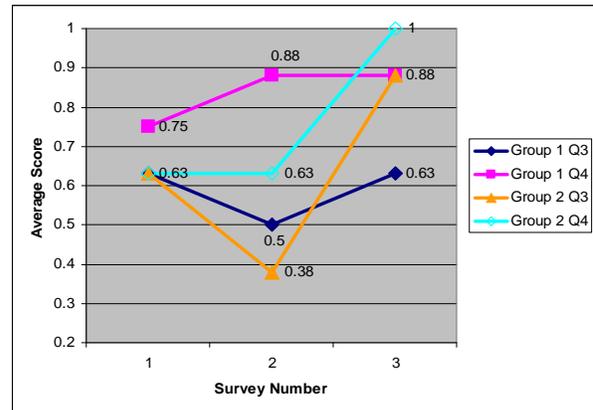

Figure 10 – Survey Questions 1-2 (Groups 1-2)

Figure 11 – Survey Questions 3-4 (Groups 1-2)
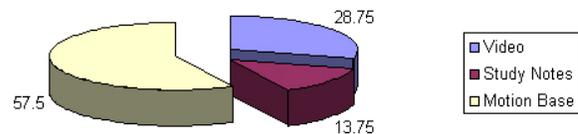

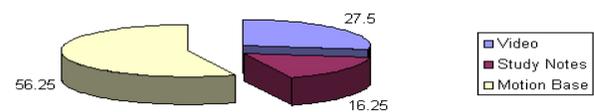**Figure 12 – Survey Question 5 (Group 1)**

Figure 13 – Survey Question 5 (Group 2)

Various observations can be made based on this preliminary sample, and are summarized as follows:

- With minor exceptions, scores generally increased progressively as students received increasingly more information from survey #1 to survey #3.
- Improvements were more pronounced (higher scores, and by a wider margin) for Group 2, who received motion base instruction after receiving more "conventional" methods of instruction, (i.e., video and notes) instead of before.
- Students of Group 2 answered Question #4 perfectly on the third survey, which was issued directly after the motion base experiment.
- By a wide margin (for both groups, more than 55%) students attributed conceptual understanding to the motion base experiments, followed by the video, followed by the study notes.

FUTURE WORK

The results of the implementation of the educational framework presented here highlight past/present work with the Road Vehicle Dynamics curriculum, exclusively. There are numerous avenues for its extensibility and expansion, all of which are presently in development, and summarized as follows:

1) Aerospace Engineering and Systems Analysis

The Flight Dynamics module, discussed in this paper, is to be implemented during the Fall, 2010 semester, in an undergraduate Flight Dynamics course required by all Aerospace Engineers. Similarly, the Sea Dynamics module is to be implemented during the Spring, 2011 semester. Plans are to incorporate content-appropriate elements of this module into separate undergraduate and graduate System Analysis courses.

2) Civil and Environmental Engineering

Our educational framework is to be implemented in a cross-departmental context, to begin during the Spring, 2011 semester. Planned course offerings include: Transportation Systems Analysis (undergraduate), Traffic Operations/Design (graduate), and Traffic Flow Theory (graduate). Planned exercises using the courseware discussed in this paper include:

- Measuring perception/reaction (P&R) time
- Fuel consumption and emissions modeling
- Pilot distraction: performance, and safety concerns

3) Engineering Technology (Buffalo State College)

A partnership is underway with Buffalo State College (BSC), whose Engineering Technology program will benefit from the simulation-based vehicle framework. BSC is also in possession of a motion platform, theirs outfitted with a Cessna aircraft cabin. As such, they will gear their experiments towards three undergraduate courses that will benefit from flight applications and educational exercises: Shock & Vibration, Dynamics, and Fluid Mechanics. Planned experiments include:

- Impact of air flow on aircraft take-off and landing
- System dynamics, vibration, and failure

4) Create a network of motion simulators

It would be useful to allow simulation participants to perform in a distributed simulation environment. Already under development is a pilot capacity for a network of users to participate simultaneously by way of TCP-IP (Yadev, 2007) and UDP (Postel, 1980) communications. In this way, multiple clients can interact within the same virtual vehicle environment controlled by a central server.

5) Integrate vehicle, traffic and network simulation

To analyze the impacts of a moving vehicle interacting with other moving vehicles located within the same vicinity, one would need to combine a vehicle simulator with an intelligent link to both a formal traffic simulator (e.g. Shiraishi et al., 2004), and a network simulator. Due to the varying requirements of each simulator type, this represents both a technical and a methodological challenge (Ciuffo et al., 2009). Such an "integrated transportation driving network" simulator could be useful for a variety of studies, including: safety studies, transportation planning, pilot training, and human factors analyses.

CONCLUSIONS

This paper describes the innovative use of a motion simulation-based educational framework to provide authentic engineering experiences for learning about vehicle dynamics. This custom-developed framework can be developed into educational courseware involving the dynamics of various classes of moving vehicles (road, air, and sea), civilian and military. The motivation for its design is to provide a concrete relationship between theory and application, unlike many conventional training mechanisms, and to better engage students within the learning process.

The design and implementation of the simulation framework has been described, as well as preliminary results (quantitative and qualitative) based on its implementation. Quantitative assessment scores improved dramatically from pre-test to post-test for a questionnaire that pertained to the vehicle-based simulation experiment. Qualitative assessment demonstrated that students learned a lot from the motion-based experiments, were engaged by such a novel method for instruction, and appreciated the appreciated the hands-on, real-world, experiential flavor of the experiments. The mixed group control study further emphasized the above findings, and demonstrated that motion-based vehicle instruction is the preferred method of learning over more conventional methods for knowledge acquisition (e.g. study notes and videos).

One of the primary advantages of the educational framework described in this paper is its potential for expansion and extensibility, in both civilian and military applications. Five such ideas were suggested here, ranging from courses in other engineering disciplines (e.g., civil, aerospace), to cross-network vehicle simulation applications.

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REFERENCES

Bowles, R.L., Parrish, R.V., and Dieudonne, J.E., (1975). "Coordinated Adaptive Washout for Motion Simulators," Journal of Aircraft, 12(1), pp. 44–50.

Ciuffo, B., Punzo, V., and Torrieri, V., (2009). "Integration of driving and traffic simulation: perspectives and first solutions", Transportation Research Board Annual Meeting 2009 Paper #09-1801.

Fossen, T.I., (1994). "Guidance and Control of Ocean Marine Vehicles", John Wiley & Sons Ltd. New York.

Fossen, T.I. (2005). "A nonlinear unified state-space model for ship maneuvering and control in a seaway", in: Lecture Notes, 5th EUROMECH Nonlinear Dynamics Conference.

Lane, S., (2005). "Promoting Learning by Doing through Simulations and Games," soVoz, Inc. White Paper, Princeton, NJ, retrieved January 6, 2010 from www.sovoz.com/soVoz_WhitePaper.pdf

Microsoft Corporation, (2008). "DirectInput C/C++ Reference", Retrieved January 15, 2010, from: http://msdn.microsoft.com/en-us/library/ee416853(VS.85).aspx.

Milliken, W. F. and Whitcomb, D. W., (1956). "General Introduction to a Programme of Dynamic Research," Proceedings of Auto. Div. Instn Mech. Engrs, 7, pp. 287-309.

Milliken, W. F. and Milliken, D. L., (1995). Race Car Vehicle Dynamics, SAE, 1995.

Perez, T., (2005). "Ship Motion Control: Course Keeping and Roll Reduction using rudder and fins", Advances in Industrial Control. Springer-Verlag.

Postel, J., (1980). "User Datagram Protocol", RFC 768, USC/Information Sciences Institute.

Prensky, M., (2001). Digital Game-based Learning. McGraw-Hill, New York, New York.

President's Information Technology Advisory Committee (PITAC), (2001). "Using Information Technology To Transform the Way We Learn", Arlington, VA.

Romano, R., (2003). "Non-linear Optimal Tilt Coordination for Washout Algorithms," AIAA Modeling and Simulation Technologies Conference and Exhibit, Austin, TX., AIAA 2003-5681.

Ross, A., Perez, T., and Fossen, T., (2007). "A Novel Maneuvering Model based on Low-aspect-ratio Lift Theory and Lagrangian Mechanics", IFAC Conference on Control Applications in Marine Systems (CAMS). Bol, Croatia.

Shiraishi, T., et al., (2004). "Development of a Microscopic Traffic Simulation Model for Interactive Traffic Environment", Proceedings of the 11th World Congress on Intelligent Transportation Systems, 2004.

Yadav, R., (2007). "Client/Server Programming with TCP/IP Sockets", www.devmentor.org, Technical Article, September 9, 2007.

Zyda, M., (2005). "From Visual Simulation to Virtual Reality to Games," *IEEE Computer*, 38(9), pp. 25-32.