Measuring Engagement as Students Learn Dynamic Systems and Control with a Video Game

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ABSTRACT

The paper presents results of a multi-year quasi-experimental study of student engagement during which a video game was introduced into an undergraduate dynamic systems and control course. The video game, *EduTorcs*, provided challenges in which students devised control algorithms that drive virtual cars and ride virtual bikes through a simulated game environment. Engagement was conceptualized through the theoretical framework of flow and measured with a technique called the Experience Sampling Method. The study compared engagement and other experiential measures in the last year before the game was introduced and in the year in which the game was fully implemented for the first time. Furthermore, the investigation made attempts to find connections between in-the-moment engagement and characteristics of students and situational factors. Finally, the study compared enrollment rates into an advanced level dynamic systems and control course across years, comparing the percentage of students taking the game-based course who chose to pursue the subject further to that of students who took the course without the game.

Keywords: video games, controls, dynamic systems, student engagement

INTRODUCTION

Recently, we began teaching a core undergraduate mechanical engineering course, Dynamic Systems and Control, with a video game. It is a driving game in which students devise control algorithms that make virtual simulated cars execute nimble maneuvers and keep bicycles balanced.

For decades, education scholars have been studying video games (e.g. [1–5]). What they have found is that the most successful games "teach" their players how to solve complex problems. The problems within a game typically start off rather easy and then progressively get more difficult as players' skills develop. Players are motivated to learn within video games because it is clear that knowledge is powerful. The learning is situated, and occurs through a process of hypothesizing, probing, and reflecting upon the simulated world within the game. The goals are clear. Games provide players immediate and unambiguous feedback on how well they are progressing. Information becomes available to players at just the time they will be able to make sense of it and use it.

Within the highly engaging techniques that game designers employ to get players to "learn" the game, one finds echoes of modern learning pedagogies such as constructionism, inquiry-based learning, and anchored instruction. Much of the emerging scholarship on video game design (e.g. [6–8]) is explicitly grounded in scholarship on cognition, including concepts such as Vygotsky's *zone of proximal development*. Theories of what make video games fun [9] focus on learning and problem solving. According to Koster [9], a game becomes fun when it requires players to gain new skills at a deep level that get "chunked" and absorbed into the subconscious mind, and then requires players to apply the skills/knowledge toward some goal. Furthermore, it remains fun if it requires players to gain new skills/knowledge, or transfer their skills to new problems within the game. Ideally, this is the type of "fun" one would like engineering education to be.

The project described in this article is our second effort to incorporate a video game into an undergraduate engineering course. Previously, we fused a driving/racing game into a core numerical methods course as can be seen in the six minute video available at www.youtube.com/watch?v=LYGwaI-haOM. Although we make no claim that the game reached the ideal described in the previous paragraph, our studies found strong evidence suggesting that students taking the game-based numerical methods course learned the material more deeply, compared to students in six traditional numerical courses taught by four different professors at two universities [10]. Anecdotally, we also noticed a change in the students. They seemed more interested in the course material and more motivated to learn it. They seemed more engaged. Preliminary analyses from our studies here at Northern Illinois University also showed that when students worked with the game in the numerical methods course, they were more engaged than when completing mechanical engineering coursework with traditional methods [11]. They also felt more intrinsically motivated and creative, while at the same time perceived the work to be more challenging and intellectually stimulating.

The project described in this article builds on our previous studies, but focuses on a new context. Within the three year time frame of the project described herein, we redesigned a Dynamics Systems and Control course in order to integrate the video game into the learning process. In this paper, we describe a quasi-experimental study comparing student engagement in the course before it was

redesigned to engagement in the course with the video game intervention (i.e., after redesign). We refer to this as a quasi-experimental study because, for practical reasons, the experimental and control groups were not randomized. Nonetheless, the study had many of the same goals and structural attributes of randomized experiments, including those that make alternative explanations for the causal inference unlikely, as will be discussed further [12].

In this article, we focus on the three questions labeled A, B, and C below:

A. Were students who learned dynamic systems and control with a video game more engaged than students who learned the material, in a more traditional way before the game was incorporated into the class?

B. Which student characteristics and situational factors predicted in-the-moment engagement when learning dynamic systems and control with the video game?

We wondered, for example, whether students with different learning styles would react differently to the game. Since the game is a car/bicycle/motorcycle driving game, we also hypothesized that students more interested in cars, bicycles, and motorcycles than other areas of mechanical engineering specialization might be particularly engaged in the game. We also wondered if the frequency of playing video games on their own would correlate with students' engagement. These issues were investigated as part of Question B above.

Previous studies have found that when students are more engaged and experience greater interest during their coursework, especially in the sciences, they are more likely to pursue a related area of specialization [13]. To get a sense of students continuing interest in dynamic systems and control, we asked a third question:

C. Did taking a game-based introductory dynamic systems and control course have an impact in enrollment in a higher level technical elective on the same subject?

During the three-year project, we also collected data on learning outcomes as measured by concept tests. A preliminary analysis of these results has been published in a conference paper [14]. Currently, we are preparing a companion article in which we plan to present a more thorough comparison of learning outcomes.

In focusing this article only on the engagement component of the project, we assert that the engagement questions are worthy of investigation for their own sake. There is a body of research (e.g. [15–17]) that suggests that the more a student is meaningfully engaged in an academic task, the more that he or she will learn [18]. A recent National Research Council Report [19] proposes a new "strands of science learning" framework that articulates key science specific capabilities for learners. Strand 1 within this framework is to "experience excitement, interest, and motivation to learn about phenomena in the natural and physical world." In fact, the charge to motivate the next generation of students in STEM professions has recently gained a parallel status to educating them. The

two-pronged strategy suggested by the President's Council of Advisors on Science and Technology was suggested in the title of their recent report to the President: "Prepare and Inspire" [20]. The study presented here provides a glimpse into the engaging and inspiring aspect of student experience. The tool we use to measure in-the-moment engagement is well established and in wide-spread use [44]. Nonetheless, we have found scant few references to the technique in the engineering education literature: [11, 18, 21]. From the perspective of engineering education, the study presents a novel approach for observing student engagement.

CONCEPTUALIZATION OF ENGAGEMENT

In this study, engagement is interpreted within the theoretical framework of Flow Theory [22]. "Flow" is a state of deep absorption in an activity that is intrinsically enjoyable, as when artists or athletes are focused on a peak performance. Individuals in this state perceive their performance to be pleasurable and successful, and the activity is perceived as worth doing for its own sake, even if no further goal is reached [23]. The individual functions at his or her fullest capacity, and the experience itself becomes its own reward [24, 25]. Highly creative artists and scholars have reported the experience of flow when engaged in their best work [26]. Flow experiences are based on a symbiotic relationship between challenges and skills needed to meet those challenges. Flow occurs when individuals stretch the limits of their abilities to meet challenges, such that skills are neither overmatched nor underutilized. [23]

Recent research has found that adolescents report the highest levels of flow during active leisure activities, especially during games and sports [27]. Studies applying flow theory to the classroom setting have found that students are most engaged in activities that are, in a sense, game-like: those perceived as relevant and offering appropriate challenges to students skills, such that students feel active and in control [28]. Mathematics and engineering classes typically offer challenge and relevance, but not the activity level and autonomy necessary to provoke the feelings of enjoyment, interest, and excitement experienced while playing a game.

Based on flow theory, student engagement was therefore conceptualized as the simultaneous occurrence of high concentration, enjoyment, and interest [28]. This conceptualization is meant to capture experiences combining the focused, disciplined aspects of work with enjoyable aspects of leisure. When the enjoyment of leisure activities are combined with the focus exacted in productive and skill-building activities, a state engagement is produced that feels like both work and play characteristic of flow experiences [29].

In addition, Flow is recognized as one of the important themes in the scholarship of video game design [6–8]. Two recent, highly acclaimed games, *flOw* and *Flower* (http://thatgamecompany.com/

games/) were designed based on the concept of flow. Flow theory has also been a theoretical base for exploring the implications of "e-learning" through educational video games due to participants' sense of immersion or being enveloped in a virtual reality, which can precipitate a deeper engagement with learning. [30–35]. E-learning games are specifically aimed at the achievement of learning goals through flow experience [36], and are particularly useful for modulating the optimal level of challenge to keep players immersed and on the edge of their abilities [2]. Scales developed for evaluating enjoyment in playing e-learning video games, called "GameFlow" or "EGameFlow," help designers to identify strengths and flaws in their programs from the learner's point of view [36, 37].

DYNAMIC SYSTEMS AND CONTROL BEFORE THE VIDEO GAME

Before 2008, the Dynamic Systems and Control course at Northern Illinois University was fairly typical. The course began with modeling and simulation of rather simple, canonical, electrical and mechanical systems. Students were taught to linearize nonlinear systems and to analytically investigate stability and frequency response. They learned the basics of feedback control using the mathematical framework provided by Laplace transforms, transfer functions, and block diagrams. Students learned how to design PID controllers that satisfy specified performance criteria (e.g. rise time, settling time, percent overshoot). In the last few weeks of the course, students learned root-locus design techniques. As the semester was finishing, we would start to think of controllers as filters and we laid the groundwork for frequency response design techniques.

The course was also typical in the sense that it was organized around a textbook (e.g. [38–41]). The text influenced the order in which material was taught, the notation used, and the level of mathematical rigor. To some degree, perhaps through its organization, the text fostered a deductive learning environment in which theory was often presented first, followed by applications of the theory.

A little less than half of the assignments were taken from the textbook. Many of the remaining assignments were mini-projects based on Simulink simulations of mechanical systems (e.g. pendula, inverted pendula, mass-spring, and hydraulic systems). Other assignments were laboratory projects centered on physical hardware in which students modeled, simulated, analyzed, and designed controllers for electric motors and position servo systems. The motivation for providing students opportunities to study and control real hardware was that they would see the limitations of the analytical methods in the presence of modeling uncertainty and measurement noise.

Even before introduction of the video game, an active learning environment was built into the Dynamic Systems and Control course. Students were required to work in small groups. They worked

on open-ended problems. They were required to reflect, in writing and orally. They were asked to design and create.

Nonetheless, Dynamic Systems and Control is a difficult subject to teach. It is highly mathematical. Mechanical engineering students find the Laplace transform framework unnatural, not intuitive [41]. They are unaccustomed to thinking of mechanical systems as input/output devices that can be chained together like components of a stereo. We found it difficult to capture students' interest and get them excited to learn the material.

DYNAMIC SYSTEMS AND CONTROL WITH THE VIDEO GAME

In 2008, we began using a video game called *EduTorcs* while teaching Dynamic Systems and Control. We created *EduTorcs* by making substantial modifications to the open-source game, TORCS (www.torcs.org). It is a driving game that has much of the same look and feel as popular commercial games such as *Need for Speed* and *Gran Turismo*. In Figure 1, we show screen shots of the game.

There were times when we played *EduTorcs* like a traditional game, joystick at the ready, and eye-hand coordination put to the test. However, in *EduTorcs*, one normally drives the car or the bike by devising algorithms, rules which take information about the vehicle and its dynamic state (position, velocity) and calculate how much to step on the gas, apply the brakes, and turn the steering wheel. In *EduTorcs*, students code their algorithms in C++ and then compile their program. The game links to the students' programs at run time. Students' algorithms determine whether the Porsche nimbly

Figure 1: Screenshots of the game EduTorcs.
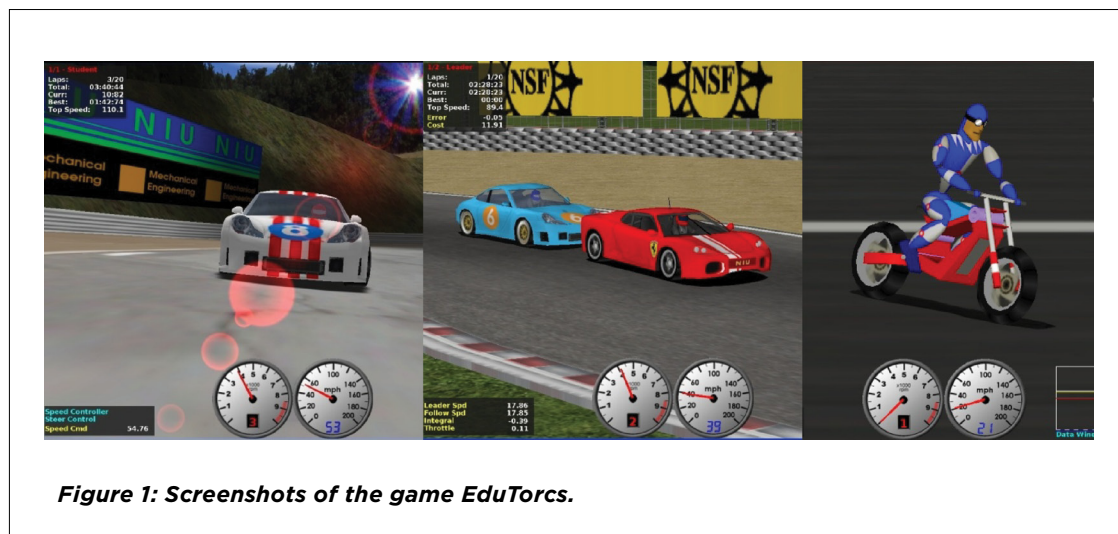
glides through an S-turn at 85 mph, or whether it spins out of control and smashes into the guard rail. Students get immediate feedback as to whether their ideas work.

At the time of writing this, *EduTorcs* is not available to the public at large.

Integrating the Course and the Game

Swain [42], in an article titled "The Mechanic is the Message," argued that in order for a *serious game* (e.g. an educational game) to communicate certain values, ideas, or lessons to a player, the game mechanic(s) must be carefully aligned with the message. Here, "game mechanics" refers to the set of rules and mechanisms which determine how a player interacts with the game environment. Game mechanics establish the goals; they determine how information is shared or hidden. To apply Swain's argument to engineering education, a game should have well designed rules, goals, values, challenges, and interactions that reflect the learning objectives. For example, it would probably not be possible to teach dynamic systems and control using the game mechanics of Pac-Man.

As we were using our driving game, *EduTorcs*, to teach numerical methods we recognized that almost an entire semester's worth of dynamic systems and control course material could naturally fit into the framework provided by the game. If we developed a bike simulation for the game as well, we could fit all of the course content. So in 2008, we began experimenting with different ways of structuring goals, developing interfaces, and embedding specific dynamic systems and control learning outcomes into the game. As described in [43], some attempts were flat-out failures whereas others seemed to work. By the Spring of 2009, we had the game (with bike simulation) fully integrated into the dynamic systems and control course.
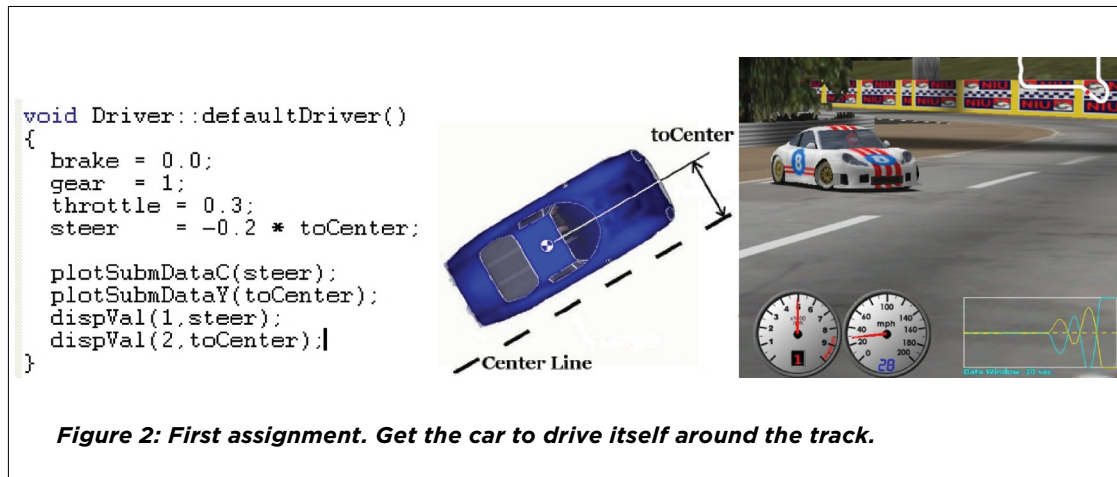
The first assignment.

When one builds a course around a video game rather than a textbook, priorities shift. For example, it is natural to look to the techniques that good video games use to engage their players. One, almost universal, principle of good video game design is to start the game with relatively easy challenges for players to face. Then, as the player's skills develop, the challenges intensify. The first game-based assignment we gave the students was to write a small and simple algorithm that makes the car steer itself around a serpentine track at modest speed.

When students received their video game software and ran it on a personal computer, the car sat motionless on a track. To get the car to move, one may write a short program similar to the one shown on the left of Figure 2.

The first line of the program, brake=0.0, tells the simulation to disengage the brakes. The second line, gear=1, puts the transmission in first gear. The third line, throttle=0.3, is equivalent

```
void Driver::defaultDriver()
{
  brake = 0.0;
  gear  = 1;
  throttle = 0.3;
  steer     = -0.2 * toCenter;

  plotSubmDataC(steer);
  plotSubmDataY(toCenter);
  dispVal(1,steer);
  dispVal(2,toCenter);
}
```

Figure 2: First assignment. Get the car to drive itself around the track.

to pressing on the gas pedal, 30% of full throttle. If the program contains just these three lines, then the car will ease forward, slowly picking up speed until the first turn in the road. Then, the car drives off the track and smashes into the wall. Clearly, the driving algorithm needs a steering command.

To get the car to steer, we suggested that students start with a command similar to the fourth line of code in Figure 2: steer= −0.2*toCenter. The variable toCenter is defined by the student programming interface. It provides the distance [in meters] of the car's lateral sensor from the center line of the track. The signed variable is positive when the car is to the left of the center line and negative when the car is to the right. Therefore, when the car is on the center line, the steer command is set to zero; a zero steer command tells the car to drive straight ahead. When the car is to the left of center, the steer command becomes negative, causing the car to turn toward the right. When the car is to the right of center, the steer command becomes positive causing the car to turn to the left. When the car is farther from the center line, the steering command is larger in magnitude. *EduTorcs* calls the student's driving commands every 0.02 seconds, giving them the opportunity to see feedback in action.

The steering strategy encoded in Figure 2 is one which continuously steers the car toward the center line of the track. To the novice students at the beginning of the semester, it seemed like a good strategy that would work in straight sections of the track and in turns. However, when we compiled the code of Figure 2 and ran it within *EduTorcs*, we encountered an unexpected behavior. The car was able to complete the first turn in the practice track, but shortly afterward, it began zig-zagging. The rightmost picture in Figure 2 shows the car as it experienced the growing lateral oscillations, just before crashing into the side wall.

This is where we handed the problem over to the students. We asked them take on the role of engineer: to fix the controller, to make it steer smoothly around the track as if a competent human was driving the car.

In doing so, we provided them ample guidance. As one of the first steps, we asked students to run a part of the game in which they plug in a joystick and drive the car like in a traditional video game. Unlike a traditional video game, though, *EduTorcs* records data from the joystick input. Afterward, students could examine the data and observe how the feedback controllers locked inside their subconscious minds are able to execute aggressive maneuvers and then damp out the lateral oscillations.

By studying the data, students discovered the key feature of the controllers inside their subconscious minds which permitted them to damp out the oscillations. Compared to the controller of Figure 2, they observed that their personal internal controllers advanced the phase of the joystick input. What does this mean? The phase advance is the result of our minds anticipating: we humans naturally begin to execute the turn before the car crosses the center line. To make the software-based controller work, we asked students to search the API and try to figure out how to incorporate that same type of anticipation. All of them figured it out, some with a little assistance.

Throughout that first exercise, students were learning about the game software. Also, they were hypothesizing, probing, reflecting. They were trying to solve a problem. It has been our experience that engineering students like to tinker and to try to figure out how to make things work. As students played, they discovered a key concept in the course: anticipation damps out oscillation.

In control theory, this concept is called derivative action or lead compensation. Normally, in a textbook-based class, derivative action is introduced several weeks into the semester. After Laplace transforming, drawing the block diagram, and performing the block algebra, an instructor can derive a closed loop transfer function and examine how the controller gains affect the roots to the characteristic equation. It has been our experience that when we stop the class during such a derivation and ask students who understands the material, most say yes. In fact, some can recite the steps verbally. However, they often fail to integrate the steps in their minds and see the big picture.

In the game-based dynamic systems and control class, we performed the same derivation in the Laplace transform domain. However, we did it a few weeks after the initial *EduTorcs* exercise. The pedagogic goal of the *EduTorcs* exercise was to provide the big picture up front so that the mathematical steps make sense.

The Rest of the Course

The game provided a tool to take a more natural and inductive approach to learning dynamic systems and control. There were several other exercises in the game-based course in which students

had the opportunity to discover key concepts, put them to practice in an authentic setting, and then learn the deeper theory so that it could be generalized. By the end of the semester, students were driving virtual motorcycles and popping wheelies.

As with the original non-game course, a little less than half of the students' assignments came from a textbook or similar source. The remainder of the course was built around the video game. Since introducing the game, we stopped using the physical lab in the course, except for demonstration purposes. The realism of nonlinear dynamics and sensor/actuator noise were incorporated into the simulation environment of *EduTorcs*.

Equivalence of Learning Outcomes

Although introduction of the video game created a dramatically different learning environment, we made every effort to keep the academic content the same, in breadth and in depth. In Year 1 of the project, before the video game was introduced, we developed a series of concept tests. In subsequent years, after incorporation of the game, students were assessed, for purposes of the research project, using the same concept tests that were originally developed for students in the non-game course.

THE STUDY OF STUDENT ENGAGEMENT

As we planned to introduce the video game into the Dynamic Systems and Control course, we also made plans to measure students' engagement. As mentioned earlier, we formulated three research questions related to engagement.

Research Question A: Were students who learned dynamic systems and control with a video game more engaged than students who learned the material in a more traditional way before the game was incorporated into the class?

Research Question B: Which student characteristics (e.g. learning styles) and situational factors (e.g. social collaborations) predicted in-the-moment engagement when learning dynamic systems and control with the video game?

Research Question C: Did taking a game-based introductory dynamic systems and control course have an impact in enrollment in a higher level technical elective on the same subject?

The Experience Sampling Method

Earlier, we outlined a conceptualization of engagement based on flow theory. Research on flow theory has made use of the Experience Sampling Method (ESM) to measure engagement and

subjective mood states of individuals interacting with their natural environment. The ESM measures participants' activity, social partners, and affective and cognitive experiences "in the moment," and therefore does not rely on memory to reconstruct engagement from past experiences. Previous research has demonstrated the ESM to be both a reliable and valid instrument [44].

Participants

Participants were undergraduate mechanical engineering students taking a Dynamic Systems and Control course at Northern Illinois University ($N = 155$) over the period of the 3-year study from 2007 to 2009. We refer to 2007 as Year 1 ($n = 50$), 2008 as Year 2 ($n = 59$), and 2009 as Year 3 ($n = 46$). Year 1 was a control year and did not make use of the video game. It was taught using methods outlined in Section 3. Year 2 of the study was markedly different from the other two. From the course content perspective, it was a time in which we were transitioning the game into the course and experimenting with different ways to construct challenges [43]. Also it was a year scarred by an unusually traumatic event. In February of 2008, while we were in class, a gunman stormed into a (different) classroom on campus and murdered five of the students' classmates, injuring dozens more. Classes resumed a little more than a week later, but the atmosphere on campus was profoundly impacted for the rest of the semester. Because we believe the events of Year 2 unduly contaminated measures of student emotions, we decided to omit data from that year. By Spring of 2009, the campus atmosphere was more normal and the game was fully integrated into the course. Therefore, analyses and results are based on Year 1 and Year 3 participants only ($N = 96$).

All participants were actively pursuing a bachelor's degree in mechanical engineering. Dynamic Systems and Control is a required course for such students, offered only once per year. The sample represented a good cross section of third and fourth year students. Eighty-eight percent of the sample was male. Fifty-eight percent was Caucasian, 14% was Asian, 4% was African American, 3% was Latino, and 21% of the students were from mixed ethnicities.

Procedure

All student participants agreed to wear digital wristwatches that were pre-programmed to sound an alarm 30 randomly selected times per week over 3 separate seven-day periods: once in the beginning (Wave 1), once in the middle (Wave 2), and once toward the end (Wave 3) of the semester in which the course was taken, for a total of 90 alarms or "beeps" per student for the semester. When signaled, each student completed an Experience Sampling Form (ESF) to record their subjective experiences. Because we were particularly interested in engagement while students were working on homework and in labs, we sampled more heavily during the days just before an assignment

was due. However, the beep schedules were randomized within these parameters so that we could sample a good cross-section of students' daily activities.

Student participants were trained on the Experience Sampling procedure during the class just before the first round of data collection began. In the training, students were told to complete an ESF, as soon as possible, after each time their watch alarm sounded. In completing the surveys, students were repeatedly asked the same questions about their different experiences as they participated in the study. In the event that a student could not complete the ESF for several hours after the signal, there was a place on the form where this was to be indicated. Later, these tardy surveys were discarded from the sample. During training and during subsequent class periods, students were explicitly given the opportunity to ask questions about the Experience Sampling procedure. In general, they indicated that they were adequately trained and understood the procedure.

Students completed each ESF on machine readable response sheets, typically taking less than five minutes. They submitted their completed forms to the instructor (the first author) in the classes throughout the week and the week just following the experience sampling.

Measures

In completing the ESF, participants first reported the nature of the activity in which they were engaged at the time the alarm sounded, and who else was doing the activity with them. If the activity was school work, they also indicated the course, instructional format (e.g., class, lab, homework, etc.), and type of technology or software being used, if applicable.

Engagement and Other Perceptions of the Activity

The next item on the ESF asked if the activity felt more like work, play, work and play, or neither work nor play. Then, participants reported their perceptions of the activity they were involved in at the time of the beep. These questions are listed on the left side of Table 1.

The final eleven questions of the survey asked students how they were feeling at the time they were beeped. The right half of Table 1 lists all 11 of the emotions listed on the survey. For all of these items, students responded via selecting one of five different choices on a Likert-type scale ranging from 1 (not at all) to 5 (very much).

Recognizing that many of the survey questions might be measuring the same dimension of experience, we performed a factor analysis using Promax rotation on the ten items related to the perception of one's activity. The factors are provided in Table 1 along with the items from which they were derived. Two factors were associated with eigenvalues greater than one. The first factor, which we labeled, "Intellectual Intensity", consisted of high loadings for *importance to you, interest, challenge, concentration, importance to future goals*, and *skills*. The second factor, which we labeled, "Intrinsic

Questions on perception.	Factor	How were you feeling?	Factor
How much **choice** did you have in what you were doing?	Motiv.	Happy	Pos.
		Creative	Pos.
How **important** was the activity to you?	Intel.	Stressed	Neg.
Was it **interesting**?	Intel.	Excited	Pos.
Was it **challenging**?	Intel.	Bored	**
Did you **enjoy** what you were doing?	Motiv.	Satisfied	Pos.
How hard were you **concentrating**?	Intel.	Irritated	Neg.
Did you feel in **control**?	Motiv.	Relaxed	Neg. #
How much were you using your **skills**?	Intel.	Proud	Pos.
Do you **wish** you were doing **something else**?	Motiv.#	Worried	Neg.
How important was it to your **future goals**?	Intel.	Active	Pos.

Note. The abbreviated factors are "Motiv." = *Intrinsic Motivation*; "Intel." = *Intellectual Intensity*; "Pos."
= *Positive Affect*; and "Neg." = *Negative Affect*. The symbol # denotes items with negative loading; **
indicates items that have low loading in the factors.

Table 1: Questions on the Experience Sampling Survey Related to Perception and Feelings.

Motivation", included high loadings for *choice, enjoy, control*, and *wish to be doing something else*. The wish item had negative loading onto the second factor, meaning that low scores on the item corresponded to higher intrinsic motivation.

A second factor analysis was performed on the 11 ESF items relating to mood. Two factors were associated with eigenvalues greater than one. The first factor, which we labeled, "Positive Affect," consisted of high loadings for *happy, creative, excited, satisfied, proud*, and *active*. The second factor was labeled "Negative Affect" and included loadings for *stressed, irritated, worried*, and *relaxed* (negative loading). Again, the factors are listed in Table 1. One item, bored, did not load highly onto the two factors.

Based upon this analysis, we defined four new composite variables (Intellectual Intensity, Intrinsic Motivation, Positive Affect, and Negative Affect) which we used in our comparisons. The variables were formed by averaging the values of their constituent items. The values of negatively loaded items were reversed. For Intellectual Intensity, $\alpha = .80$; for Intrinsic Motivation, $\alpha = .73$; for Positive Affect, $\alpha = .79$; for Negative Affect, $\alpha = .79$. The item that did not load highly onto a factor, bored, was discarded from the analyses.

Consistent with our conceptualization of engagement discussed in Section 2, we also formed a composite variable for global student Engagement (to incorporate aspects of both intellectual intensity and intrinsic motivation) by combining concentration, interest, and enjoyment ($\alpha = .58$).

Characteristics of the situation

Several characteristics of the learning situation were derived from the ESFs:

1. *Social Partners*. The ESF included questions asking whether students were with an instructor (including teaching assistant), and asking how many classmates they were with at the time of the signal. Students' responses were mapped to three categories used in the study: With an Instructor (including teaching assistant), With One Classmate, and With Two or More Classmates.

2. *Wave*. All ESFs were marked by a researcher for the part of the semester in which the experience sampling occurred. Wave 1 occurred at about week 5, Wave 2 at about week 9, and Wave 3 during week 13 of a fifteen week semester. In the different waves, students were learning different course material and applying it to different problems in the game. For example, during Wave 1, students were deriving simple lane-change control algorithms for the simulated Porsche within *EduTorcs* and assessing performance characteristics at different speeds. In Wave 2, students were designing balancing feedback control laws for the pendu-car (a car with an inverted pendulum attached to its roof) using PD techniques. In Wave 3, students were using root locus techniques to keep bicycles/motorcycles balanced while simultaneously navigating a course.

Student Background Data

In addition, we collected background information on each student so that we could account for any relationships between students' experiences in the dynamic systems and control course and their personal characteristics. These personal background factors were:

1. *General Mechanics Conceptual Knowledge*. In the first week of the semester, we administered a test that assessed students' knowledge of basic mechanics concepts. Items were chosen from the Force Concept Inventory and the Mechanics Baseline Test. Both are reliable and valid [45, 46]. In particular, we chose items which focused on the following topics: (a) relationships between position, velocity, and acceleration, including the meaning of differentiation and integration in calculus; (b) simple consequences of Newton's Second Law, including paths that particle trajectories take; and (c) centripetal acceleration.

2. *Learning Styles*. Students completed Felder and Soloman's Index of Learning Styles [47]. The instrument measures students' learning preferences in four dimensions (Active/Reflective, Sensing/Intuitive, Visual/Verbal, Sequential/Global). The 44-question instrument generates a score between −11 and +11 for each of the four dimensions. Reliability and validity of the Index of Learning Styles for engineering education has been established in [48–50].

3. *Game Use Survey*. We surveyed students on their personal use of digital games, where "digital games" refers to video games, computer games, on-line games, and games on cellular phones and other portable devices. Students were told that the definition does not include *EduTorcs* unless they play the game outside of regular class assignments. The 16-item survey asked students how often they played video games, what types/genres of video games they played, and on what types of platforms.

In the engagement study reported herein, we primarily concentrate on the two items in the survey that focused on overall frequency of play, and frequency of playing sports and driving games in particular (since this is the genre to which *Edutorcs* belongs). The first item was: "How often do you normally play digital games?" Possible responses included "a few hours per day or more"; "a few hours per week"; "a few hours per month"; "a few hours per year"; and "less often or never."

The second item was: "How often do you play sports and driving games." Of those listed in the survey, this is the genre to which *EduTorcs* belongs. To this, students responded: "often," "sometimes," "seldom," or "never."

4. *Student Interests Survey*. Because mechanical engineering is very broad and students may be attracted to the field for very different reasons, we constructed a Student Interests Survey, asking students which types of systems they would like to work with/on when they graduate. The list of 30 types of systems includes some standard ones such as automobiles, aircraft, motorcycles, and robots. The list also includes less canonical mechanical engineering system such as wheel chairs, prosthetic limbs, water desalination plants, and toys. Students were asked to rate the systems on a scale from 1 to 6 according to their level of interest. In order to force students to make some meaningful distinctions in their level of interest between the choices, they were not allowed to assign the same rating more than five times.

Exploratory factor analysis was also performed on the 30 items of the student interest survey. It yielded only two groupings. Both made conceptual sense and possessed high inter-item reliability. The first, which we call Interest in Vehicles, consisted of self-reported interest in automobiles, bicycles, and motorcycles. This factor appeared to be particularly relevant to our study because our video game, *EduTorcs*, simulates automobiles, bicycles, and motorcycles. The second factor, Interest in Electronics, consisted of interest in telecommunications equipment and consumer electronics (e.g. computers, MP3 players, cellular telephones). These are areas not normally thought of as mechanical engineering domains. Composite variables were constructed based on the groupings (for Interest in Vehicles, $\alpha = 0.60$; for Interest in Electronics, $\alpha = 0.57$).

5. *Demographic variables*. Demographic variables such as gender and ethnicity were also derived from student background surveys.

Data Processing

Raw data were machine scanned from the student response forms and stored in an electronic file. We wrote a small program to pre-process the data which deleted outlying survey responses and reformatted the valid responses for importation into SPSS. An ESF entry was deleted if three or more items were unanswered or if the survey was completed more than two hours after the "beep." This resulted in the deletion of approximately 100 ESFs. We retained a total of 5,934 valid self-reports from 96 students, for an average of nearly 62 valid ESFs per student. Response rates for Years 1 and 3 were nearly the same.

Analyses and Results

We focused our analyses only on the self-reports in which students indicated that they were working on homework or labwork for the dynamic systems and control course ($N = 657$ ESFs). In our analyses of the participants and their ESFs, it is important to note that the survey data are structured hierarchically. Because each participant completed one set of background surveys, but multiple ESFs sampling their experience, the data structure consisted of repeated measures of experience within participants. Specifically, 657 surveys were nested within the 96 participants (i.e., each participant contributed some portion of the 657 surveys).

Hierarchical Linear Models (HLM) are an analytic tool for nested data [51]). Within the context of HLM, the repeated measures are considered to reside at Level 1 of the hierarchical structure, while participant data such as survey data resides at Level 2. We constructed a series of two-level regression models which divided the variance in engagement into a within-person (Level 1) and between-persons (Level 2) component. This is done in order to allow us to estimate and predict differences in engagement between participants, as well as the variation in engagement that exists as a single participant moves from one experience to the next.

Research Question A

To test the first research question, raw survey responses were first normalized by individual to generate z scores, such that each individual's distribution of responses was given a mean of 0 and a standard deviation of 1. Responses to each item were therefore transformed to reflect the deviation from that individual's own mean on a standardized scale. For example, a z score of 1.0 for the Engagement variable on a specific activity would indicate that the student's level of engagement is one standard deviation above his or her average, over all reported activities. Because z-scores are measured relative to each student's own experience in academic and non-academic activities throughout the semester, z scores are sensitive to the effect of contextual factors on each student's quality of experience. This sensitivity was considered desirable for comparisons of engagement using a game-based versus a non-game-based approach to mechanical engineering instruction.

Next, we ran a separate regression model to estimate the average difference in each experiential variable of interest between students in Year 1 (without the game) and those in Year 3 (with the game). For each, average experience in the course was predicted with our measure of the experimental condition (Year 3 dummy variable) at level 2, controlling for several other person-level variables: gender, ethnicity, score on the baseline mechanics test, and learning style. Figure 3 provides average experience in Year 1 (without game) and Year 3 (with game), adjusted for these control variables, followed by the T-ratio indicating if the mean difference was statistically significant. Thus, we assessed the effect of the intervention as a difference between Year 1 and Year 3 students ($N = 96$).

Results suggest that students were significantly more engaged in Year 3 when they were working on their game-based homework and labwork, compared to students in Year 1, whose coursework was not game based. Students taking the game-based course experienced significantly more Intrinsic Motivation and more Positive Affect, and significantly less Negative Affect. There was no significant difference in the Intellectual Intensity of coursework reported between Year 1 and Year 3 students.

However, it is worth noting that the coefficient for a level-1 dummy variable indicating if participants were using the game when beeped indicated that the average z-score for Intellectual Intensity was 0.30 higher when students played with the game than when doing their coursework without it
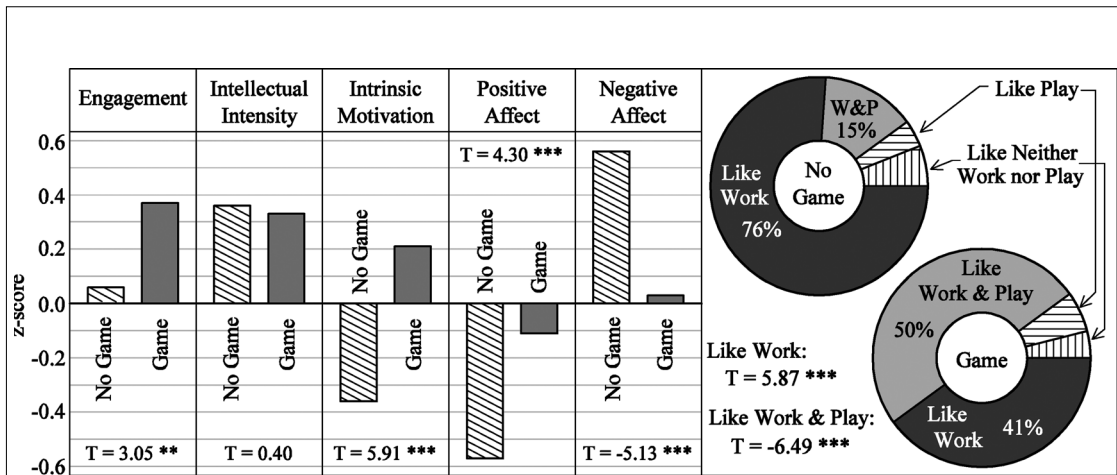
*Figure 3: Comparisons of experiential variables while completing homework and labwork in Year 1 (No Game) versus Year 3 (Game). Charts on the right aggregate responses to the question that asks students whether their homework/labwork felt more like work, play, both, or neither. In all parts of the figure, asterisks denote levels of significance: * p < 0.05; ** p < 0.01; *** p < 0.001.*

($t = 3.09$, $p < 0.01$). In other words, when we compared the difference in experiences (within students, or level 1) in which Year 3 students were playing the video game compared to when they were not playing the game,the difference was statistically significant. This was true not only for Intellectual Intensity, but for all of the other outcome variables as well.

Aggregating responses to the item that asked if the activity felt like work, play, both, or neither while doing homework or labwork yielded an average percentage of time that each student marked a given category. Results are shown in the pie charts on the right of Figure 3. In both years, students responded "like work" and "like work and play" a combined total of 91% of the time. However, in Year 1, the students reported that their coursework felt "like work" the vast majority (76%) of the time. In Year 3, the students reported that their game-based coursework was "like work and play" more frequently than "like work" (50% of the time compared to 41%).

To estimate the percentage of between-persons (level 2) variance accounted for by the experimental condition, we compared the level-2 variance component from a fully unconditional model (i.e., no predictors) to the residual level-2 variance of an unconditional experimental model (i.e., Year 3 dummy was the only predictor). The percentage accounted for was determined by subtracting the residual variance in the unconditional experimental model from the fully unconditional variance component, divided by the fully unconditional variance component [51]. Results showed that 19% of the person-level variance in Engagement was accounted for by the treatment condition. The percentage of variance in the other composite variables accounted for by the treatment condition was as follows: ~0% for Intellectual Intensity, 36% for Intrinsic Motivation, 23% for Positive Affect, 48% for Negative Affect, and 63% for the perception of the activity as like Work and Play.

Research Question B

The second research question asks which student and activity characteristics predict Engagement and the other composite variables we measured. For the analyses, we selected only the participants and self-reports in Year 3 in which students indicated that they were playing the video game.

To test the second research question, we conducted separate two-level models for each of six dependent variables: our five composite experiential variables (Engagement, Intellectual Intensity, Intrinsic Motivation, Positive Affect, Negative Effect), and the perception that the activity was like both Work and Play since it was the category that best represents flow (see Table 2). For all models, dependent variables were raw ESM scores so that effects of independent variables could be interpreted in terms of the scale utilized on the survey. All continuous independent variables were first standardized (using the sample average) and entered uncentered.

A list of the characteristics we tested is provided in the first column of Table 2, beginning with "Female." Though desired, the models could not be estimated with the inclusion of ethnicity variables, likely due to lack of significant ethnic variability. Following "Female," in Table 2 is "Baseline

Fixed Effects	level	Engage-ment	Intellectual Intensity	Intrinsic Motivation	Positive Affect	Negative Affect	Work and Play
Intercept		3.31	3.45	2.98	2.47	2.77	0.39
Female	2	0.83 (0.48)	0.50 (0.45)	1.56** (0.51)	0.60 (0.74)	−1.10 (0.55)	0.40 (0.32)
Baseline Mech.	2	0.17 (0.07)	0.14 * (0.06)	0.20 ** (0.07)	0.17 (0.11)	−0.19 * (0.08)	0.08 (0.05)
LS: Actv/Refl	2	0.10 (0.07)	0.09 (0.07)	0.13 (0.08)	0.06 (0.12)	0.05 (0.09)	0.03 (0.05)
LS: Sens/Intv	2	0.02 (0.08)	0.04 (0.07)	0.02 (0.08)	0.12 (0.12)	−0.07 (0.09)	−0.07 (0.05)
LS: Vis/Verb	2	−0.11 (0.09)	−0.12 (0.08)	0.01 (0.09)	0.06 (0.14)	−0.07 (0.10)	0.01 (0.06)
LS: Seq/Glo	2	−0.05 (0.08)	−0.10 (0.07)	−0.05 (0.08)	−0.02 (0.12)	0.06 (0.09)	0.00 (0.05)
Int. Vehicles	2	−0.01 (0.08)	−0.06 (0.07)	0.11 (0.08)	−0.01 (0.12)	−0.14 (0.09)	0.01 (0.05)
Int. Electr.	2	−0.17 * (0.08)	−0.16 * (0.08)	−0.13 (0.09)	−0.18 (0.13)	0.14 (0.09)	−0.11 (0.05)
Game Freq.	2	−0.24 ** (0.08)	−0.18 * (0.07)	−0.25 ** (0.08)	−0.13 (0.12)	0.18 * (0.09)	−0.15 ** (0.05)
Sports/ Driving	2	−0.02 (0.08)	−0.04 (0.07)	0.06 (0.08)	0.03 (0.12)	−0.07 (0.09)	−0.03 (0.05)
Wave 2	1	0.15 * (0.07)	0.07 (0.07)	0.17 ** (0.06)	0.18 ** (0.07)	−0.29 ** (0.10)	0.23 *** (0.06)
Wave 3	1	−0.03 (0.07)	−0.07 (0.07)	−0.05 (0.06)	−0.02 (0.07)	−0.14 (0.11)	0.002 (0.07)
w/ Instructor	1	0.25 * (0.10)	0.19 (0.10)	0.18 (0.09)	0.19 (0.11)	0.15 (0.15)	−0.05 (0.10)
1 Classmate	1	−0.03 (0.11)	−0.10 (0.11)	0.04 (0.09)	−0.05 (0.11)	−0.03 (0.15)	0.04 (0.10)
2+ Classmates	1	−0.06 (0.08)	−0.06 (0.08)	−0.08 (0.07)	−0.01 (0.08)	−0.03 (0.11)	0.05 (0.07)

*Table 2: Two-level HLM analysis: The Effects of Situational and Personal Factors on Engagement and Experience when Working in EduTorcs (Year 3 only). N (participants) = 46; N (ESFs) = 303. Coefficients for continuous variables are standardized betas. Coefficients for categorical variables indicate the deviation from a baseline variable. Numbers in parentheses are standard errors. Asterisks denote significance: * p $<$ .05   ** p $<$ .01   *** p $<$ .001.*

Mech.," representing students' scores on the baseline mechanics test described in item 1 of Section 5.4.3. The next four characteristics in the table refer to the Felder-Soloman learning styles (LS); respectively they correspond to Active/Reflective, Sensory/Intuitive, Visual/Verbal, Sequential/ Global dimensions.

The "Int. Vehicles" and "Int. Electr." abbreviations for Interest in Vehicles and Interest in Electronics come from the student interest survey and resulting factor analysis discussed in Section 5.4. "Game Freq." is an abbreviation for Digital Game Frequency and "Sports/Driving" represents the frequency at which students played sports and driving games, both derived from the game use survey described in Section 5.4.3.

The above personal characteristics were all level-2 variables, as indicated in the second column of Table 2. The remaining variables listed in the first column are level-1 variables that refer to characteristics of students experience with their homework/lab activities as indicated in their surveys. Recall that level-1 variables are repeated measures that are associated with individual students at level-2. Wave 2 and Wave 3 refer to the week in the semester in which the survey was conducted, with Wave 1 as the default variable.

Finally, "w/ Instructor," "1 Classmate," and "2+ Classmates" refer to the social partners students indicate they are with when they were "beeped." The "w/ Instructor" variable includes instances with the professor or teaching assistant. "1 Classmate" indicates being with one classmate, and "2+ Classmates" refers to two or more classmates. No Classmates was the default category.

All level-2 variables were modeled to predict the intercept only. The only level-1 slope with significant variability among participants was for Wave 2 in which students were using the pendu-car within *EduTorcs*; cross level interaction effects were tested to determine if the Wave 2 slope significantly varied by any of the level-2 variables, but it did not for any of the outcome variables. Subsequently level-2 predictors of the Wave 2 slope were removed from the model, and all level-1 effects were modeled as fixed.

Results of the analysis are displayed in Table 2. The intercepts shown in the first row can be interpreted as the adjusted mean for the dependent variable (controlling for all the variables in the model). For example, 3.31 is the adjusted mean for the Engagement variable. The remaining numbers in each column are the coefficients for the independent variables, with their standard errors in parentheses. For categorical variables, they indicate deviations from a baseline variable. For example, Engagement for females was on average 0.83 higher than for males, and the standard error associated with that mean difference is 0.48. For coefficients that are sufficiently large relative to the corresponding standard errors, we have included asterisks to denote statistical significance.

The analysis suggests a handful of the independent variables were significant predictors. Being female coincided with significantly higher levels of Intrinsic Motivation. Higher levels of general

mechanics conceptual knowledge predicted higher levels of Intellectual Intensity, higher levels of Intrinsic Motivation, and lower levels of Negative Affect. The learning styles produced no significant effects on the dependent variables, nor did Interest in Vehicles, even though *EduTorcs* is a vehicle simulation game. Interest in Electronics, however, appeared to have a negative impact on Engagement and Intellectual Intensity. In addition, playing digital games often outside of class corresponded to significantly lower levels of Engagement, Intellectual Intensity, and Intrinsic Motivation, and higher levels of Negative Affect. Gamers were also less likely to describe their homework "like work and play" than those who played digital games less frequently. Playing Sports and Driving games in particular was not a significant predictor of any of the experiential variables, however. The activity associated with the second wave of data collection had a positive influence on Engagement, Intrinsic Motivation, Positive Affect and Work and Play, and a negative effect on Negative Affect. Wave 3 did not produce a significant effect on any of the outcome variables, however. There was also a significantly positive effect of interacting with the instructor on the Engagement variable, but no other significant effects produced by any of the social partner variables.

The percentage of level-I and level-2 variance accounted for by each model was determined by comparing the residual variance components with those in the fully unconditional model for each dependent variable, and using the appropriate formula stated above. The percentage of level-2 variance accounted for by model predictors was: 23% for Engagement, 22% for Intellectual Intensity, 27% for Intrinsic Motivation, 19% for Positive Affect, 39% for Negative Affect, and 58% for the perception of the activity as like work and play. Model predictors did not account for any (or only negligible) level-1 variance in the dependent variables. Specifically, they accounted for 1% of the level-1 variance in the perception of the activity as like work and play, and none of the variance in Engagement, Intellectual Intensity, Intrinsic Motivation, Positive Affect, and Negative Affect.

Research Question C

In addition to the introductory Dynamic Systems and Control course that was the focal point of this study, there is a second, more advanced course in the subject at Northern Illinois University that students may choose to take as a technical elective after completing the introductory course. It is also cross-listed as a graduate course. The more advanced course is normally offered every other year.

Figure 4 shows the percentage of students, in odd numbered years, who took the introductory Dynamic Systems and Control class in the spring semester and then chose to take the more advanced Dynamic Systems and Control course in the following fall. In calculating the percentages, we did not include students who graduated and left the university between the spring and fall and thus did not have the opportunity to take the advanced course.

There was a significant association between the type of course students took (game vs. no game) based on year taken and whether students chose to take the upper level dynamic systems

*Figure 4: Recent history showing percentage of students in the Dynamic Systems and
Control course who chose to take the more advanced course as a technical elective.*
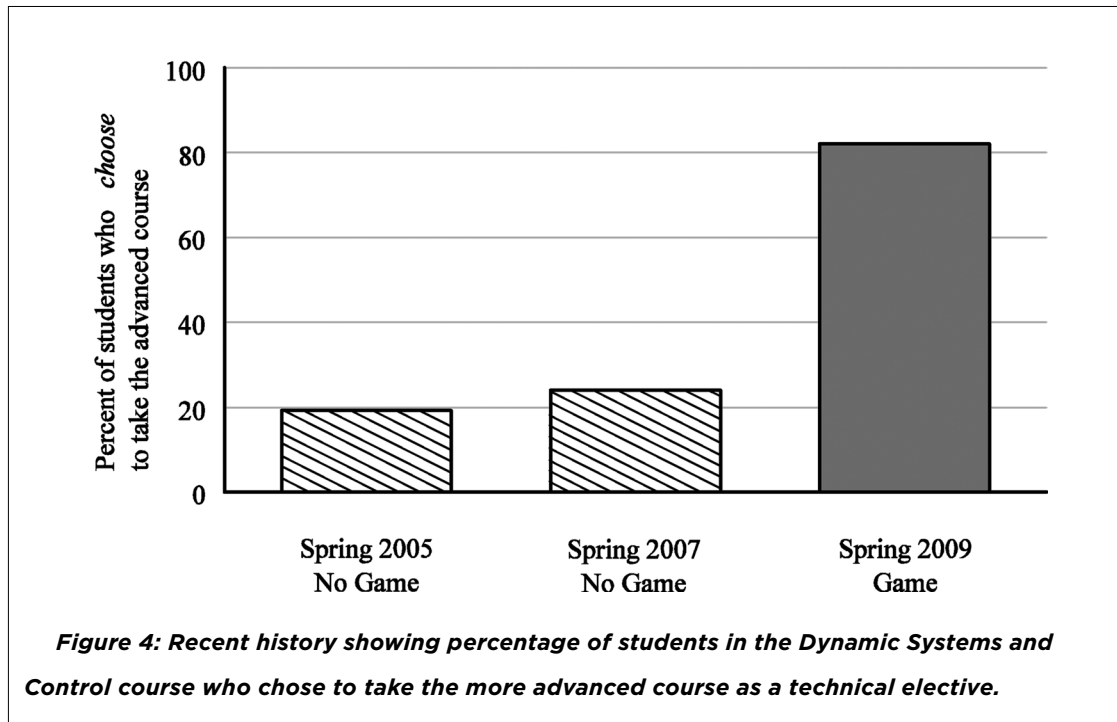
and control course, $\chi^2 = 34.8$, $p < 0.001$. Approximately 80% of the students taking the course in 2009, which is Year 3 of the engagement study, chose the advanced dynamic systems and control course compared to approximately 20% of students in the previous two years. In terms of the odds ratio, the odds of students taking the more advanced course was 20 times higher if the courses were game based.

Summary of Preliminary Results Comparing Learning Outcomes

In addition to the measures of engagement discussed above, we also collected data on student learning. Before and during Year 1 of the study, we created two multiple choice tests, consisting of a total of 96 questions, covering 21 concepts that the instructor (lead author) thought were most important in the Dynamic Systems and Control course. In each year of the study, students took the multiple choice concept test. Although the questions were originally derived in the context of the course without the game, the same questions were used in Years 2 and 3. In all three years, the concept tests were given a few days prior to their midterm and final exams. They were considered practice tests. Students were not allowed to keep the test questions; therefore, there was little chance that students in subsequent years had a chance to see the questions before taking the concept tests.

Currently, we are in the process of writing an article in which we analyze the learning data. The analysis will contain a level of detail similar to that of this paper, in which we explore relationships between test scores and personal characteristics such as learning styles, gaming preferences, and other potential factors listed in Table 2.

Nonetheless, in effort to place the engagement results described above in the context of learning that occurred in the game-based and non game-based dynamic systems and control courses, we summarize preliminary results published in [14]. The article presents results from simple t-test analyses comparing scores from Years 1 and 3 for each of the 21 concepts. In the analysis, we found that students in Year 3 (with the game) scored better, on average, on 18 out of the 21 concepts than students in Year 1 (without the game). In 14 of these cases, the difference was statistically significant at the $p < 0.05$ level. There was only one concept in which students in Year 1 scored significantly better than students in Year 3.

In the more detailed analyses in preparation, we are finding similar results.

DISCUSSION

Results of the present study suggest that students who took the experimental course in Dynamic Systems and Control experienced higher intrinsic motivation, positive affect and overall student engagement during their game-based homework and labwork than students taking the course in a control year who did not play the game as integral to their instruction. Students in the experimental year were also significantly more likely to consider their coursework like both work *and* play, a primary characteristic of flow experiences, than students in the control year who usually perceived their coursework to be "like work." Results suggested that the computer game "treatment" accounted for between 19% and 63% of the variation in between students' average quality of experience when completing homework and labwork in the course. The quasi-experimental design is suggestive with respect to causal inference, but there are other possible explanations for differences in experience between Year 1 and Year 3, especially cohort differences between the two groups and associated covariates. However, these factors cannot explain *within-person* effects of using the video game on the same outcome variables in Year 3. That is, not only were the students in Year 3 higher than the students in Year 1 on most of the experiential variables tested (i.e., all but intellectual intensity), but they also reported higher quality of experience on all experiential variables when they used the game in their homework and labs than when they did not. These latter, within-person results cannot be explained by cohort differences or other person-level confounds that can be responsible for differences between persons. Thus, the

effect of the game on student experience remains even when these alternative explanations are not possible. In keeping with a strong quasi-experimental design [12], alternative explanations created by the lack of randomization were thus rendered unlikely.

Interpreting Greater Engagement in the Game-Based Course

Engineering courses typically offer a high level of intellectual intensity, in which students feel that materials are challenging and important. Even though the between-person difference in Intellectual Intensity between Year 1 and Year 3 students was not significant, the within-person difference in intellectual intensity when playing the game vs. not playing the game among Year 3 students was significant. According to cognitive psychologist, Daniel Willingham[52], the thinking necessary for solving complex problems is slow, hard, and effortful. To be sure, problem solving can be fun and enjoyable, but the conditions have to be just right for thinking for concentration to be pleasurable.

Students who took the course in the game-based experimental year also experienced greater enjoyment and interest in addition to higher concentration, as encapsulated in the Engagement variable. Students often choose to pursue engineering because they like to build things and make things work, not necessarily due to a fondness of mathematics. Although the vehicles which students control in the game-based course are virtual, the process of getting the controllers to work in the simulated environment is real and authentic. We suspect that game-based exercises resonate with students' desire to design and build more than the non-game learning exercises of Year 1 in which, for example, students would watch computer-generated step response plots evolve as one adjusts feedback gains. We suspect that the intrinsic rewards and deep satisfaction derived from solving meaningful problems and making complex systems work may account for the fact that a variety of positive emotions comprising Positive Affect (e.g., feeling happy, creative, active, proud, and satisfied) were also significantly higher during coursework in the game-based year. At the same time, negative emotions like feeling stressed, worried, and irritated were lower than in traditional coursework, likely due to the clear goals and constant feedback inherent to the video game, keeping students informed about their progress at all times, thus reducing their anxiety. Overall, *EduTorcs* appeared to add a measure of spontaneous enjoyment and fun to an academically rigorous course, while reducing the perception that coursework was stressful or merely drudgery.

The findings are consistent with previous ESM research in high school classes revealing that students often report high concentration and challenge (as with important work) or interest and enjoyment (as with spontaneous play), but rarely experience both dimensions simultaneously [28]. Because Intrinsic Motivation and Intellectual Intensity emerged as separate factors in the present sample, this pattern may hold just as well for undergraduate engineering students. When

engineering students performed their coursework with the video game, however, both dimensions were simultaneously higher, however. This fusion of work-like and play-like components of engagement, which has been described as like "playful work" or "serious play" [53, 54] indeed appears to become activated through playing *EduTorcs* as part of a Dynamic Systems and Control course.

Suggestive influence of engagement on learning outcomes

The higher levels of Engagement and other improved measures of experience in Year 3 coincide with what appear to be improvements in learning outcomes. In our preliminary study [14], we found the learning improvements in the Dynamic Systems and Control course to be broadly distributed across most concepts assessed.

Given the gains in learning we measured with an instrument designed to assess the non-game course, and given the similar levels of Intellectual Intensity measured in this study, the findings seem to dispel the belief by some that a video game-based course would be easier or not as academically rigorous. The gains in learning were consistent with what we found when we used *EduTorcs* to teach a different course: computational methods [55]. In that previous study [10], we found that students taking the game-based course generated deeper connections within and between course subjects on a concept mapping exercise.

Currently, we are completing a more thorough analysis of learning outcomes in the Dynamic Systems and Control course, searching for connections between learning outcomes and the personal factors listed in Table 2. To the extent that we continue to find that use of the game enhances learning, we believe that the finding is directly related to their higher levels of engagement with the video game The higher levels of concentration, interest, and enjoyment experienced when working with *EduTorcs* are the emotional ingredients that foster optimal learning [28]. A heightened state of concentration is most likely to occur when a person is working in an area that requires talent or skill [56]. Concentration has been shown to be related to depth of cognitive processing and to academic performance [57,58]. Immersion in video games [33, 35] is central to the concept of flow [34], which has been found to be related to learning and talent development [56]. Nevertheless, the potential influence of engagement on learning outcomes, and more specifically, the hypothesis that engagement mediates the relationship between game use and learning outcomes, remains an empirical question that we will investigate further in our future studies.

Personal and Situational Factors Influencing Engagement with the Video Game

The results in Table 2 on how engagement in game-based learning varied by personal factors seem to contradict some commonly held beliefs and expectations on how a video game would work in engineering education.

First, it is well known that males and females generally prefer different types of video games [59, 60]. Because *EduTorcs* is a sports and driving video game, a genre which tends to be male dominated, one might expect males to respond more favorably to the game-based learning environment. The fact that females did not report significantly different levels of engagement, and did achieve higher levels of intrinsic motivation may be surprising.

Secondly, one might expect video game-based learning to resonate more with students who most enjoy video games in their leisure time. Instead, the data reveal the opposite effect. "Non-gamers" reported a higher quality of experience while working with the video game in almost all respects than the "gamers" who generally played video games more frequently.

Along the same lines, one might also expect that interest in sports/driving games would have an impact on the students level of engagement and the other experiential variables we measured. However, this was not the case.

One possible explanation for the unanticipated results relates to the use and design of the video game itself. All three expectations outlined above assumed that *EduTorcs* is similar to a typical driving game or other commercial video game. It is not, especially within the context of the Dynamic Systems and Control course. For example, commercial driving games are often centered around competition against other players: human players or computer generated (AI) players. To succeed at traditional driving games (i.e. win races), one must get a feel for the car: its cornering ability, its oversteer/understeer characteristics, and its power potential. At high levels of such games, players often choose appropriate cars to race on specific tracks.

EduTorcs, in contrast, especially as implemented in the Dynamic Systems and Control course, had no competition events. In fact, it had only one event for which there were quantitative goals. In 2008, we discovered that quantitative goal structures were often counterproductive in the Dynamic Systems and Control version of *EduTorcs*. In these assignments, students would often "cheat" in ways that would circumvent the learning objectives of the task [43]. Therefore, we created events for the game that had qualitative goals: for example, to figure out how to design a controller that can balance a bike. Other events within the game were exploratory in nature. A good example of this is described in Section 4.1.1 in which students use the game, with joysticks plugged in, to reveal how the controllers locked inside their subconscious minds are able to damp out oscillations.

The goals when playing *EduTorcs* in Dynamic Systems and Control all revolve around exploring, tinkering, figuring out how things work, and designing new features into the systems. This type of play resembles the serious and goal-oriented but fun play of children building with blocks or construction sets, the type of play that inspires many to pursue engineering. This type of play lies at the heart of engineering. Although *EduTorcs* and commercial driving games look very similar on the surface, the game dynamics are very different. The required skills are different. A passion

for fast cars and an encyclopedic knowledge of NASCAR racing probably will not be a great advantage when playing *EduTorcs*. However, a knowledge of calculus and elementary mechanics will. This observation helps to explain why one of the only positive influences on engagement and other experiential measures was a high score on the baseline mechanics test. When we examined the effect of the same independent variables we tested in Year 3 on experience while doing homework and labwork in Year 1, the only significant effect we found was a negative effect of the baseline mechanics score on intrinsic motivation. This suggests that students with advanced knowledge coming into the course, in particular, were more bored by the traditional approach than other students.

With respect to gender, research has shown that male players tend to seek mastery over video games, while females tend to play regardless of their score [59–61]. Females are the dominant players of games like *The Sims*, in which there are no externally defined goals. Although the Dynamic Systems and Control version of *EduTorcs* has the appearance of being a masculine game, the internal game-play may be better aligned with the preferences of females.

The only significant effect of the social partner variables was the positive influence of the presence of an instructor or TA on engagement. This result may have been related to the so-called "grill sessions" built into many of the assignments. Usually it was not sufficient for students to simply get a controller to work. Students also had to explain, orally, how it worked and to justify the choices they made. The instructor used these meetings to encourage and support students to think deeply about the assignment, to make connections to previously covered material, and to preview future topics. The additional support and scaffolding may have enhanced students' engagement. However, we do not know why there was not any significant effect of the other social partner categories.

The activity of focus in Wave 2 was significantly more engaging than those in the other two waves. It was an assignment in which students were given the task of controlling the so-called pendu-car, a car with a pendulum attached to its roof. The objective was to keep the pendulum balanced vertically upward while simultaneously navigating the car around the track. Qualitatively, the pendu-car control problem is dynamically equivalent to riding a bicycle, the subject of the assignment during Wave 3. The assignment in Wave 2, however, had more of a tinkering/exploratory character, while Wave 3 was centered around a more analytical root-locus exercise.

Continued Motivation to Pursue the Dynamic Systems and Control

A recent National Research Council Report [20] proposes a new "strands of science learning" framework that articulates key science specific capabilities for learners. Strand 1 within this framework is to "experience excitement, interest, and motivation to learn about phenomena in the natural

and physical world." The ESM data provide snapshots of elevated levels of engagement, excitement, and motivation while learning the game. The data in Figure 4 showing a dramatic increase in the percentage of students who choose to take the more advanced level dynamics systems and control course as a technical elective depicts a positive change in behavior on a longer time scale, a motivation to learn the material that carries on throughout the summer break and lasts until at least the fall semester. Interest and enjoyment, in particular, have been shown to be the key factors predicting long-term commitment and motivation that can lead to career identity and specialization [13]; this is an important educational goal in its own right [62].

In designing the learning environment for this game-based dynamic systems and control class, we tried to include more authentic elements of designing, building, tinkering, and figuring out how to make things work. We wanted students to see—and really experience—the purpose of the relatively dense mathematical theory that lies at the heart of the Dynamic Systems and Control course. Centering the course around an educational video game, to some extent, appeared to provide this opportunity.

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