Video Game-Based Education in Mechanical Engineering: A Look at Student Engagement

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One of the core courses in the undergraduate mechanical engineering curriculum has been completely redesigned. In the new numerical methods course, all assignments and learning experiences are built around a video/computer game. Students are given the task of writing computer programs to race a simulated car around a track. In doing so, students learn and implement numerical methods content. The article describes a preliminary study to measure student engagement. Results show that students "playing" the video game in their homework are significantly more engaged than when working on homework in other engineering courses.

Key words: video game, serious game, simulation, numerical methods, mechanical engineering, student engagement

INTRODUCTION

At Northern Illinois University, as at many places, undergraduate mechanical engineering students must take a course in numerical methods. The goal of the course is to teach students the fundamentals of how to get a computer to perform calculations that are too difficult or too cumbersome to perform and check by hand. Major themes include discretization, iteration, sources of numerical error, and practical management of that error. These are the fundamentals that undergird most of the modern engineering and scientific computational tools that have become indispensable in contemporary practice.

Despite its importance, it is a challenge to make the material engaging for students. Although the top selling textbooks attempt to make connections to engineering, the homework problems are typically superficial, unconvincing, and uninspiring. An example is presented later in this article. In a companion paper still in preparation, Coller and Scott report that graduating mechanical engineering students, on average, rate their numerical methods course as one of the least important classes in the curriculum.

Since 2005, we have been teaching the numerical methods course with the use of a video game. Technically speaking, it is a "computer game" rather than a "video game." However, we choose not to make the distinction here. The game anchors almost all class instruction, learning exercises, assignments and class projects. The goal was to leverage the aspects of video games that adolescents and young adults find to be highly engaging, and to see if that same engagement was transferable to learning the material in numerical methods.

This article has three threads of discussion. First we outline a general rationale for incorporating a video game into a core mechanical engineering course. Second, we give an example of how the game is utilized. Finally, we present evidence supporting a hypothesis that students taking the game-based engineering course are more engaged in their homework compared to students involved in other engineering coursework. Experiential data was collected through a technique called the Experience Sampling Method or ESM [1]. The findings dovetail a companion study in preparation in which students taking the game-based course spend more time on their course work; they exhibit dramatically better learning outcomes; and they better appreciate the importance of the course material.

WHY A VIDEO GAME?

One should think of video games as a distinct medium or mode of conveying information. What distinguishes the game from other common educational media such as books or videos is the degree of interactivity. Video games require their “players” to respond to events occurring in a simulated world. The players’ actions then affect the way that the simulation unfolds. At the heart of a video game is a computational model of a simulated world. The computational model, however, does much more than determine the “physics” of the video game world. A video game model also provides a series of challenges to test the player. The progression of challenges is often embedded in a storyline that has elements of humor, suspense, or drama. The computational model defines what it means to succeed or to fail. When video game designers put these elements together in compelling ways, they are able to effectively leverage the extra dimensions of engagement within the medium.

Over the past few years, scholars have written a new wave of books and reports urging educators to look to video games for ideas on how to engage students in deep, meaningful learning experiences [2-5]. This was not a completely new idea, however. Academics have studied the engaging power of video games from an education perspective since the 1980s, when the United States was in the midst of a “*Pac-Man* Fever” epidemic [6,7]. However, as video games have evolved dramatically over the past few decades, the thinking about how they can impact education has become more sophisticated.

The goal of video game designers has always been to engage players. In the 1980s, there was also an incentive to keep the games short in duration so that adolescents with pockets full of quarters would keep feeding the machines. Now, video games are primarily sold as software for consumers to play on their home equipment. Video games today are much longer in duration. Since players can even freeze and save a game in progress to be resumed at a later time, the games can last tens or hundreds of hours. The games are no longer simple tests of eye-hand coordination and reflexes. The most successful games often guide their players through rich and complex problem solving processes every bit as complicated, if not more challenging, than the types of homework problems students encounter in their undergraduate engineering courses. Advances in graphics, networking, and computational technologies have provided unprecedented possibilities for immersion into simulated worlds using common off-the-shelf equipment.

As video games are becoming longer, harder, and require more strategic and cerebral investment than ever, they are becoming more popular than ever. The Kaiser Family Foundation [8] recently reported that 83% of children between 8 and 18 years old had at least one video game console in their home; 31% had three or more. Children of all races, genders, and economic status within this age group spend considerable time playing games, 68 minutes per day on average. In September 2007, Microsoft’s video game, *Halo 3,* earned $170M in revenue during its first 24 hours on the market. For comparison, the movie box office record at this time was held by *Spider Man 3,* which took in $151M in its 3-day opening weekend earlier that year.

Learning Principles Embedded in Games

So why is Johnny able to learn and master the intricate cause and effect relationships in the video game, *Roller Coaster Tycoon*, but seemingly unable to grapple with the second law of thermodynamics in his engineering textbook? Spending several hours playing such games suggests a number of answers [2, 9]:

1. When players begin a video game, they plunge into it. They have no need for a manual. The goals of the game are clear. "Players know why they are learning something, and there are plenty of opportunities to apply what they learn." "There is little ambiguity about why knowledge is powerful since the power can be put to use immediately." Feedback as to whether they are achieving the goals is immediate, abundant, and unambiguous. Players are able to achieve initial success fairly quickly, but challenges intensify progressively to keep players at the edge of their abilities. Therefore, time on task is neither mundanely repetitious nor overwhelmingly difficult.

2. To help players progress, the most successful video games establish environments that encourage active and critical learning, and have incorporated, whether intentionally or by accident, the need for superior learning strategies. Player/learners can take risks in a space where real-world consequences are lowered. Necessary knowledge and skills are discovered "from the bottom up" through direct experiences, in a cyclic process of probing, reflecting, hypothesizing, and testing. Information becomes available to players/learners at just the time they are able to make sense of it and to use it.

3. Finally, video games offer their players escapism or fantasy, stirring the imagination with a sense of unlimited possibilities. Players become gnomes, F-16 pilots, world rulers, (or, in our case, even engineers). They experience a virtual world from a compelling perspective that is integral to successful completion of the game.

The learning principles embedded in good video games are consistent with constructivist theories of learning, active learning, and metacognition [10]. The explanation for why Johnny is a video game wizard but cannot pass his engineering exams may lie in the fact that these same learning strategies are often absent from the classroom.

Video Games for Training and Learning

Spurred by a National Academy of Sciences report [11], the U.S. Department of Defense has teamed with the video game industry to create some of the most compelling instructional video games. The game, *Full Spectrum Warrior*, for example, is being used to teach (real) soldiers to be flexible and adaptable to a broad range of operational/combat scenarios. At the same time, a limited version has been released to the public and has become a commercial success. Video games designed primarily for learning and/or training have been classified as "Serious Games" (See www.seriousgames.org). As a video game, *Full Spectrum Warrior* succeeds for the reasons enumerated above. Gee [12] additionally emphasizes that it succeeds an instructional video game due to its "authentic professionalism." As the game teaches the player to be a professional soldier, it demands that the player think, value, and act like a soldier to succeed.

In a recent book, Shaffer [3] frames this feature within the language of epistemology. Video games have the potential of placing students in simulated environments where they face authentic, open-ended challenges similar in nature to those faced by real-world professionals. Because it is a simulated environment, aspects can be tailored to ease students into the roles of professionals. The consequences of failure are dramatically lowered. Students have the freedom to experiment with multiple approaches and learn from their relative success. Of course, the meaning of success is specified by the rules of the game. By defining the rules carefully, so that creative strategies are rewarded over formulaic ones, one may foster a system of meaning-making which requires students to think, value, and act like professionals. Learning is increasingly recognized to be a social and situated endeavor as learners participate within a "community of practice": a group of people who share a concern, passion, or interest in a joint enterprise, and regularly interact in order to do it as well as possible. A profession is a quintessential community of practice [13, 14].

In contrast, the epistemic frame of the traditional school setting, Shaffer argues, is one for which (almost) all questions have right or wrong answers, and the answers can be found in an all-knowing textbook or instructor. To exhibit knowledge is to correctly answer a battery of small, self-contained, narrowly focused examination questions. Generally, this is *not* what is valued in the real world beyond school.

Over the past decade, there has been a small but growing number of educators and researchers who have been experimenting with video game-based or game-enhanced instruction (e.g. [15-21]). However, research into their effectiveness is spread very thinly over a wide range of subject areas, age groups, and educational settings. Canon-Bowers [22] summarized the situation most clearly:

> We have plenty of empirical studies about simulations over the last 25 years. We know simulations work . . . Yet, I challenge anyone to show me a literature review of empirical studies about game-based learning. There are none. We are charging head-long into game-based learning without knowing if it works or not. We need studies.

Similarly, Mayo [23] writes:

> There are perhaps only a handful of solid studies that rigorously measure the learning outcomes of immersive games compared to other teaching methods. Of them, few tackle science and engineering as subject matter.

In the review, Mayo is only able to report on two groups of researchers creating games in physical science and engineering in higher education, one of which is us. The other group, from North Dakota State University, has created games for geology and cellular biology [24]. In a companion paper, we investigate learning outcomes of students in a game-based engineering course. Herein, we take a look at engagement.

A VIDEO GAME FOR ENGINEERING EDUCATION

In the spring of 2005, we began teaching our undergraduate numerical methods class with a video game called *NIU-Torcs*. Screen shots of the game are shown in Figure 1. It has much in common with the *Need for Speed* series as well as *Gran Turismo 4*, which was the second best selling video game of 2005. We built *NIU-Torcs* on top of an existing open-source video game called *Torcs* (www.torcs.org) available under the GNU Public License. *NIU-Torcs* borrows most of the graphics engine of *Torcs*. Among other enhancements, we gave the game a higher fidelity simulation of the car's physics, including the engine, transmission, differential, suspension, tire mechanics, and more. In creating *NIU-Torcs*, we sought to straddle the boundary between rigorous engineering simulation and an accessible video game that could guide students through engaging and authentic engineering problems.

Figure 1: Screen shots of *NIU-Torcs*.

At the beginning of the course, each student receives his or her own car within the video game environment which sits motionless on a track. Unlike a traditional commercial video game, students do not have steering wheels, gearshifts, accelerator, or brake pedals to get the car to move. Instead, each student must write a C++ program that gives the car its driving commands: how much to step on the gas pedal; how much to step on the brake pedal; which gear the transmission should be in; and how much the steering wheel should be turned to the left or the right. The driving program queries from the simulation important information, such as the car's distance from the center line of the track, the heading angle of the car relative to the local heading angle of the track, wheel rotation rates, and copious information about the track itself which students may use in computing their driving strategies. Students compile their driving programs into a library which is then linked to the main *NIU-Torcs* code at run time. Then, students are able to see the fruit of their effort. The car simulation runs in real time, displaying the behavior of the car in full 3D graphics.

Getting the car to simply move and navigate its way around the track is a fairly simple task. We have invited high school students onto campus to play the game; and most were able to accomplish this within an hour or two. Making the car move fast and nimbly without skidding off the road, however, is a challenge that takes nearly fifteen weeks to fully realize. Students calculate the optimal instants to shift gears, the fastest speeds at which the car can navigate each turn, the best moment to begin braking before entering turns, and many more aspects of driving the car at the edge of its capabilities. Students seek sources outside the video game to learn numerical root finding, solving systems of linear algebraic equations, differentiation, integration of functions and ordinary differential equations, curve fitting, and simple optimization. For a detailed description of the tasks, and the numerical techniques used to solve the tasks, the interested reader is encouraged to see [25]. The semester climaxes with an open-ended project in which students form teams and participate in a friendly competition. The final project rewards technical acumen as well as creativity. A six-minute video highlighting the students' work is posted at the web site: www.ceet.niu.edu/faculty/coller/video.htm.

A COMPARISON OF LEARNING ACTIVITIES

To compare the type of learning activity that occurs in the game-based numerical methods course to those that take place in a traditional course (or at least a typical undergraduate textbook), we present the example of root finding. It is one of the most fundamental topics in any undergraduate numerical methods course.

Root finding, a textbook problem.

Below, we have reproduced a typical homework problem from [26], one of most widely used textbooks in engineering numerical methods courses.

> ([26], Problem 2.6) The normal stress induced at the inner fiber of a torsional helical spring is given by
>
> $$\sigma_i = \left\{ \frac{4C^2 - C - 1}{4C(C-1)} \right\} \frac{Mc}{I} ,$$
>
> where $I = \pi d^4/64$, $c = d/2$, $C = D/d$, M is the bending moment, D is the mean coil diameter, and d is the wire diameter. Find the value of C that corresponds to a stress of $\sigma_i = 55{,}000$ psi when $M = 5$ lb-in. and $D = 0.1$ in.

In informal discussions, we found that engineering educators like to assign problems like this. It has an unmistakable engineering context. Furthermore, the problem makes a connection to the students' prior strength of materials course.

However, we get a different perspective when we ask the question "why would a student care about this problem?" The normal stress induced at the inner fiber of a torsional helical spring is not something that naturally inspires the imagination of most 20-year-olds, not even the engineers-to-be. Finding the "correct" answer is not likely to tell them anything that they naturally want to know. Since the correct answer only serves to give them credit toward their grade, students are likely to ignore the engineering context and treat it as a generic math problem.

With luck, students working on the problem above will learn a numerical root finding technique. But, which technique? And what will they learn about it? Chapter 2 of [26] presents eight root finding techniques that can be used in a variety of circumstances. It turns out that any of the eight can be used to solve the torsional spring problem. The problem does not stipulate which technique to use. There is no value to choosing a technique that converges quickly, compared to one with slow convergence. The problem only needs to be solved once so there is little benefit to choosing a technique whose iterative process starts easily. In fact, there is no need to use any of the numerical methods covered by the textbook. Students may use a plotting package to solve it graphically. They may perform a manual search by punching numbers into a pocket calculator. They may find a canned routine that generates the root(s) without requiring any thought at all.

Coller [25] describes these types of problems as "artificial engineering problems" Effectively, they are generic math problems disguised in an engineering context. These problems, and others which have no connection to engineering/science whatsoever, make up the bulk of problems in two of the best selling books geared toward engineering students.

The root of motivation within the game.

In the game-based numerical methods course, the seeds of motivation are sewn in the first week of the semester. As stated in the previous section, students first devise simple algorithms for steering their cars toward the center line of the road as it drives around a serpentine track. The task is not trivial. To figure it out, students must think deeply about how they keep their own car (or bicycle or tricycle) on a desired trajectory, and then encode the scheme into a short computer program. It almost never works correctly on the first try. But students are able to slow down the simulation and carefully compare what their algorithm is doing against what they think it should be doing at each instant of time. In relatively short time, students are able (sometimes with some prompting) to get their cars to smoothly drive a complete lap around the practice track, albeit slowly.

At this point, students generally feel a great sense of accomplishment. For most, it is their first experience writing a computer program that has meaning. Previously, they had spent a semester learning elementary programming by writing programs that sorts generic lists of names and/or averages meaningless collections of numbers. Engineers naturally like to build things. Even though the cars they drive are virtual, the algorithms they develop are real, and the process of deriving the driving strategies is authentic.

Also, engineers like to tinker with things and figure out how to make them work better. While getting the car to drive around the track inspires a sense of pride, the fact that the car reaches a top speed of about 35 mph (56 Km/h) opens the door for many more possibilities. After the first assignment, students immediately begin experimenting. We encourage students to “play” with different ideas and we give them time to do so. They begin writing computer code that speeds up the car in the straights and slows it down for turns. Left to their own devices, students proceed via trial and error to create a tangled mess of computer code that does a mediocre job at driving on the practice track and is completely unable to adapt to different tracks, different pavement conditions, and different cars. Through direct experience, students quickly recognize the need for a systematic approach to creating driving algorithms. They are ready and eager to learn the computational methods that will help them dramatically improve their performance in the game.

A root finding problem within the game.

A few weeks into the semester, students encounter a particularly challenging “level” in the video game. Students’ cars are placed on a long straight section of track, 700 meters from the finish line. Starting from a complete stop, the students’ computerized drivers must bring the car up to speed quickly and cross the finish line within a specified amount of time in order to successfully complete the event.

Since there are no turns in this portion of track, the strategy seems simple: just go as fast as possible. Giving a full throttle command to the virtual gas pedal is easy enough. However, in order to cross the finish line within the allotted time, students must program their drivers to shift gears from first gear contiguously through fourth gear at (almost) exactly the right moments.

Over a duration of two lecture periods, the students and instructor work together to formulate a strategy for calculating the optimal shift points. To summarize, students would drive their cars on an oval track with long straight sections to collect acceleration data. Figure 2a shows the track, while Figure 2b depicts acceleration versus speed data when the small sports car is in full throttle in each of the four gears. Upon examination of the plots, the optimal gear shifting strategy becomes evident: at any given speed, the driver should place the transmission in the gear which produces the largest possible acceleration. Thus the driver should shift from first gear to second gear at the speed for which the first and second gear acceleration curves intersect. Similarly, the optimal shift points from second to third gear and from third gear to fourth gear occur where the corresponding acceleration curves intersect. *Determining these intersection points is a root finding problem.*

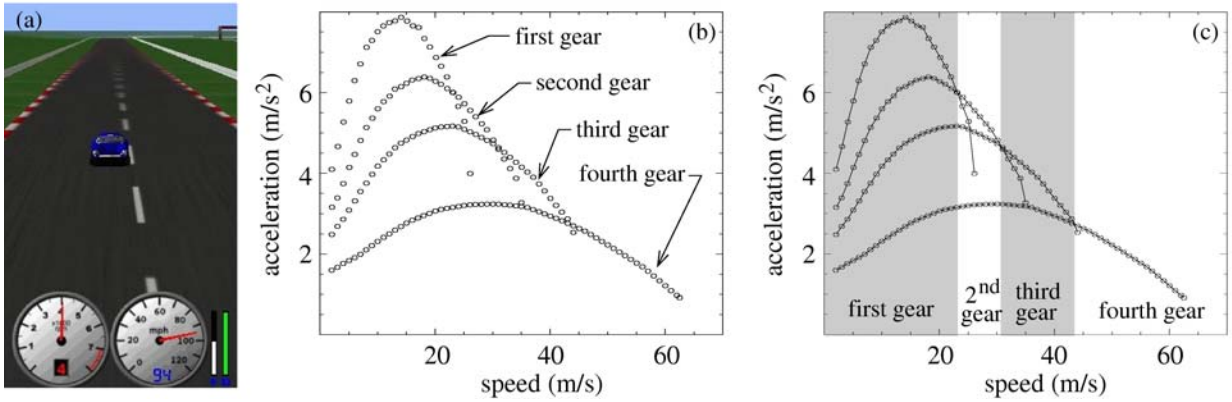

Figure 2. To determine optimal shift points, students must calculate speeds at which acceleration curves intersect. It is an authentic root finding problem.

A different kind of root finding problem.

The root finding problem embedded within *NIU-Torcs* is different from the textbook problem in several respects. First, it arises naturally and authentically through an engineering problem that students *want* to solve. Second, the root finding problem is not a simple self-contained problem that fits conveniently within the confines of a single topic within the course. Like real-world engineering problems, achieving the goal requires students to conquer several technical hurdles and then piece together the facets into a properly functioning whole. In particular, notice that the root finding formulation requires students to obtain acceleration data versus speed for each gear. However, the driver interface does not allow students to query the speed or acceleration of the car directly from the simulation. They do have access to rotation rates for each of the four wheels (which rotate at different rates from each other depending on the braking/acceleration/cornering state of the car.) Students make some engineering judgments and then program a speedometer for their car. Next students must learn how to approximate derivatives of discretely sampled data (another numerical methods topic) in order to estimate acceleration. Furthermore, all root finding routines require continuous representations of functions. Therefore students needed to curve fit the discrete acceleration data (another numerical methods topic).

When it was finally time to perform the root finding, choice of numerical techniques was critically important. Any technique that relied on taking derivatives was doomed to fail: differentiation of discrete data is inherently noisy. Furthermore, students needed a technique that had robust convergence properties. Their shift point calculation methods were supposed to work with any car and any transmission, information students did not know a priori.

In summary, students had to make value judgments that arise naturally out of the problem. This is what happens in engineering practice. Students learned to think, act, and value as engineers do. They took on identities of engineers rather than mere engineering students. As such, the game is used to create a strikingly different type of learning environment compared to that of the textbook.

A LOOK AT ENGAGEMENT

In creating and implementing the video game, we sought to leverage the features of the medium to engage students in difficult but rich learning experiences. In this section we present a preliminary study investigating a hypothesis that students doing numerical methods coursework with the video game *NIU-Torcs* are more engaged than students working on other engineering coursework.

The Experience Sampling Method

The primary instrument for measuring experiential engagement was the Experience Sampling Method (ESM). 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. It is particularly valuable for eliciting the subjective experiences of persons interacting in their natural environments. Previous research has demonstrated ESM as both reliable and valid [1].

Procedure

We sampled the experiences of 51 students in a Dynamic Systems and Control course at Northern Illinois University. This is a required course for undergraduate mechanical engineering students, offered only once per year. The sample represents a good cross section of third and fourth year students. Twelve of the 51 students were concurrently taking the game-based numerical methods course. The relatively small number of participants makes this study somewhat preliminary in nature.

All 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, once in the middle, and once at the end of the spring 2007 semester, for a total of 90 alarms or "beeps." When signaled, each student completed an Experience Sampling Survey (ESS). Because we were particularly interested in engagement while students were working on homework, we asked participants to complete schedules detailing the most likely times of the week for homework completion, as well as times that they could not tolerate random beeping. Beep schedules were therefore individually customized to maximize beeps during homework time and avoid times in which participants preferred not to participate. The schedules were randomized within these parameters, however.

Each time the alarm sounded, students completed an Experience Sampling Survey. They were repeatedly asked the same questions about their experiences as they participated in the study. First, participants reported the nature of the activity in which they were engaged 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. In the next set of questions, 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. Machine readable response sheets accepted answers on a Likert-type scale ranging from 1 (*not at all*) to 5 (*very much*).

Questions on perception.	**Factor**
How much **choice** did you have in what you were doing?	Motiv.
How **important** was the activity to you?	Intel.
Was it **interesting**?	Intel.
Was it **challenging**?	Intel.
Did you **enjoy** what you were doing?	Motiv.
How hard were you **concentrating**?	Intel.
Did you feel in **control**?	Motiv.
How much were you using your **skills**?	Intel.
Do you **wish** you were doing **something else**?	Motiv.#
How important was it to your **future goals**?	Intel.

How were you feeling?	**Factor**
Happy	Pos.
Creative	Pos.
Stressed	Neg.
Excited	Pos.
Bored	**
Satisfied	Pos.
Irritated	Neg.
Relaxed	Neg. #
Proud	Pos.
Worried	Neg.
Active	**

Table 1. Questions on the Experience Sampling Survey related to perception and feelings. 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.

The final eleven questions of the ESS asked students how they were feeling at the time they were beeped. The right half of Table 1 lists all 11 of the feelings listed on the ESS. Again, students responded via selecting one of five different choices ranging from “not at all” to “very much.” The survey typically took less than five minutes to complete.

Data Processing

Raw data were machine scanned from the student response forms into a spreadsheet, and later converted to an SPSS file for analyses. A total of 3,171 self-reports were obtained from 51 participants for an average of 62 responses per student. Recognizing that many of the ESS questions might be measuring the same dimension of experience, we first performed a factor analysis using Promax rotation on the ten items related to the perception of one’s activity. 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 Motivation*, included high loadings for *choice, enjoy, control,* and *wish* to be doing something else. The *wish* item had negative loading in the second factor, meaning that low scores on the item correspond to higher intrinsic motivation. The factors are listed in Table 1 along with the questions.

A second factor analysis was performed on the 11 ESS 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,* and *proud.* 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. Note that there are two items, *active* and *bored*, that 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, α = .81; for Intrinsic Motivation, α = .52; for Positive Affect, α = .79; for Negative Affect, α = .63. In addition, we formed a composite variable for global student engagement (to incorporate aspects of both intellectual intensity and intrinsic motivation) by combining concentration, interest, and enjoyment (α = .59). The two items that did not load highly onto a factor, *active* and *bored*, formed separate, stand-alone dependent variables.

In creating the variables, raw survey responses were normalized by individual to generate *z* scores, so 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 especially for within-person comparisons of engagement using an alternative versus traditional approach to mechanical engineering instruction.

Analysis

In our data collection, we captured 673 instances of 50 students working on homework for engineering courses other than numerical methods. All students were in their third or fourth year, so the other engineering courses tended to be relatively advanced courses in the core mechanical engineering curriculum. We also captured 71 instances when twelve of those same students were completing homework in the numerical methods course using the video game *NIU-Torcs.* We conducted a series of Hierarchical Linear Models (HLMs) [27], computing a coefficient for average engagement and emotions while in other engineering course among the 50 students, as well as a coefficient for the average within-person difference in engagement among the twelve students in the numerical methods course when they completed homework with NIU-Torcs. From these coefficients, means for engagement while completing homework using both approaches were calculated. Means are reported in Table 1 along with the T-ratio associated with the second coefficient, providing a statistical test for the within-person difference in engagement when completing homework with the video game approach versus the conventional approach. Three levels of significance are indicated by asterisks.

The data suggest that students experienced significantly more intellectual intensity, intrinsic motivation, positive affect and overall student engagement when completing homework with *NIU-Torcs* in the numerical methods course compared to homework completion in other engineering courses. They also reported feeling more creative and less worried. Among the greatest differences in terms of magnitude related to the experiential dimensions of interest and enjoyment: students reported being a good deal more interested in their homework, and enjoying it more, when working in *NIU-Torcs*.

Table 2. Z-score means and T-Values related to the difference in experiential variables when completing homework in a numerical methods course (with *NIU-Torcs*) vs. in other engineering courses (within-subject comparison) using two-level hierarchical linear models (HLMs). Sample sizes reflect the number of self-reports, not individuals. Symbols are defined as follows: + $p < 0.10$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Variable	Numerical Methods with *NIU-Torcs*	Other Engineering Courses	T-ratio
Engagement	0.82	0.19	5.90***
Intellectual Intensity	0.96	0.68	3.01**
Intrinsic Motivation	-0.29	-0.52	2.45*
Positive Affect	0.07	-0.18	2.19*
Negative Affect	0.35	0.46	-0.87
Active	0.17	0.08	0.82
Bored	-0.13	-0.02	-1.02
Challenge	0.97	0.76	2.17*
Interest	0.80	0.08	6.70***
Enjoyment	0.13	-0.36	4.67***
Creative	0.69	0.29	3.20**
Worried	0.06	0.36	-2.29*
N	71	673	

DISCUSSION

While only preliminary, results suggest that students experience higher intellectual intensity, intrinsic motivation, and overall student engagement when working in *NIU-Torcs* compared to traditional approaches to homework and classwork in mechanical engineering. By reporting greater levels of challenge and concentration on the one hand, and enjoyment and interest on the other, the experience of students working in *NIU-Torcs* is consistent with concept of engagement and learning through “serious games.” The finding is also consistent with previous research demonstrating that adolescents report the highest levels of engagement during active leisure activities, especially during games and sports [28, 29]. Engineering courses typically offer a high level of intellectual intensity, in which students feel that materials are challenging and important. The video-game approach appeared to significantly raise the level of challenge from traditional homework while adding the experiential characteristics of active leisure pursuits: students also felt active and interested, possibly because goals were clear and feedback about performance was immediate and free-flowing [30]. Feeling more creative and less worried are also hallmarks of peak engagement during active leisure pursuits.

As stated earlier in the article, we have a companion study, involving more students, in which we study learning outcomes. Students taking the game-based numerical methods course are compared directly to students taking traditional lecture/textbook-based courses. The companion paper still in preparation reports that game-based students exhibit more depth of knowledge than their counterparts and the difference is significant. We believe that greater learning found may be directly related their higher levels of engagement. When working in *NIU-Torcs*, students experienced higher levels of *concentration*, *interest*, and *enjoyment*—the emotional ingredients that foster optimal learning [30]. A heightened state of *concentration* is most likely to occur when a person is working in an area that requires talent or skill [31]. Concentration has been shown to be related to depth of cognitive processing and to academic performance [32, 33]. *Immersion* in video games [34, 35] is central to the concept of *flow* [36], which has been found to be related to learning and talent development [31]. In addition, when students are *interested* in an activity, they are more likely to identify with its goals and regard it as personally important [37]. Interest directs attention, stimulates the desire to continue to engage in an activity, and is related to school achievement [38-43]. *Enjoyment*, which includes feelings of fun and pleasure, reflects the perceived competence, and social recognition and support. Enjoyment has also been found to be related to the demonstration of competencies, creative accomplishment, and school performance [31, 38, 44-46]. In sum, when genuine enjoyment and interest are combined with challenge and concentration, students are most likely to be meaningfully engaged in the learning process [47].

CLOSING REMARKS

We feel that it is important to reiterate that, due to the relatively small number of students participating in the engagement study, the results reported herein should be regarded as preliminary. In addition, self-report data can be prone to error (i.e., from falsification, exaggeration, or poor memory), and the correlational nature of the results can render causal relationships only speculative. That said, we find the preliminary results very encouraging. They corroborate ample anecdotal evidence that something special is happening in the class. In more than ten years of teaching engineering, the lead author has never seen so many students eager to learn and eager to take on difficult challenges as he has in the game-based numerical methods course. He has never seen so many students bring their parents, siblings, and friends outside of engineering into the lab to show what they have been doing. The lead author has been surprised to see so many students create videos of their cars in action to show to prospective employers.

In the upcoming months and years, we will be collecting more data. In addition to the types of analyses discussed in this article, we plan to study the role of various individual-level or group factors. For example, is the benefit of using video games on engagement and learning greater for males or females, or for members or certain ethnic groups, or students with certain learning styles or motivational orientations?

Our successful foray into video game-based engineering education has encouraged us to advance the field further. We are making improvements to the video game, and we are expanding its use by incorporating it into a second mechanical engineering course: Dynamic Systems & Control. Students in the new class will develop controllers for the cars and for bicycles and motorcycles. In the near future, we also hope to develop additional games. Stereotypically, cars have a masculine quality associated with them. We have ideas for creating more gender neutral games, and are curious to explore their effect on learning and engagement.

Acknowledgment

The authors gratefully acknowledge the support from the National Science Foundation of the United States under grants 0354557 and 0633162. Any opinions, findings, or conclusions are those of the authors and do not necessarily reflect those of the National Science Foundation. The authors also acknowledge the help of Anna Strati in collecting data used in this study.

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CAPTIONS

Figure 3. Screen shots of *NIU-Torcs.*

Figure 4. To determine optimal shift points, students must calculate speeds at which acceleration curves intersect. It is an authentic root finding problem.

Table 3. Questions on the Experience Sampling Survey related to perception and feelings. 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 4. Z score means and T-test results of students' experience completing homework in a numerical methods course (with *NIU-Torcs*) vs. in other engineering courses. Sample sizes reflect the number of self-reports, not individuals. Symbols are defined as follows: + $p < 0.10$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

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