AC 2010-543: AN INITIAL ANALYSIS OF STUDENT ENGAGEMENT WHILE LEARNING ENGINEERING VIA VIDEO GAME

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An Initial Analysis of Student Engagement when Learning Engineering via Video Game

Abstract

The paper presents data from a multi-year study during which a video game is introduced into a dynamic systems and control course for mechanical engineering undergraduates. The video game, *EduTorcs*, provides challenges in which students devise control algorithms that drive virtual cars and virtual bikes through a simulated game environment. Elsewhere, the authors presented results showing that students taking the game-based course exhibit a better conceptual understanding of course content. Data on student engagement presented in this paper offer a possible explanation of why. On most measures, students taking the game based course have a more positive experience than students who took the more traditional version of the course from the same instructor before the game was introduced. Data were collected through a technique called the Experience Sampling Method and analyzed through the lens of flow theory.

Introduction

One of the most difficult courses in the undergraduate mechanical engineering curriculum is Dynamic Systems & Control (DS&C). Students find the Laplace-domain mathematics unnatural and confusing[1]. Yet, the highly mathematical and abstract topics come in rapid-fire succession. As a consequence, students often resort to coping strategies in which they attempt to memorize formulas and mathematical recipes. The strategies are frequently sufficient for generating “right answers” to narrowly defined textbook problems. And they may be sufficient for earning a passing grade in the course. However, when large numbers of students flounder on open-ended problems that require deeper understanding of the material, it becomes clear that the educational process is not working.

Cognition research[2,13,15] has addressed situations such as these in which students are faced with tasks that do not have apparent meaning or logic. For students to “learn with understanding,” they need to “take time to explore underlying concepts and to generate connections to other [knowledge] they possess.”[2] For several years, our teaching strategy has focused on giving students first-hand experiences with electric motors and balancing devices in the laboratory. We had students generate mathematical models and computer simulations of the systems. They developed and implemented controllers for the systems. We required them to reflect and to exhibit other metacognitive traits.

Recently, we began replacing many of the physical laboratory experiments and textbook exercises with a new type of learning experience. Students experimented on, and developed controllers for virtual dynamic systems within a virtual game-like simulated environment. They were learning dynamic systems and control by playing a video game.

Our motivation for this unorthodox approach came from our experience of using a video game in teaching a different undergraduate course: computational methods. It appeared that students in that course were more engaged in the learning process. Furthermore, in a study using concept maps, we found that students taking the game based numerical methods course expressed a much richer and deeper understanding of the course material compared to students who took more traditional courses without video games[3].

In 2007, we began modifying the video game so that it would fit into the DS&C course. We also began collecting baseline data of learning and engagement of students taking the course before the game was introduced. In 2008, we began transitioning toward a game-based DS&C course[4]. In the Spring semester of 2009, we fully integrated the game, *EduTorcs*, into Dynamic Systems and Control. Furthermore, we repeated the learning and engagement measures in order to make comparisons.

From our mountain of data, an interesting picture is beginning to emerge. As reported elsewhere[5], students taking the game-based DS&C course in 2009 scored significantly higher on a concept test than their counterparts taking the "traditional" course in 2007. In this article, we present an initial analysis of the engagement data. To measure engagement, we used a technique called the Experience Sampling Method which attempts to capture snapshots of students' attitudes and feelings "in the moment." After statistical processing, data are interpreted within the framework of flow theory.[6—9].

Conceptualization of Engagement

"Flow" is a state of deep absorption in an activity that is intrinsically enjoyable, as when artists or athletes are focused during 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[14]. The individual functions at his or her fullest capacity, and the experience itself becomes its own reward[10,11]. Highly creative artists and scholars have reported the experience of flow when engaged in their best work[7]. 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[14].

Recent research has found that adolescents report the highest levels of flow during active leisure activities, especially during games and sports[16]. 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[18]. 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[18]. 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[17].

The Video Game, *EduTorcs*

Our video game is called *EduTorcs*. At its heart, the game is a sophisticated vehicle simulator. It has a realistic computational model for automobile physics. More recently we have added a bicycle/motorcycle model to the game. We have built our video game on top of an existing open-source game called *Torcs* (www.torcs.org). *Torcs* provides the game framework and graphics engine for our game. It synchronizes our simulations so that they run in real time, and it gives *EduTorcs* the look and feel of commercial video games similar to *Need for Speed* or *Gran Turismo*. See Figure 1 for screen shots of the game.

Figure 1: Screen shots from the game *EduTorcs*.

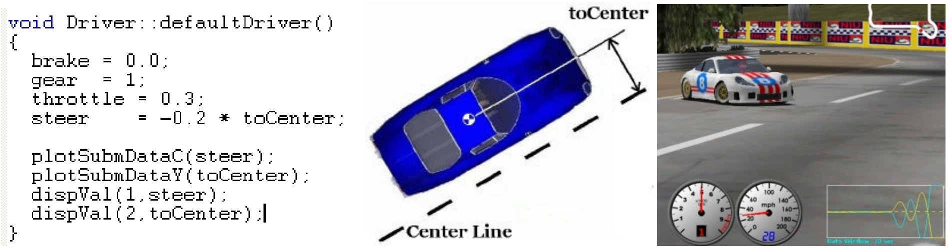
Even with all its similarities, students normally do not "play" *EduTorcs* like a traditional video game. They primarily interact with the game through a software interface that we have created. Instead of spending countless hours, joystick in hand, honing one's eye-hand coordination and reaction skills, our mechanical engineering students improve their "driving" skills by applying tools and techniques of dynamic systems & control, and by applying sound engineering decision-making to the problem. The game's student interface provides access to certain data directly from the simulation. Students write driving algorithms in C++, and their programs get linked to the game at run time.

Our reason for choosing a car driving theme for the game, rather than rockets or airplanes, is because (almost) all our students know how to drive (in real life). Following a constructivist paradigm, we ask students to build upon this foundational knowledge in an effort to devise computational algorithms so that the car can drive itself around the track.

First Steps in the Game

Good video games are designed so that the initial challenges within the game are relatively easy to accomplish. Then, as the player's skills develop, the challenges intensify. Likewise, in *EduTorcs*, we start with a simple task: write a small algorithm that will steer the car around a serpentine track at modest speeds.

When students first run *EduTorcs*, their car sits motionless on the track. To get the car to move, one may write a short program similar to the one shown on the left of Figure 2.



```
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 steps, getting the car to drive around the track.

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 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 suggest 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 interface. It contains 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; negative values of steer command 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. The farther the car is from the center line, the larger the steering command.

The driving function gets called every 0.02 sec. Therefore, driving commands are updated 50 times per second. Students get to see the mechanism of feedback in action. The steering strategy encoded in Figure 2 is one which continuously steers the car toward the center line of the track. It seems like a good strategy that will work in straight sections of the track and in turns.

When we compile the code of Figure 2 and run it within *EduTorcs*, we see that the car is able to complete the first turn in the practice track. Shortly afterward, however, the car begins zigzagging. The rightmost picture in Figure 2 shows the car as it is experiencing the growing lateral oscillations, shortly before it crashes into the side wall.

This is where we hand the problem over to the students. We ask them to fix the controller, to make it steer smoothly around the track as if a sober human was driving the car.

In doing so, we provide them ample guidance. To begin, we ask students to run a part of the game which allows players to plug in a joystick and drive the car like in a traditional video game. There is an important difference, though. *EduTorcs* will record data from the joystick input. Afterward, we can examine the data and observe how the feedback controllers locked inside our subconscious minds are able to execute aggressive maneuvers and then damp out the lateral oscillations.

Students *discover* the distinguishing feature of the controllers inside their minds which permits them to damp out the oscillations. Their personal internal controllers advance the phase of the joystick input, compared to the controller of Figure 2. What does this mean? The phase advance is the result of our minds anticipating. We begin executing the turn before the car crosses the center line. To make the software-based controller work, students must incorporate that same type of anticipation. All of them figure it out, some with a little help.

It has been our experience that engineering students like to build things. They like to tinker. They like to figure out how to make things work. With the video game, all the tinkering takes place in the virtual world. Nonetheless, we suspect that tinkering virtual objects exercises the same cognitive muscles. At the same time, students are absorbing important concepts of automatic control. First, they are witnessing the important role of feedback. Secondly, they discover the powerful role of anticipation (also known as lead compensation or derivative action) in creating stability. The lesson was learned organically without any theorems or integral transformations.

In a typical textbook, the latter principle is presented theoretically, through the mathematics of Laplace transforms, block diagram algebra, and fundamental properties of roots of polynomial functions. Each individual step might make sense in isolation. However, our experience is that students have difficulty integrating all the elements into a coherent, big-picture understanding of how and why derivative action works.

In the game-based dynamic systems & control course, we go through the same derivation, but we do it a few weeks *after* the initial *EduTorcs* exercise. By the time they see the long series of mathematical manipulations, students have a chance to develop an intuitive understanding how derivative action works. They appreciate the technique, and they might have a deeper motivation to see the theory behind it.

Rest of the Game

As the game progresses, challenges become more difficult. Students eventually develop controllers for driving the bike, including stabilization of "wheelies" and riding the bike in the reverse direction so that the steered wheel is in the back. We tackle these challenges in much the same way as lead compensation concept described above. That is, we use the game as an authentic way to introduce students to key concepts *before* we bombard them with mathematics. Concepts include steady state error, integral action, lag compensation, root locus design, Bode-Nyquist design, non-minimum phase systems, and more.

Measuring Engagement

In creating and implementing the video game, we sought to leverage features of the medium to engage students in difficult but rich learning experiences. In this section we present an initial study investigating a hypothesis that students working on game-based DS&C coursework are more engaged than students working on homework for DS&C course without the game.

The Experience Sampling Method

Our 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[12].

Participants

We sampled the experiences of students taking a Dynamic Systems and Control (DS&C) course at Northern Illinois University (N = 155) over the course of the 3-year study from 2007 to 2009. The course was offered once per year. We refer to 2007 as Year 1 (n = 50), 2008 as Year 2 (n = 59), and 2009 as Year 3 (n = 46).

DS&C is a required course for undergraduate mechanical engineering students, offered only once per year. The sample represented a good cross section of third and fourth year students.

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[4]. Also it was a year scarred by an unusual traumatic event. In February of 2008, while we were in class, a gunman stormed into a (different) classroom 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 have decided to omit data from that year.

Procedure

In Year 1 (control year), the course was taught in a way outlined in the second paragraph of this article. The original course was structured to promote active learning, inquiry, and reflection. However, we used traditional tools of engineering education: textbook problems, laboratory exercises on simple elecro-mechanical devices, and standard computation and simulation tools such as Matlab and Simulink. In Year 3 (experimental year), most of the laboratory exercises had been replaced by challenges within the game. Students work out fewer textbook problems. The amount of Matlab/Simulink stayed about the same.

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 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 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. They next completed an item asking if the activity felt more like work, play, work and play, or neither work nor play. 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).

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.

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	Pos.

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.

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 5,934 self-reports were obtained from 96 participants for an average of nearly 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*, *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. Note that 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, α = .73; for Positive Affect, α = .79; for Negative Affect, α = .79. 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 = .58). The item that did not load highly onto a factor, *bored*, formed a separate, stand-alone dependent variable.

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 for comparisons of engagement using an alternative versus traditional approach to mechanical engineering instruction.

Analysis

The central question we seek to answer is whether students in Year 3 (with the video game) experienced a different level of engagement than students in Year 1 (without game), while working on their DS&C course work, outside the regularly scheduled lecture period. In our data collection, we captured 657 instances of the 96 students from Years 1 and 3 while working on homework or lab work for the DS&C course. z-scores scores for all experiential variables were next aggregated by participant, yielding a single average z-score on each experiential variable for each participant while completing lab work or homework in DS&C. Next, independent samples t-tests were utilized to compare mean differences on each experiential variable between Year 1 (control group) and Year 3 (experimental group). Means and t-ratios are reported in Table 2. Three levels of significance are indicated by asterisks.

The data suggest that students experienced significantly more intrinsic motivation, positive affect, and overall student engagement when using *EduTorcs* for homework and lab work compared to the traditional method. There was no significant difference in terms of intellectual intensity or negative affect. Students also reported less boredom when working with *EduTorcs*. Among the greatest differences in terms of specific dimensions of task involvement were related to participants' reports of experiencing more interest, enjoyment, and control when using *EduTorcs*. Emotionally, participants also felt appreciably more happy, creative, and relaxed, while feeling less stressed, irritated and worried when working in *EduTorcs*.

Aggregating responses to the item that asked if the activity felt like work and/or play yielded an average percentage of time that each student marked a given category while doing homework or lab work. Participants in the in the experimental year reported that their homework and lab work with *EduTorcs* felt like work a significantly smaller percentage of time than students using the traditional approach (41% compared to 76%); and they stated that it felt like both work and play a significantly higher percentage of time (50% compared to 15%).

Variable	*Year 1*	*Year 3*	*T-ratio*
Engagement	0.27	0.68	-3.97***
Intellectual Intensity	0.78	0.82	0.49
Intrinsic Motivation	-0.55	0.06	-4.06***
Positive Affect	-0.18	0.22	-2.76**
Negative Affect	0.67	0.19	1.89
Bored	-0.02	-0.22	2.17*
Choice	-0.67	-0.42	-2.45*
Interest	0.17	0.54	-3.37**
Enjoyment	-0.36	0.17	-5.85***
Control	-0.57	-0.14	-3.93***
Happy	-0.55	-0.12	-4.43***
Creative	0.32	0.56	-2.02*
Stressed	0.56	0.20	3.12**
Irritated	0.50	0.12	3.18**
Relaxed	-0.54	-0.13	-4.39***
Worried	0.47	0.11	3.24**
Felt like work	76%	41%	5.87***
Felt like play	4%	6%	-1.13
Felt like work and play	15%	50%	-6.49***
Felt like neither work nor play	6%	4%	0.036
N	50	46	

Table 2. Z-score means and T-Values reflecting the difference in experiential variables completing homework or labwork in year 1 (control) vs. year 3 (*EduTORCS*). Symbols are defined as follows: * $p < .05$ ** $p < .01$ *** $p < .001$.

Discussion

Results suggest that students experience higher intrinsic motivation, positive affect and overall student engagement when working in *EduTorcs* compared to traditional approaches to homework and lab work in mechanical engineering.

Engineering courses typically offer a high level of intellectual intensity, in which students feel that materials are challenging and important. Students using *EduTorcs* experienced comparable levels of intellectual intensity (e.g., challenge and concentration) to students taking the course in the more traditional way (i.e. intellectual intensity was slightly higher for students in the experimental year, but not significantly so). However, their sense of enjoyment, interest, control, and positive emotions was significantly higher than students using the more traditional approach. This appears to indicate that *EduTorcs* added a measure of spontaneous enjoyment and fun to an academically rigorous course, which had the effect of raising students' engagement in interacting with course material.

For students using *EduTorcs*, the experience of homework and lab work took on the experiential characteristics of active leisure pursuits as is evident in students' work/play responses. In the traditional approach, students somewhat predictably experienced their homework and labwork to feel only like work. When working in *EduTorcs*, however, they were much more likely to experience their coursework as both work-like and play-like, the exact combination characteristic of flow and deep engagement in learning. The combination of work-like and play-like dimensions of experience has special significance in contexts for learning, since learning is not always enjoyable, but can be, a condition under which humans will be driven to learn. According to cognitive scientist, Daniel Willingham[19], thinking for humans is slow, hard, and effortful, such that conditions have to be just right for thinking or concentration to be pleasurable. For example, a problem must not be overly complicated, and the correct solution must be perceived as attainable, or most people will give up. At the same time, there is little pleasure obtained if the correct answer is simply given. Video games are particularly effective at allowing users to modulate the challenge of the activity according to their skill level, and continually increase the level of challenge to keep players on the edge of their abilities. Other elements of flow are also present: goals are clear, feedback is immediate, players feel to be in control, and the activity is self-rewarding.

As stated earlier in the article, we have a companion study[5] in which we compared students' performance on a concept test. Students taking the game-based scored better than the non-game students on 18 out of 21 concepts; 14 of the 18 were statistically significant. The non-game students scored significantly better on one concept. We believe that greater learning may be directly related their higher levels of engagement.

Future Directions

In the upcoming months and years, we will be conducting additional analyses in order to determine the relationship between engagement and students' test scores in DS&C, as well as the influence of various personal factors on students' performance and engagement in the course. For example, what effect, if any, does students' background characteristics, prior knowledge, learning style, or motivational orientation have on students' engagement and performance? Did "dosage," or the number of times and duration that students played the game, affect their performance in the course? We will also explore the influence of group dynamics when working with the video game. Were students more engaged when working in groups or with the instructor than individually, and were the effects of social partner mediated by students' background characteristics such as gender or ethnicity? Having now answered our central experimental hypothesis comparing students' engagement and performance in Year 1 to Year 3, answering questions like these will further our understanding of how *EduTorcs* operates to enhance students' mechanical engineering education.

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