Using Computer Simulation and Animation to Improve Student Learning of Engineering Dynamics

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Abstract

This paper reports the longitudinal assessment results of an interactive computer simulation and animation (CSA) learning module that was developed for, and implemented in, an engineering dynamics course. The module aimed to help students learn projectile motion, one of the most important kinematics phenomena in engineering dynamics. Longitudinal assessments were conducted in four semesters involving 304 engineering undergraduates. Pre-post tests that consisted of four technical questions and problems were administered to measure student learning gains. Questionnaire surveys were also administered to determine students' attitudes and experiences with the CSA learning module. The assessment results show that students made an average learning gain of 36 to 85 percent. A total of 58 to 88 percent of the students who responded to the survey indicated positive experiences with the CSA learning module.

Keywords: Computer Simulation, Animation;

1. Introduction

Engineering dynamics is a high-enrollment, high-impact, core course that nearly all mechanical, civil, aerospace, and biomedical engineering students are required to take. This sophomore-level, gateway course covers a broad spectrum of foundational concepts and principles, such as displacement, velocity, acceleration, force, work, energy, impulse, momentum, and vibrations (Hibbeler, 2009; Bedford & Fowler, 2009; Beer, Johnston, Clausen, Eisenberg, & Cornwell, 2009). The course is an essential basis of, and fundamental building block for, many advanced studies in subsequent courses such as vibration, structural mechanics, system dynamics and control, and machine and structural designs.

Many students, however, fail the dynamics course. Barrett, LeFevre, Steadman, Tietjen, White, & Whitman (2010) reported that in the standard Fundamentals of Engineering examination in 2009 in the U.S.A., the national average score on the dynamics exam was only 53%. In a recent survey conducted by the author of this paper at Utah State University, students were asked to share their perspectives about dynamics. More than 60% of the students surveyed used phrases such as "much harder than statics," "extremely difficult," "very challenging," and "I am afraid of it."

Computer simulation and animation (CSA) receives growing applications in the science, technology, engineering, and mathematics education community because it provides a visualization tool to help students learn (Nutter, 2010; Bernadin, Kalaani, & Goforth,

2008; Donnelly, Wu, & Hodge, 2004). For instance, CSA has been developed for and applied in engineering statics (Philpot, Hall, Hubing, Flori, & Yellamraju, 2005), mechanics of materials (Philpot and Hall, 2006), engineering thermodynamics (Huang and Gramoll, 2004), heat transfer (Clark and DiBiasio, 2007), and electronics (Academy of Electronic Media, 2010). Various CSA learning modules have also been developed for engineering dynamics by using computer programming tools such as ADAMS, Apple, Matlab, Working Model 2D, and Adobe Flash (Everett and Elsa, 2006; Flori, Oglesby, Philpot, Hubing, Hall, & Yellamraju, 2002; Flori, Koen, & Oglesby, 1996; Stanley, 2009, 2008).

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Many existing CSA programs use graphs, charts, and curves to show what happens in science or engineering phenomena, but do not show and explain the mathematical equations used to generate those graphs, charts, and curves. Students clearly see "what" happens but may not understand and be able to explain "why" and "how" it happens. In recent efforts by the author of this paper, mathematical modeling was integrated with CSA to help students not only see "what" happens but also understand "why" and "how," or in other words, to help students connect dynamics phenomena with the mathematics behind. A set of interactive CSA learning modules were developed by using Adobe Flash for students to learn dynamics. One module focuses on projectile motion, one of the most important kinematics phenomena in engineering dynamics.

This paper reports recent efforts in assessing the effectiveness of the interactive CSA learning module that focuses on projectile motion. Two assessment questions were:
Question 1: Was the developed CSA learning module effective in improving students' understanding of projectile motion?
Question 2: What were students' attitudes towards and experiences with the developed CSA learning module?

Longitudinal assessments included pre-post tests to assess students' learning gains as well as questionnaire surveys. Assessment data was collected from a total of 304 engineering undergraduates who enrolled in the dynamics class in four semesters. After a brief description of projectile motion and its associated mathematical equations, this paper describes pre-post tests and questionnaire surveys results. Representative student comments are also provided, followed by the discussions of the limitation of the present study. The answers to the two assessment questions are provided at the end of the paper.

2. Projectile motion

Figure 1 shows projectile motion of a particle, with the initial velocity V_o (in m/s) and the initial launch angle θ (in degrees).

The horizontal component V_{ox} of the initial velocity is expressed as

$$V_{ox} = V_o \cdot \cos\theta \tag{1}$$

The vertical component V_{oy} of the initial velocity is expressed as

$$V_{oy} = V_o \cdot \sin\theta \tag{2}$$

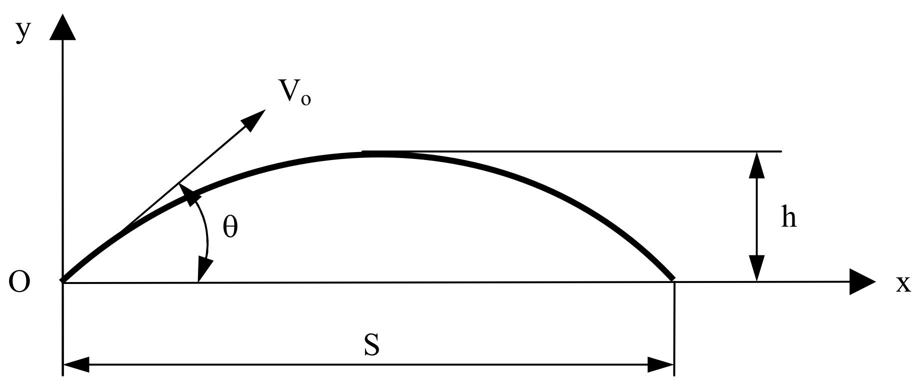

Figure 1. Schematic diagram of projectile motion

Supposing it takes t_m seconds for the particle to reach the maximum height h (ignoring air resistance), we have

$$0 = V_o \cdot \sin\theta - g \cdot t_m \quad (3)$$

where g is gravitational acceleration ($g = 9.81\ m/s^2$). Thus,

$$t_m = V_o \cdot \sin\theta / g \quad (4)$$

The total travel time t_{total} of the particle is calculated as

$$t_{total} = 2 \cdot t_m \quad (5)$$

The total travel distance S (refer to Figure 1) is expressed as

$$S = V_{ox} \cdot t_{total} \quad (6)$$

The maximum height h that the particle reaches (refer to Figure 1) is calculated as

$$h = V_{oy} \cdot t_m - \frac{1}{2} \cdot g \cdot (t_m)^2 \quad (7)$$

All the above equations (1)-(7) are provided on the Graphic User Interface (GUI) of the CSA learning module. The interactive GUI also allows students to change the initial velocity V_o and the initial launch angle θ to see how high and how far the particle reaches, and how the variables V_{ox}, V_{oy}, t_m, t_{total}, S, and h simultaneously change. Therefore, students can connect projectile motion with the mathematical equations that govern the motion.

3. Pre-post tests

The CSA learning module has been implemented and assessed in an engineering dynamics course taught by the author of this paper. Assessment data was collected from a total of 304 engineering undergraduates who enrolled in the dynamics class in four semesters (referred to as Semesters #1-4 in this paper). Table 1 shows student demographics. As seen from Table 1, the majority of students were either mechanical and aerospace engineering majors or civil and environmental engineering majors. Approximately 10% of the students were females.

Table 1. Student demographics (number of students in different majors)

Student major *	Semester #1 (n = 65)	Semester #2 (n = 58)	Semester #3 (n = 128)	Semester #4 (n = 53)	Total (n = 304)
MAE	25	22	72	25	144 (47.4%)
CEE	18	20	34	20	92 (30.2%)
Other	22	16	22	8	68 (22.4%)

* MAE: Mechanical and aerospace engineering
CEE: Civil and environmental engineering
Other: Biological engineering, general engineering, pre-engineering, undeclared, or non- engineering majors

A total of four technical questions were developed and employed in pre-post tests. The first two questions were conceptual questions, and the last two questions required students to do calculations. The four questions are listed below:

Question 1: The magnitude of the horizontal component of velocity _________ during a projectile motion from the beginning to the end.

A) increases and then decreases
B) deceases and then increases
C) remains constant
D) always decreases
E) always increases

Question 2: The magnitude of the vertical component of velocity _________ during a projectile motion from the beginning to the end.

A) increases and then decreases
B) deceases and then increases
C) remains constant
D) always decreases
E) always increases

Question 3: To reach the maximum distance, the initial angle of firing a ball should be (ignoring air friction) _________.

A) 30 degrees
B) 45 degrees
C) 60 degrees
D) None of above, and more information is needed

Question 4: In the motion of a projectile, the initial velocity V_0 of firing the ball is 98.1 m/s at $\theta = 30$ degrees. How long does it take for the ball to reach its highest point?

A) 5 seconds
B) 10 seconds
C) 15 seconds
D) 20 seconds

The average pretest score and the average post-test score were calculated for all students on all pre-post test questions. These two average scores are listed in Tables 2 and 3, respectively.

Table 2. Average pretest score (%) for all students in four semesters

Question number	Semester #1 (n = 65)	Semester #2 (n = 58)	Semester #3 (n = 128)	Semester #4 (n = 53)	Four-semester average
1	67	79	79	68	73
2	72	80	71	69	73
3	79	81	87	89	84
4	51	38	71	16	44

Table 3. Average post-test score (%) for all students in four semesters

Question number	Semester #1 (n = 65)	Semester #2 (n = 58)	Semester #3 (n = 128)	Semester #4 (n = 53)	Four-semester average
1	97	95	97	95	96
2	79	89	90	71	82
3	97	86	93	93	92
4	74	68	93	67	76

Based on the average pre-post test scores, the following equation (Hake, 1998) was further employed to calculate the average learning gain for all students:

$$\text{Average learning gain} = \frac{\text{Average post-test score (\%) - Average pretest score (\%)}}{\text{100 (\%) - Average pretest score (\%)}} \quad (8)$$

Table 4 lists the average learning gain for all students in four semesters. As seen from Table 4, on average, students made 36 to 85 percent learning gains with the CSA learning module.

Table 4. Average learning gain (%) for all students in four semesters

Question number	Semester #1 (n = 65)	Semester #2 (n = 58)	Semester #3 (n = 128)	Semester #4 (n = 53)	Four-semester average
1	91	76	90	84	85
2	25	45	66	6	36
3	86	26	46	36	49
4	47	48	76	61	58

4. Questionnaire surveys

Questionnaire surveys, including both Likert-type items and open-ended questions, were administered in the first two semesters. The following list five Likert-type questions employed in surveys:

1. Compared to other engineering classes, please rate your overall experience using the simulation modules:

   Negative 1 2 3 4 5 Positive

2. I would rate the overall quality of the simulation modules as:

   Low 1 2 3 4 5 High

3. Computer simulations help me understand *the concepts and physics* of dynamics problems:

   Disagree 1 2 3 4 5 Agree

4. Computer simulations help me understand *the mathematics behind* dynamics problems:

   Disagree 1 2 3 4 5 Agree

5. Computer simulations help me understand *the connections between the physics of and the mathematics behind* various dynamics problems:

Disagree 1 2 3 4 5 Agree

Sixty out of 65 students in Semester #1, and 51 out of 58 students in Semester #2 chose to respond to the questionnaire surveys. Table 5 shows the percentage of the students who provided 4 or 5 scales for each survey item. As seen from Table 5, 58 to 88 percent of the students surveyed indicated positive experiences with the CSA learning modules. Table 6 shows the mean and standard deviation of student responses to each survey item. The data shown in Table 6 are consistent in two semesters.

Table 5. Percentage of the students who provided 4 or 5 scales

Survey item number	Semester #1 (n = 60)	Semester #2 (n = 51)
1	85.0	88.2
2	86.7	88.2
3	80.0	86.3
4	60.0	58.8
5	73.3	78.4

Table 6. Mean and standard deviation of student responses

Survey item number	Mean		Standard deviation	
	Semester #1 (n = 60)	Semester #2 (n = 51)	Semester #1 (n = 60)	Semester #2 (n = 51)
1	4.31	4.12	0.73	0.80
2	4.04	4.07	0.66	0.58
3	4.22	4.03	0.95	1.01
4	3.75	3.60	0.98	1.15
6	4.06	3.95	0.95	0.91

In the open-ended questions of questionnaire surveys, students were asked to describe to what extent the computer simulation helped, or did not help, with their conceptual understanding and mathematical understanding of the course content. Representative student comments [original, without editing] are listed in the following paragraphs:

- "When visual and math come together, see and understand much better."
- "I was able to see the math laid out in front of me. Then I can see the physics as it moves in real life. This links the two."
- "They helped me see that happens and see why."
- "I could see how different factors changed the simulation and in what way."
- "They helped me visualize the relationships of how the mathematics changes when the calculations are altered."
- "They are almost like an experiment, so it is more hands on so easy to learn concepts!"
- "They help me connect what is happening conceptually to mathematically."
- "When the mathematics was included in the simulation it helps connect math with physics, so I can know what the outcome will be when I change the variable."

- "The fact that the numbers were changing as I altered elements of the computer simulation made it possible to see how the equation changed immediately."
- "I could see how different factors changed the simulation and in what way."

6. Discussions

Longitudinal assessments through pre-post tests and questionnaire surveys confirm the positive impact of the interactive CSA learning module on student learning. However, the present study is limited in the following two aspects:

First, no control group was involved in the present study. In ideal cases, educational research is supposed to include both experimental and control groups (Gay, Mills, & Airasian, 2006). This means that students are randomly split into two groups: The experimental group learns via the CSA module, and the control group does not learn via it. This presented a challenge at the author's university where it was difficult to schedule a separate classroom (session) for different groups.

Second, the scope of the present study is limited in assessing whether or not the CSA module helps students learn. No efforts were made in the present study to investigate "how" the CSA module helped students learn, that is, how students processed information during their learning. To answer the "how" question, multi-disciplinary collaboration among engineering educators, education psychologists, and neuroscientists is necessary (Bransford, Brown, & Cocking, 2000).

7. Conclusions

This paper has reported the assessment results of the interactive CSA learning module developed for, and implemented in, an engineering dynamics course. This particular module focuses on projectile motion. The answers to the two assessment questions were:

Question 1: Was the developed CSA learning module effective in improving students' understanding of projectile motion?

Answer: The results of the pre-post tests that involved a total of 304 students in four semesters showed that on average, students made 36 to 85 percent learning gains with the CSA learning module.

Question 2: What were students' attitudes towards and experiences with the developed CSA learning module?

Answer: The results of questionnaire surveys that involved 101 students in two semesters showed that 58 to 88 percent of the students had positive experiences with the CSA learning module.

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