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Interactive Computer Simulation and Animation (CSA) to Improve Student Learning of Impulse and Momentum in Rigid-Body Engineering Dynamics

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Abstract

Engineering dynamics is a foundational engineering science course that many undergraduate students struggle with because the course requires students to have a solid conceptual understanding and problem-solving skills. This paper presents an interactive computer simulation and animation (CSA) learning module recently developed to improve student learning of impulse and momentum in rigid-body engineering dynamics. The paper describes the development of the CSA learning module and its important features. A quasi-experimental study involving pre- and post-tests on 134 engineering undergraduates in two groups (comparison vs. intervention) was conducted. The results show that the developed CSA learning module increased the normalized student learning gain by 51.5%.

Keywords: Computer simulation and animation (CSA), impulse, momentum, technology-enhanced science learning

1 Introduction

Among a variety of educational technologies developed to date, computer simulation and animation (CSA) has been receiving growing attention, especially in science, technology, engineering, and mathematics (STEM) disciplines [1] [2] [3] [4]. In most cases, students only need a computer to run CSA programs, which keeps the financial burden on students at a minimum. Research shows that well-designed CSA programs can improve student learning outcomes [5][6].

This paper (maximum six pages) is for a presentation at the *18th International Conference on Learning Technologies and Learning Environments* (LTLE 2025) under one of the conference topics on *Technology Enhanced Science Learning*. The paper describes a CSA learning module recently developed to improve student learning of impulse and momentum in Engineering Dynamics, a foundational engineering science course that many 1st-year or 2nd-year undergraduates are required to take. This course is challenging to many students because it covers numerous concepts and problem-solving procedures, especially those related to impulse and momentum [7] [8]. Fang [9] found that many students have difficulties comprehending impulse and momentum. Saifullah et al. [10] found that students have difficulties in solving relevant problems because they lack conceptual understanding and are deficient in using vectors when applying impulse and momentum concepts.

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The CSA learning module developed from the present study is innovative compared to the existing CSA programs developed for engineering dynamics [11] [12]. The CSA programs developed by Flori et al. [11] and Stanley [12] primarily focused on the CSA's animation function with less focus on step-by-step mathematical modeling. Moreover, their research on the effectiveness of CSA primarily relied on student surveys, which could be subjective.

The following sections describe how the CSA learning module presented in this paper was developed and its important features. A quasi-experimental study was conducted using pre- and post-tests on 134 engineering undergraduates in two groups (comparison vs. intervention). Results are presented, followed by discussions. Conclusions are made at the end of the paper.

2 Computer Simulation and Animation Learning Module

A computer simulation and animation (CSA) learning module was developed in the following steps:

Step 1: Design the learning objective.

Step 2: Design the technical problem addressed in the CSA learning module.

Step 3: Design the features and graphical user interface of the CSA learning module.

Step 4: Design the corresponding computer code.

Step 5: Test and finalize the learning module.

The learning objective was to apply the Principle of Linear Impulse and Momentum and the Principle of Angular Impulse and Momentum to calculate the angular velocity of a rigid body after impact. Figure 1 shows the technical problem addressed in the CSA learning module.

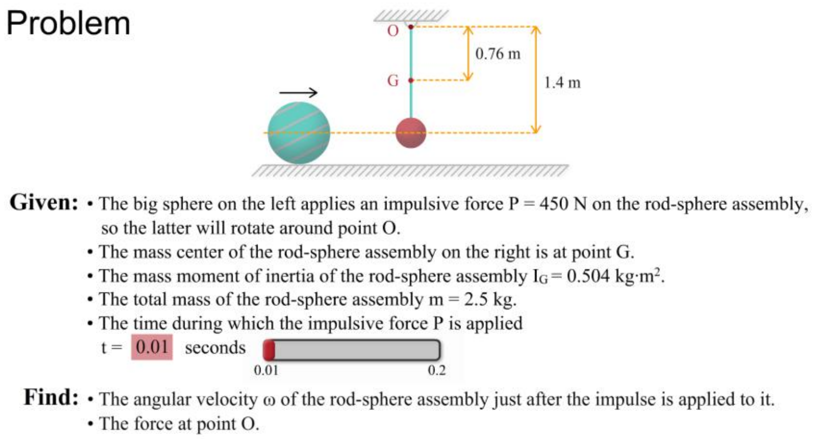

Figure 1: The technical problem addressed in the CSA learning module

The CSA learning module has three important features. First, it has a built-in animation function allowing students to observe how the objects involved move before and after impact, as shown in Figure 2. Second, it provides students with a step-by-step mathematical solution to the technical problem addressed in the CSA learning module. Third, it allows students to change the input (i.e., the time t of the impact) to observe how outputs vary simultaneously. As shown in Figure 3, students can change the value of time t by moving the horizontal bar at the top-right concern of the computer graphical user interface to see how the angular velocity ω of the rod-sphere assembly after the impact changes.

(a) Before impact (b) After impact

Figure 2: The animation feature of the CSA learning module

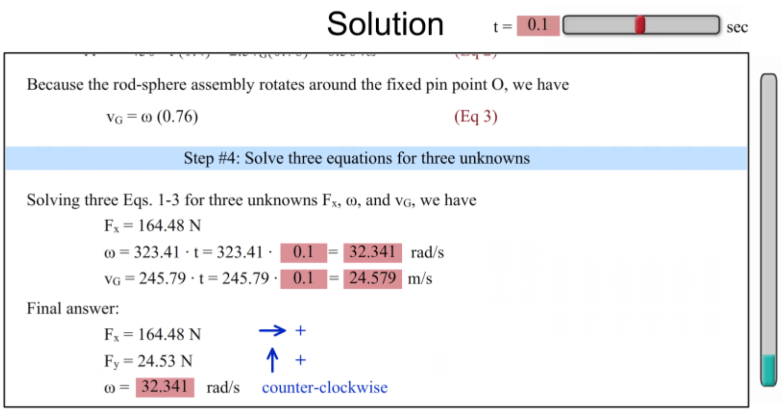

Figure 3: Student interactions with the CSA learning module

3 Research Method and Data Collection

A quasi-experimental study was conducted to answer the following research questions: Did the CSA learning module developed from the present study improve student learning of impulse and momentum in rigid-body engineering dynamics? If yes, to what extent?

A total of 134 engineering undergraduates were recruited over two semesters to participate in the present study. They included 58 students (as the comparison group) in Semester A when the CSA learning module was not employed and 76 students (as the intervention group) in Semester B when the CSA learning module was employed.

All these student participants were from the College of Engineering at the author's institution, a public research institution in the Mountain West region of the U.S. Most student participants were from two departments: Mechanical and Aerospace Engineering as well as Civil and Environmental Engineering. When they participated in the present study, they were also taking Engineering Dynamics and were taught by the same instructor (i.e., the author of this paper) using the same course syllabus. They took the same pre- and post-tests.

Descriptive and inferential statistical analyses were conducted on the collected data. Normalized learning gains were calculated for each student using the following formula [13]:

Normalized learning gain = [Post-test score (%) - Pre-test score (%)] / [100% - Pre-test score (%)]

The group-average normalized learning gains were calculated for comparison purposes.

4 Results and Analysis

Table 1 shows the results of descriptive statistical analysis. The normalized learning gain was 10.7% for the comparison group and 62.2% for the intervention group. In other words, the developed CSA learning module increased the normalized student learning gain by 51.5%.

Table 1: The results of descriptive statistical analysis

Student groups	Pre-test mean (%)	Pre-test SD[a] (%)	Post-test mean (%)	Post-test SD[a] (%)	Normalized learning gains (%)
Comparison group (n = 58)	19.52	16.84	28.13	23.79	10.7
Intervention group (n= 76)	27.38	17.35	72.52	17.01	62.2

[a] SD stands for standard deviation.

The Mann-Whitney U test [14] was further conducted to determine whether there exists a statistically significant difference between intervention and comparison groups. The reason for choosing the Mann-Whitney U test instead of the commonly used t-test was that the data collected from the present study were in non-normal distributions. Table 2 shows the results of the Mann-Whitney U test. Based on the asymptotic significance value (p-value) in Table 2, the difference in the normalized learning gain between the two groups (intervention vs. comparison) was statistically significant. The effect size (Cliff's d) was 0.47, representing a medium effect of the developed CSA learning module on student learning [15].

Table 2: The results of the Mann-Whitney U test

Variables	Mann-Whitney U	Standardized test statistic (Z value)	Asymptotic sig.[a]	Effect size d
Normalized learning gains	1,008.0	-5.41	0.000	0.47

[a] A p-value <0.05 indicates a statistically significant difference between intervention and comparison groups.

5 Discussions

The above-described results confirm the effectiveness of active learning and technology-enhanced learning theories, and the effectiveness of the CSA learning module developed from the present study in improving student learning of impulse and momentum in rigid-body engineering dynamics. Although there was a 7.86% difference in the pre-test score between the two groups, the intervention group outperformed the comparison group by 51.5% in the post-test mean score. In future studies, two fully randomized groups will be involved to minimize the disparity in their pre-test mean score. Assessment work will also be conducted on a longer-term basis on other learning topics, including more student participants.

Although it was not the focus of this paper, a questionnaire survey was conducted on the students in the intervention group to find out why the CSA learning module helped with their learning. Students provided positive comments about their learning experiences with CSA.

Representative student comments are listed below:

- "Being able to visualize what was going on in the problem and gaining a visual of what I was solving for was incredibly helpful."
- "Being able to see the animations and the relations with the equations."
- "Seeing the overall picture of how the system functions and how the concepts are applied to find a solution. It helped to identify what values were given and what needed to be found so that determined which equations to use."

Further analysis of individual student responses to the pre- and post-test shows that the primary challenge students experienced in problem-solving occurred in Step 1: drawing impulse-momentum diagrams. For instance, students included linear momentum only (without angular momentum) on the after-impact momentum diagram and included forces, rather than impulses, on the impulse diagram. If students cannot correctly draw these diagrams in the first step, all mathematical treatments in subsequent problem-solving steps will be wrong.

The reason that students had difficulty in drawing correct impulse-momentum diagrams is related to their lack of understanding and mastery of four higher-order concepts involved: linear impulse (i.e., force times time), angular impulse (i.e., moment times time), linear momentum (i.e., mass times velocity), and angular momentum (i.e., mass moment of inertia times angular velocity). Each higher-order concept involves basic, lower-order concepts, such as force, moment, and velocity. As many lower- and higher-order concepts are involved in problem-solving, students often get confused and cannot determine the similarities and differences between them.

Therefore, although computer simulation and animation (CSA) is a powerful tool to supplement student learning, we recommend developing CSA learning modules that can also help students understand both higher- and lower-order concepts. Future work will be conducted to enhance the functionality of the CSA learning module developed from the present study.

6 Conclusions

This paper has described an interactive computer simulation and animation (CSA) learning module to improve student learning of impulse and momentum in rigid-body engineering dynamics. The results show that students in the intervention group increased the normalized learning gain by 51.5% compared to those in the comparison group. CSA can be used as an effective tool to enhance student learning because it allows students to visualize the technical problems involved and helps students with mathematical modeling. Future work will also be conducted to further improve the functionality of the developed CSA learning module, such as the illustration of both higher- and lower-order concepts.

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