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The Effects of Computer Simulation and Animation (CSA) on Student Learning and Problem Solving in Engineering Dynamics*

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This paper aims to study the effects of computer simulation and animation (CSA) on student learning and problem solving in Engineering Dynamics, a second-year foundational undergraduate engineering course required in many engineering programs. Two new CSA modules were developed, focusing on Newton's second law of motion and the principle of angular impulse and momentum, respectively. A significant amount of qualitative verbal data generated from 24 student participants' think-aloud activities was analyzed based on five of the six categories in the cognitive process dimension of Revised Bloom's Taxonomy: remember, understand, apply, analyze, and evaluate. The research findings from the present study reveal that compared to traditional textbook style (TTS) instruction, CSA enabled students to perform mental activities more frequently in the "understand" category during learning, and more frequently in all five categories (remember, understand, apply, analyze, and evaluate) during problem solving.

Keywords: Computer simulation and animation (CSA); traditional textbook style (TTS) instruction; learning; problem solving; Engineering Dynamics

1. Introduction

1.1 Challenges Students Have in Learning and Problem Solving in Engineering Dynamics

Engineering Dynamics is a second-year foundational undergraduate course that many engineering programs, such as mechanical, aerospace, civil, and environmental engineering programs, require students to take during their undergraduate study. This course is a prerequisite for many subsequent advanced courses, e.g., advanced dynamics and vibration, fluid mechanics, and machine design. In many cases, it is the last introductory engineering course undergraduates must take before they are allowed to enter a professional engineering program, such as a mechanical engineering program [1, 2].

Nevertheless, students widely regard Engineering Dynamics as one of the most challenging courses during their undergraduate study [3, 4]. Built upon Newtonian mechanics, the course covers numerous fundamental concepts, such as Newton's second law of motion, the principle of work and energy, the principle of linear impulse and momentum, and the principle of angular impulse and momentum, as well as numerous problem-solving procedures associated with these fundamental concepts. The course requires students to have strong spatial visualization and analytical skills to successfully learn and solve problems. Spatial visualization skills help students mentally see the motion of objects involved in a problem. Analytical skills help students select and apply correct concepts for effective problem solving.

For example, in solving a particle dynamics problem associated with Newton's second law of motion, students must be able to identify and mentally visualize the type of motion involved, i.e., is the involved motion rectilinear or curvilinear? Then, students must be able to draw correct free-body and kinetic diagrams corresponding to the type of motion identified. Finally, based on free-body and kinetic diagrams and Newton's second law of motion, mathematical equations need to be set up to arrive at a quantitative solution to the problem.

1.2 Instructional Technologies to Improve Student Learning and Problem Solving in Engineering Dynamics

To enhance students' spatial visualization and analytical skills, a variety of instructional technologies have been developed and implemented inside and outside the classroom. These instructional technologies include computer simulations [5, 6], virtual reality [7], augmented reality [8], virtual labs [9], tablet PC [10], audience response systems [11], and so forth. For instance, Karadoğan and Karadoğan [5] developed three computer simulation modules for an Engineering Dynamics course by using C++ and OpenGL graphics library in Visual

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C++ IDE. The three modules included "Crate on the ramp," "Race car on the Track," and "Sliding Box." Eleven students participated in the pretest and posttest to evaluate the effectiveness of computer simulations on student understanding of three important concepts in Engineering Dynamics. Karadoğan and Karadoğan [5] reported that "the number of correct answers students provided in the post-test was 0.92 SD [standard deviation] more than in the pre-test."

Lee and Hwan [6] developed a computer simulation program for students to learn important concepts, such as angular position, angular velocity, and angular acceleration, involved in circular motions. Their computer simulation program was developed using Visual BASIC Programming Language and animated the circular motion of a moving particle at varying time instants and plots the quantitative relationships of angular position vs. time, angular velocity vs. time, and angular acceleration vs. time. A questionnaire survey was administered to solicit student feedback on computer simulations. Lee and Hwan [6] concluded that computer simulations greatly improved student motivation and helped students develop a better understanding of the theories of circular motions.

1.3 The Innovation and Contribution of the Present Study

Although a variety of computer simulations have been developed for Engineering Dynamics and its closely associated physics mechanics courses, existing studies of assessing the effectiveness of computer simulations on student learning and problem solving have two research gaps. First, the vast majority of studies rely on questionnaire surveys and interviews to assess the effectiveness of computer simulations [12–16]. Although questionnaire surveys and interviews are helpful for assessments, they are primarily based on student opinions and feelings, which are subjective rather than objective. Although a few studies involved pretests and posttests [5], quantitative assessments are still uncommon in the vast majority of existing relevant literature. Second, a variety of theories and perspectives [17–19] have been developed to encourage using computer simulations in teaching and learning. For instance, it is argued that computer simulations provide students with hands-on experiential learning opportunities; therefore, they should be employed in educational practices. However, further in-depth studies are still lacking to investigate how computer simulations play a role in students' cognitive processes.

The present study fills in the above-described research gaps. The innovation and contribution of the present study are justified as follows. First, two new computer simulation and animation (CSA) modules focusing on Newton's second law of motion and the principle of angular impulse and momentum, respectively, have been developed in the present study. Newton's second law of motion and the principle of angular impulse and momentum are among the most important topics students must learn and master in Engineering Dynamics. The present study adopts the research method described in the authors' previous work [20], the latter of which involved the development of a CSA module focusing on the principle of work and energy in Engineering Dynamics. The principle of work and energy [20] is a concept different from Newton's second law of motion and the principle of angular impulse and momentum that are addressed in the present study.

Second, a new set of qualitative verbal data generated from student participants' think-aloud activities [21] on two new CSA modules was quantified and analyzed based on five of the six categories in the cognitive process dimension of Revised Bloom's Taxonomy [22]. These five categories include: remember, understand, apply, analyze, and evaluate. The research findings from the present study illustrate how computer simulations play a role in students' cognitive processes.

In the remaining sections of this paper, overall research design and methods for data collection and analysis are described first. Then, the research results are presented and analyzed, followed by the description of the limitations of the present study. Conclusions are made at the end of the paper.

2. Research Design and Data Collection and Analysis Methods

2.1 Student Participants and Overall Research Design

The present study included a total of 24 student participants from two engineering departments: Mechanical and Aerospace Engineering (MAE) and Civil and Environment Engineering (CEE) at Utah State University, a public research institution in the United States of America. These students were taking an Engineering Dynamics course taught by the first author of this paper while they participated in the present study. The students were divided into two groups with 12 students in each group. One group learned Engineering Dynamics through traditional textbook style (TTS) instruction. The other group learned Engineering Dynamics through computer simulation and animation (CSA).

In the TTS instruction, students learned how to solve problems printed on physical papers, like students were reading a traditional, printed textbook. In CSA, students learned how to solve problems embedded in digital CSA learning modules. After learning, both TTS and CSA groups solved new problems printed on physical papers, like students were doing individual homework assignments after classroom lectures.

The two research questions of the present study are as follows:

1. Compared to the TTS instruction, how does CSA affect student learning in Engineering Dynamics?
2. Compared to the TTS instruction, how does CSA affect student problem solving in Engineering Dynamics?

Two case studies were conducted to answer the above research questions. The first case study involved student learning and problem solving with Newton's second law of motion, and the second case study with the principle of angular impulse and momentum. Newton's second law of motion and the principle of angular impulse and momentum are among the most important student learning outcomes in Engineering Dynamics.

Fig. 1 shows the overall research design that includes three components: pretests, interventions, and posttests. In pretests and posttests, the same assessment problems were employed. In interventions, worked example problems were presented in either TTS or CSA format. The assessment problems employed in pretests and posttests were similar to, but not as the same as, the worked example problems employed in interventions.

Table 1 summarizes student groups and their tasks in learning and problem solving. For instance, CSA group I had six students who learned Newton's second law of motion through CSA learning module I. After learning, they solved assessment problem I. TTS group II had six students who learned the principle of angular impulse and momentum through TTS learning module II. After learning, they solved assessment problem II.

2.2 Design of Worked Example Problems

Research has shown that worked example problems help students learn a variety of topics [23–26]. In the present study, two worked example problems were developed, with one problem for students to learn Newton's second law of motion and the other problem for students to learn the principle of angular impulse and momentum. The first worked example problem, named "Particle kinetics: force and acceleration in a relative motion," has the following learning objectives:

1. Develop free-body diagrams for particles in a relative motion
2. Apply Newton's second law of motion to determine forces and acceleration of particles in a relative motion

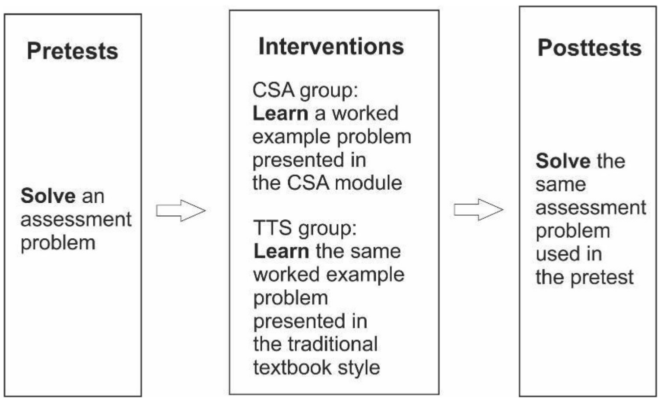
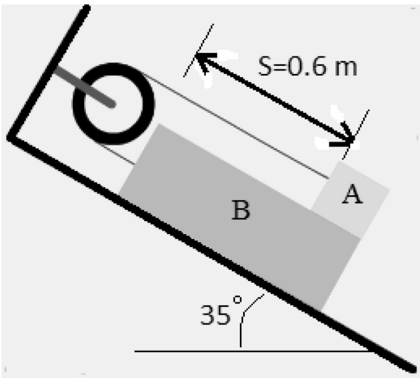


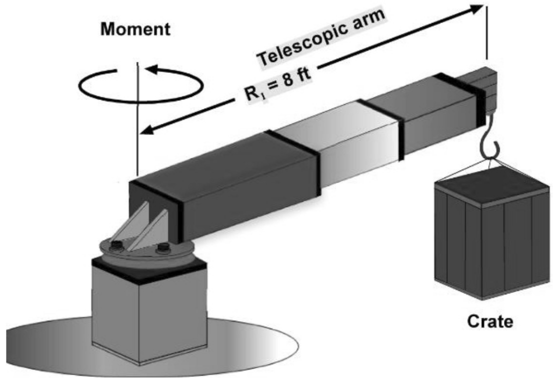
Fig. 1. Overall research design.

Table 1. Student groups and their tasks in learning and problem solving

Student groups	Number of students	Learning worked example problems	Interventions used in learning	Solving assessment problems used in pretests and posttests
CSA group I	6	I: Newton's second law of motion	CSA learning module I	Assessment problem I
TTS group I	6	I: Newton's second law of motion	TTS learning module I	Assessment problem I
CSA group II	6	II: the principle of angular impulse and momentum	CSA learning module II	Assessment problem II
TTS group II	6	II: the principle of angular impulse and momentum	TTS learning module II	Assessment problem II



(a)



(b)

Fig. 2. Worked example problems: (a) Newton's second law of motion and (b) the principle of angular impulse and momentum.

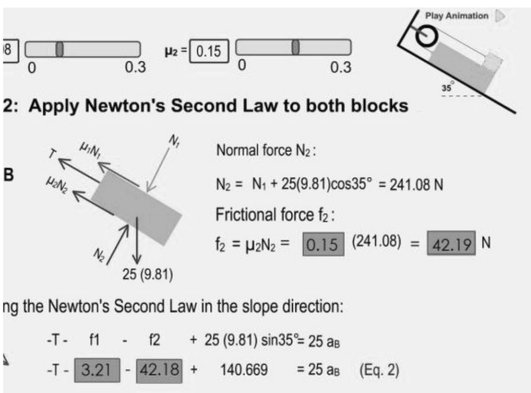
Fig. 2(a) shows the first worked example problem, which is described as follows: Two blocks are placed on a slope with block A on the top of block B. The two blocks are also connected through a cable-pulley system, so block A can move upwards along the top surface of block B while block B moves downwards. The mass of block A and the mass of block B are: m_A = 5 kg, m_B = 25 kg. The slope angle is θ = 35°. The coefficient of kinetic friction between blocks A and B is μ_1 = 0.2. The coefficient of kinetic friction between block B and the slope is μ_2 = 0.3. The total length that bock A can travel over block B from one end to the other end is s = 0.6 m. Determine the tension force T in the cable and the time t that block A travels over block B for the length of s.

The second worked example problem, named "The principle of angular impulse and momentum for particle dynamics," has the following learning objectives:

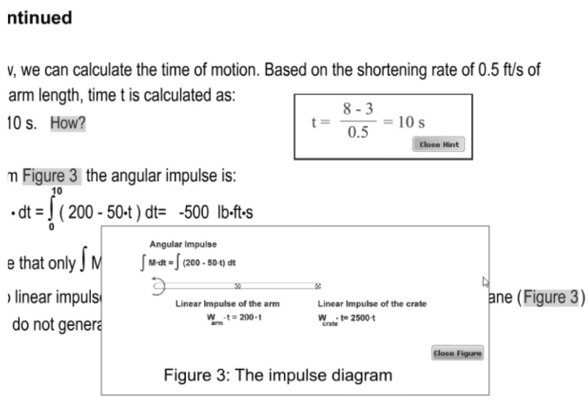
1. Determine angular impulse of a particle undergoing a rotation motion
2. Determine angular momentum of a particle undergoing a rotation motion
3. Apply the principle of angular impulse and momentum to solve a particle kinetics problem

Fig. 2(b) shows the second worked example problem, which is described as follows: A varying moment of M = (200 - 50·t) lb·ft, where t is time, is applied to rotate a telescopic arm of a horizontal crane, as shown in the figure. A crate of 2,500 lb is attached to the tip of the telescopic arm. While rotating, the arm simultaneously shortens its length. The total weight of the arm is 200 lb and its center of mass is assumed to be at the midpoint of the arm all the time. The initial length of the arm is R_1 = 8 ft. The initial speed of the arm tip is v_{arm1} = 1.5 ft/s. As the telescopic arm rotates, its length is shortened at a rate of 0.5 ft/s. Determine the speed v_{arm2} of the arm tip when the arm length is reduced to R_2 = 3 ft.

Each worked example problem was presented in two forms: CSA and TTS. Student participants in the CSA group learned problem solving via CSA learning modules. Fig. 3(a) and (b) show represen-



(a)



(b)

Fig. 3. Representative computer graphical user interfaces of CSA learning modules: (a) Newton's second law of motion and (b) the principle of angular impulse and momentum.

tative computer graphical user interfaces of CSA learning modules for Newton's second law of motion and the principle of angular impulse and momentum, respectively.

The CSA learning modules, developed by using Adobe Flash, have four major features. (1) Students can use the animation function embedded in these learning modules to visualize the motion of objects. (2) Students can change the values of input variables and immediately see how the values of output variables simultaneously change. (3) Hints pop up on the computer screen whenever students click on "hints" buttons. (4) Step-by-step solutions to worked example problems are displayed on multiple computer graphical user interfaces, rather than on one single computer graphical user interface, in order to reduce cognitive loads of students [27].

Student participants in the TTS group learned how to solve worked example problems via TTS paper copies. The following paragraph provides a representative example of the instruction materials provided to student participants for them to learn how to solve the worked example problem focusing on Newton's second law of motion.

> "The next step is to calculate the time that A travel on B. The relative acceleration of block A relative to block B is $A_{rel} = a_A - a_B = 0.8 - (-0.8) = 1.6$ m/s^2. With the distance of s = 0.6 m, one can write the basic kinematic equation of motion as follows: $s = a_{rel} \cdot t^2 + v_o \cdot t + s_o$. That is $0.6 = 1.6 \cdot t^2 + 0 \cdot t + 0$. Hence, t = 0.86 seconds."

2.3 *Design of Assessment Problems Employed in Pretests and Posttests*

Two assessment problems that are similar to worked example problems were developed for use in pretests and posttests. The purpose was to assess if students could transfer what they had learned from worked example problems to solve new problems. Figs. 4(a) and (b) show problems for assessing students' problem-solving skills of applying Newton's second law of motion and the principle of angular impulse and momentum, respectively.

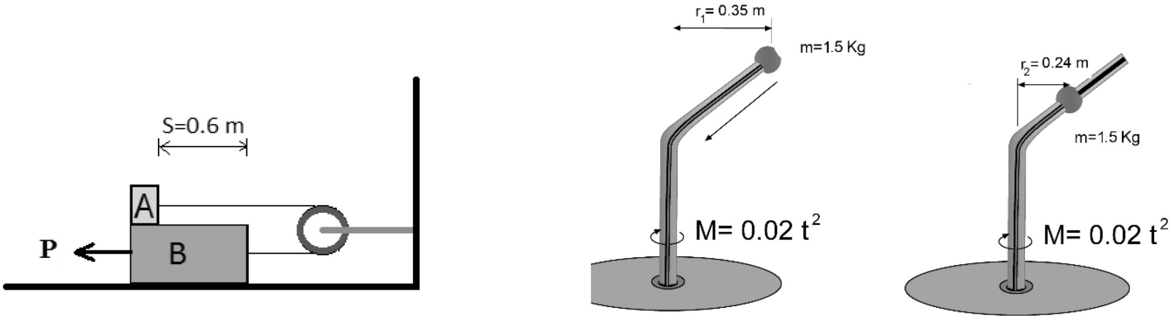
The assessment problem shown in Fig. 4(a) is described as follows. Block A is placed on the top of block B. While a tension force P of 300 N draws block B to the left, block A moves to the right through a cable-pulley system that connects the two blocks. The mass of block A and the mass of block B are: $m_A = 15$ kg, $m_B = 30$ kg. The total length that block A can travel over block B from one end to the other end is s = 0.6 m. The coefficient of kinetic friction between block A and block B is 0.4, and the coefficient of kinetic friction between block B and the ground surface is 0.5. Determine the time that block A travels over block B for the length of s.

The assessment problem shown in Fig. 4(b) is described as follows. A cable going through the inside of a pole is attached to a 1.5 kg sphere. The cable shortens with a constant rate of 0.05 m/s to drag the sphere, so the sphere slides along the pole. At the same time, a varying moment of $M = 0.02 \cdot t^2$ (where t is time in seconds) is applied on the pole to rotate the pole. The sphere starts from rest, with the initial distance of the sphere to the rotating center being 0.35 m. The friction between the sphere and the pole, and the mass of the pole are both neglected. Determine the speed of the sphere after 3 seconds when the distance of the sphere to the rotating center is reduced to 0.24 m.

2.4 *Data Collection, Coding, and Analysis*

Data was collected using the think-aloud approach [21], in which student participants talked aloud to themselves during the process of learning and the process of problem solving, so researchers could know the detailed thoughts of student participants and understand how they learned and solved problems. Each of the 24 student participants performed think-aloud activities, generating a significant amount of verbal data. The verbal data was video-recorded and audio-recorded and transcribed into texts for subsequent coding and data analysis.

The overall theoretical framework to guide data coding and analysis was Revised Bloom's Taxon-



(a) (b)

Fig. 4. Assessment problems: (a) Newton's second law of motion and (b) the principle of angular impulse and momentum.

omy [22] that has been well known and widely accepted in the education community. The cognitive process dimension of Revised Bloom's Taxonomy includes six categories: remember, understand, apply, analyze, evaluate, and create. "Remember" is the most fundamental level involving recalling and recognizing concepts and knowledge. "Create" is the highest level involving generating hypotheses, planning designs, and producing products. The present study did not include student activities in creativity and innovation. Therefore, only the first five categories – remember, understand, apply, and analyze – were included in data coding and analysis in the present study. Table 2 describes the final coding categories and subcategories.

Note that in order to cover all academic disciplines, Revised Bloom's Taxonomy provides only general categories and subcategories without given specific disciplinary or subject contexts. In the present study, which is within the specific context of Engineering Dynamics, some original subcategories of Revised Bloom's Taxonomy [22] were not included and others were expended. For instance, the first category of "remember" in Table 2 included two subcategories: remembering simple concepts and remembering advanced concepts. Revised Bloom's Taxonomy [22] does not differentiate simple concepts from advanced concepts. The third column in Table 2 provides descriptions of what those subcategories mean in the context of the present study.

The coding method described in the qualitative research literature [28–30] was employed. Two trained coders were involved to ensure inter-coder reliability. In cases two coders could not reach an agreement for coding particular verbal data, the third researcher joined as a mediator. The coding process was iterative, time-consuming, and labor-intensive due to a significant amount of data involved.

To quantify qualitative data for comparison purposes, the concept of frequency index proposed in the author's previous work [20] was employed in the present study. As a quantitative measurement of qualitative data, frequency index is calculated as the product of the total number of students who conducted the same mental activity (in the subcategory) and the total number of times the same mental activity appeared in all transcripts. The higher a frequency index, the more popular (or common) the

Table 2. Descriptions of coding categories and subcategories

Coding categories	Coding subcategories	Descriptions in the context of the present study
Remember	Remembering simple concepts	Recognizing simple concepts such as velocity, acceleration, and force.
	Remembering advanced concepts	Recognizing advanced concepts that combine several simple concepts or that illustrate quantitative relationships among simple concepts (such as the principle of impulse and momentum).
Understand	Interpreting	Interpreting textual information (such as a step-by-step problem-solving procedure) in a meaningful and reasonable way.
	Exemplifying	Providing a specific example or illustration of a concept in Engineering Dynamics.
	Classifying	Categorizing a group of concepts and identifying core concepts in Engineering Dynamics based on their common characteristics.
	Summarizing	Providing a brief statement of main points embedded in textual or graphic information.
	Inferring	Making inferences or drawing conclusions from the given information.
	Comparing	Comparing prior knowledge with present knowledge and comparing two relevant concepts (such as impulse and momentum) involved in the problem.
	Explaining	Explaining reasons for a phenomenon (such as the motion of a block) or an activity during learning and problem solving, making relevant comments while reading and reviewing the materials.
Apply	Executing	Listing given inputs of the problem, structuring textual and graphical information, drawing free-body diagrams of objects, and selecting appropriate dynamics principles for problem solving.
	Implementing	Developing textual and/or graphical representations of the problem and adopting a problem-solving strategy, plugging correct numbers into mathematical equations, and executing mathematical calculations.
Analyze	Differentiating	Distinguishing interim unknown variables (such as angular momentum) from known variables (such as velocity).
	Organizing	Establishing relationships among relevant variables, such as impulse and momentum.
	Attributing	Constructing mathematical equations to generate results.
Evaluate	Checking	Detecting small errors made during learning or problem solving and monitoring mathematical equations for syntax accuracy.
	Critiquing	Correcting incorrect variables used and judging the reasonableness of the final solution to the problem.

corresponding mental activity is among all students [20].

Two hypothetical scenarios are provided to help readers understand why it is necessary to use frequency index to quantify qualitative data. These two hypothetical scenarios involve a total of 10 individual students. Scenario I: one student performs the "understand" activity for 10 times; however, none of the other 9 students performs the "understand" activity. Scenario II: each of 10 students performs the "understand" activity for one time. In both scenarios, the total number of the "understand" activity performed by all students is the same (10). Without using frequency index and only counting the total number of the "understand" activity performed by all students, one can reach to a conclusion that the "understand" activity is equally popular in two scenarios, which is apparently wrong. Frequency index in Scenario II is much higher than that in Scenario I. Therefore, the "understand" activity is more popular in Scenario II than in Scenario I, which is a reasonable conclusion.

3. Results and Analysis

3.1 Effects of Interventions on Student Learning

Figs. 5(a) and (b) show the comparisons of the effects of two types of interventions (i.e., CSA and TTS) on student learning concerning Newton's second law of motion and the principle of angular impulse and momentum, respectively. The horizontal axis in each figure lists five categories of Revised Bloom's Taxonomy. The vertical axis shows the total frequency index, which was calculated by adding all frequency indexes in the subcategories of which the category consists.

Based on Figs. 5(a) and (b), student participants in two groups (CSA and TTS) performed mental activities in the "understand" category much more frequently than they did on mental activities in other four categories (i.e., remember, apply, analyze, and evaluate). Therefore, the dominant mental activity students performed during the learning process was to understand the problem.

Moreover, the CSA group performed "understand" activities more frequently than did the TTS group. As seen in Fig. 5(a), when students learned the worked example problem concerning Newton's second law of motion, the total frequency index in the "understand" category was 276 for the CSA group and 119 for the TTS group. 276 is 132% more than 119. Fig. 5(b) shows that when students learned the worked example problem concerning the principle of angular impulse and momentum, the total frequency index in the "understand" category was 285 for the CSA group and 186 for the TTS group. 285 is 53% more than 186.

3.2 Effects of Interventions on Student Problem Solving

Figs. 6(a) and (b) show the comparisons of the effects of two types of interventions (i.e., CSA and TTS) on student problem solving concerning Newton's second law of motion and the principle of angular impulse and momentum, respectively. The following observations and analysis are made based on the comparison between Fig. 6 and Fig. 5 as well as on Fig. 6 itself.

First, students performed more mental activities in problem solving (Fig. 6) than in learning (Fig. 5). The height of a bar in Figs. 5 and 6 represents the number of mental activities students performed. Most bars in Fig. 5 are low, except the bars corresponding to the "understand" activity. In contrast, most bars in Fig. 6 are high, except the

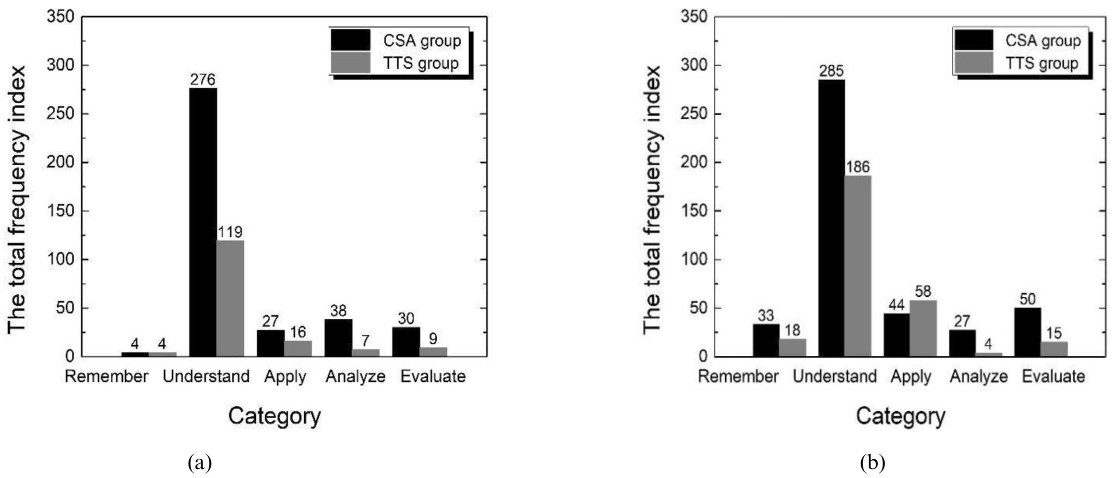
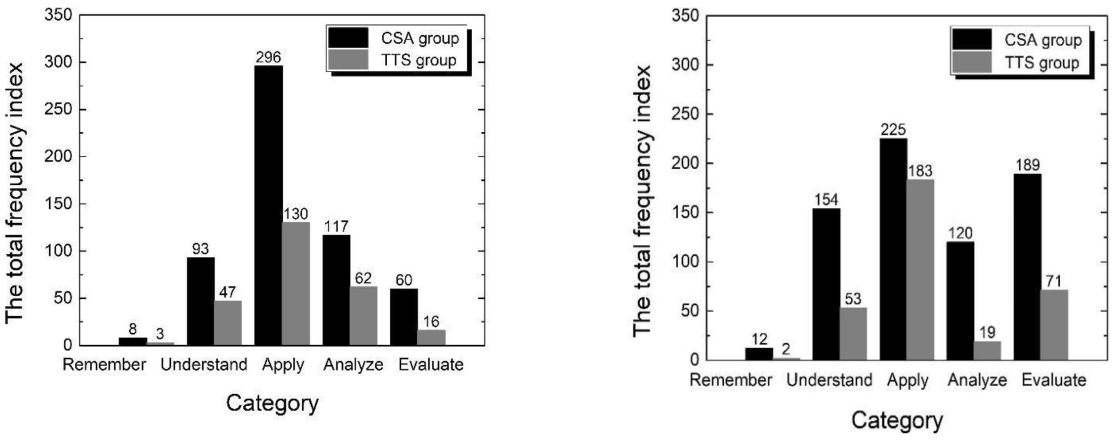


Fig. 5. Comparisons of the effects of two types of interventions on student learning: (a) Newton's second law of motion and (b) the principle of angular impulse and momentum.



(a) (b)

Fig. 6. Comparisons of the effects of two types of interventions on student problem solving: (a) Newton's second law of motion and (b) the principle of angular impulse and momentum.

bars corresponding to the "remember" activity. These results are reasonable and expected because problem solving is typically harder than learning and requires more mental efforts.

Second, Figs. 6(a) and(b) show that the dominant mental activity students performed during problem solving was "apply," regardless the group (CSA or TTS) students belonged to. As seen in Fig. 6(a), the CSA group had the total frequency index of 296 in the "apply" category, much higher than those in all other four categories. Fig. 6(b) shows the CSA group had the total frequency index of 225 in the "apply" category, the highest among that in all five categories.

Third, the CSA group performed mental activities in all five categories more frequently than did the TTS group. As seen in Fig. 6(a), when students solved the assessment problem concerning Newton's second law of motion, the total frequency index in the "apply" category was 296 for the CSA group and 130 for the TTS group. 296 is 128% more than 119. Fig. 6(b) shows that when students solved the assessment problem concerning the principle of angular impulse and momentum, the total frequency index in the "apply" category was 225 for the CSA group and 183 for the TTS group. 225 is 23% more than 183. The percentage difference, 128% vs. 23%, suggests that the technical context, i.e., Newton's second law of motion vs. the principle of angular impulse and momentum, also played a role in affecting the number of mental activities students performed in a specific category.

4. Limitations of the Present Study

The first limitation of the present study is it involved only two case studies on Newton's second law of motion and the principle of angular impulse and momentum, respectively, and both case studies address particle dynamics only. Engineering Dynamics consists of particle dynamics and rigid-body dynamics, each covering a wide variety of learning topics [1, 2], e.g., Newton's second law of motion, the principle of work and energy, conservation of energy, the principle of linear impulse and momentum, conservation of linear momentum, the principle of angular impulse and momentum, and conservation of angular momentum.

Rigid-body dynamics is more complex than particle dynamics and hence more challenging to many students. Therefore, the research findings generated from the present study apply to student learning and problem solving in particle dynamics only. A new set of CSA and TTS learning modules for rigid-body dynamics needs to be developed in order to verify if the research findings generated from the present study are applicable in rigid-body dynamics also.

It should be pointed out that the present study included two case studies on 24 student participants only. Although this sample size was not big, it would not significantly change the research findings made from the present study on particle dynamics because those research findings were consistent in both case studies. Both case studies have revealed a number of differences in the effects of CSA and TTS on student learning and problem solving.

The second limitation of the present study is it cannot answer the question of why those differences in the effects of CSA and TTS on student learning and problem solving exist. For example, from the present study, it has been found that the CSA group performed "understand" activities more frequently than did the TTS group during the process of learning. However, the root reason that the CSA group performed "understand" activities more frequently than did the TTS group remains unclear. Was it because CSA is more interesting (such as animations) than TTS, so students made more mental efforts in trying to understand the problem? Was it because CSA has many built-in functionalities (such as pop-up hints) and therefore is more engaging than TTS? Was it because of some other reasons? Further research involving cross-disciplinary collaborations with neuroscientists and cognitive psychologists are needed in order to discover the fundamental root reason concerning how neural networks in the human brain react to external stimuli.

5. Conclusions

This paper has described two case studies to investigate the effects of computer simulation and animation (CSA) on student learning and problem solving in Engineering Dynamics, a second-year foundational undergraduate engineering course required in many engineering programs. These two case studies involved two important topics in particle dynamics: Newton's second law of motion and the principle of angular impulse and momentum. This paper has also described CSA learning modules and traditional textbook style (TTS) learning modules employed in each case study. The major conclusions made from the present study are summarized in the following paragraphs.

When students learned Engineering Dynamics, CSA enabled them to perform mental activities more frequently in the "understand" category than did TTS. The dominant mental activity students performed during the learning process was to understand the problem, regardless which group (CSA or TTS) students belonged to.

When students solved problems in Engineering Dynamics, CSA enabled them to perform mental activities more frequently in all five categories (remember, understand, apply, analyze, and evaluate) than did TTS. The number of mental activities students performed in a specific category is also affected by the specific technical context, i.e., Newton's second law of motion vs. the principle of angular impulse and momentum.

References

1. R. C. Hibbeler, *Engineering Mechanics: Dynamics* (14th ed.), Pearson Prentice Hall, Upper Saddle River, NJ, 2015.
2. B. Ferdinand, E. Johnston, P. Cornwell and B. Self, *Vector Mechanics for Engineers: Dynamics* (11th ed.), McGraw-Hill Education, New York, NY, 2015.
3. S. Y. Yoon, P. K. Imbrie, T. Reed and K. J. Shryock, Identification of the engineering gateway subjects in the second-year engineering common curriculum, *International Journal of Engineering Education*, **35**(1), pp. 232–251, 2018.
4. G. Gray, F. Costanzo, D. Evans, P. Cornwell, B. Self and J. Lane, The Dynamics Concept Inventory assessment test: A progress report and some results, *Proceedings of the 2005 ASEE Annual Conference and Exposition*, Portland, OR, 2005.
5. E. Karadoğan and F. Karadoğan, Simulation-based learning modules for undergraduate engineering dynamics, *Computer Applications in Engineering Education*, **27**(4), pp. 846–862, 2019.
6. W. -P. Lee and C. -L. Hwan, A computer simulation in mechanics teaching and learning: A case study in circular motions, *Computer Applications in Engineering Education*, **23**(6), pp. 868–871, 2015.
7. M. T. Valdez, C. M. Ferreira and F. P. M. Barbosa, Distance education using a desktop virtual reality (VR) system, *Proceedings of the 24th International Conference on European Association for Education in Electrical and Information Engineering*, Chania, Greece, 2013.
8. Y. Wang, S. K. Ong and A. Y. C. Nee, Enhancing mechanisms education through interaction with augmented reality simulation, *Computer Applications in Engineering Education*, **26**(5), pp. 1552–1564, 2018.
9. J. Magana, J. D. Ortega-Alvarez, R. Lovan, D. Gomez, J. Marulanda and S. Dyke, Virtual, local and remote laboratories for conceptual understanding of dynamic systems, *International Journal of Engineering Education*, **33**(1), pp. 91–105, 2017.
10. A. G. Enriquez, Impact of Tablet PC-enhanced interactivity on student performance in sophomore-level engineering dynamics course, *Computers in Education Journal*, **8**(3), pp. 69–84, 2008.
11. B. Schmidt, Teaching engineering dynamics by use of peer instruction supported by an Audience Response System, *European Journal of Engineering Education*, **36**(5), pp. 413–423, 2011.
12. M. Ceberio, J. M. Almudí and Á. Franco, Design and application of interactive simulations in problem-solving in university-level physics education, *Journal of Science Education and Technology*, **25**(4), pp. 590–609, 2016.
13. D. F. Villegas, H. G. Sanchez and C. A. Riberos, Strategies for the teaching-learning experiences in the engineering dynamics course based on the information and communication technologies, *Journal of Physics: Conference Series*, **1161**(1), Article number 012011, 2019.
14. B. Deliktas, Computer technology for enhancing teaching and learning modules of engineering mechanics, *Computer Applications in Engineering Education*, **19**(3), pp. 421–432, 2011.
15. R. Stanley, An efficient way to increase the engineering student's fundamental understanding of particle kinematics and kinetics by using interactive web based animation software, *Computers in Education*, **18**(3), pp. 23–41, 2008.
16. R. E. Flori, M. A. Koen and D. B. Oglesby, Basic engineering software for teaching (BEST) dynamics, *Journal of Engineering Education*, **85**(1), pp. 61–67, 1996.
17. M. Develaki, Methodology and epistemology of computer simulations and implications for science education, *Journal of Science Education and Technology*, **28**(4), pp. 353–370, 2019.
18. W. T. Botelho, M. D. G. B. Marietto, J. C. D. M. Ferreira and E. P. Pimentel, Kolb's experiential learning theory and Belhot's learning cycle guiding the use of computer simulation in engineering education: a pedagogical proposal to shift toward an experiential pedagogy, *Computer Applications in Engineering Education*, **24**(1), pp. 79–88, 2016.

19. S. J. Kaheru and J. Kriek, The effect of computer simulations on acquisition of knowledge and cognitive load: A gender perspective, *African Journal of Research in Mathematics, Science and Technology Education*, **20**(1), pp. 67–79, 2016.
20. N. Fang and M. Tajvidi, The effects of computer simulation and animation (CSA) on students' cognitive processes: a comparative case study in an undergraduate engineering course, *Journal of Computer Assisted Learning*, **34**(1), pp. 71–83, 2018.
21. G. L. Rikard and D. J. Langley, The think aloud procedure: a research technique for gaining insight into the student perspective, *The Physical Educator*, **52**(2), pp. 93–97, 1995.
22. L. W. Anderson (ed.), D. R. Krathwohl (ed.), P. W. Airasian, K. A. Cruikshank, R. E. Mayer, P. R. Pintrich, J. Raths and M. C. Wittrock, *A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's taxonomy of Educational Objectives* (Complete ed.), Longman, New York, NY, 2001.
23. A. Darabi, D. W. Nelson, R. Meeker, X. Liang and W. Boulware, Effect of worked examples on mental model progression in a computer-based simulation learning environment, *Journal of Computing in Higher Education*, **22**(2), pp. 135–147, 2010.
24. S. L. Gestson, M. S. Barner, M. G. Abadi, D. S. Hurwitz and S. Brown, Problem solving personas of civil engineering practitioners using eye tracking techniques, *International Journal of Engineering Education*, **35**(4), pp. 1074–1093, 2019.
25. J. Leppavirta, H. Kettunen and A. Sihvola, Complex problem exercises in developing engineering students' conceptual and procedural knowledge of electromagnetics, *IEEE Transactions on Education*, **54**(1), pp. 63–66, 2011.
26. J. Greeno, A. Collins and L. Resnick, Cognition and learning, in *Handbook of Educational Psychology*, Macmillan, New York, NY, 1996.
27. R. C. Clark, F. Nguyen and J. Weller, *Efficiency in Learning: Evidence-Based Guidelines to Manage Cognitive Load.* Wiley, San Francisco, CA, 2005.
28. M. B. Miles, A. M. Huberman and J. Saldana, *Qualitative Statistical Analysis: A Methods Sourcebook*, SAGE Publications, Washington, D.C., 2014.
29. J. W. Creswell, *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches* (4th ed.), SAGE Publications, Thousand Oaks, CA, 2013.
30. J. A. Maxwell, *Qualitative Research Design: An Interactive Approach (Applied Social Research Methods)*, SAGE Publications, Washington, D.C., 2013.

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