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Effectiveness of Computer Models on Learning Outcomes in a Dynamics Course – A Pilot Study

Arup Bhattacharya and Ehsan Mousavi, Ph.D.
Clemson University
Clemson, SC

The introductory courses in applied science education are formative and shape problem-solving skills. The application of gained knowledge beyond college is crucial to the success of engineers in the industry. As hands-on, active learning is key to understanding and analyzing a problem, the traditional instructional method often lacks these components. Courses such as Engineering Dynamics are usually deemed hard because the classroom experience does not augment the visualization of parts in motion. In this pilot study, the student's learning outcome in an Engineering Dynamics course was assessed by comparing the students' performance in solving dynamic problems with and without computer simulation models. Measuring student scores in problem-solving exercises, this paper demonstrated that computer-generated simulation models could be beneficial for the students to better grasp the dynamic concepts through engaging in active learning. Statistically significant differences were shown in the score when comparing a student group that used interactive simulation models to solve a dynamic problem with another group that had access to a stationary figure describing the system's initial state.
Key Words: Learning outcome, Student pedagogy, Computer simulation model, Dynamics

Introduction

Learning is a self-initiated continuous process of gaining new understanding, weaving into the existing experience. Encouraging students to take on a Science, Technology, Engineering, and Math (STEM) major has recently been a top priority in the nation's policy-making debates. In applied STEM courses like Construction Science, active learning is crucial to understanding and applying knowledge. Courses that discuss the physics behind systems are often deemed complex and demanding, resulting in high dropout rates (over 40% in the freshman year), and the difficulty in conceptualizing the problems can impede the individuals from pursuing a successful career (Bernold, 2005). The construction industry demands engineers with strong analytical skills to solve open-ended problems. Often, the instructional methods fail to provide the tool enabling them to bolster their understanding (Hermann, 1990, Hernández-de-Menéndez, 2019).

To be able to understand, analyze, and apply the knowledge indicate the effectiveness of learning, as proposed by Bloom and colleagues in 1956 (Benjamin, 1984). The conceptual understanding of problems helps students see the 'big picture' of a system and its components. In the introductory courses related to the mechanical systems of the natural world, statics is discussed at first, where the state of the system does not change with time. Hence, it is easier to conceptualize from a stationary picture presented through the examples in class. But, progressing to dynamics, where time is a variable, students often have difficulties capturing the time component of the problem. A stationary picture fails to provide enough information required to visualize the problem and, therefore, the understanding. In 2001, a report from the U.S. Department of Education found that 87% of engineering professors use lectures as their primary method of teaching (National Center for Education Statistics 2001072, 2001). It is a challenge for the instructors to present innovative approaches that can demonstrate the change of state of the system with time using two-dimensional and pictorial tools traditionally available in the classroom setting. This study assessed the effectiveness of computer-based models that illustrated the motions involved in the problems presented in an Engineering Dynamics class on students' pedagogy.

Literature Review

As computers are omnipresent in today's classrooms and integral to student learning, instructional methods demand the utilization of computing capabilities. To that end, computer-aided interactive simulations of dynamics problems can help learners visualize and fully apprehend the problem. Hailed as the pioneer of dynamic system modeling, Forrester (1968) argued that modeling dynamic problems helps clarify one's mental image of the system and foster comprehensive understanding (Forrester, 1968), as models are created to imitate the natural systems, their components, and the interactions within those components (Kornblugh & Little, 1976). Science education reform efforts, such as Project 2061 of the American Association for the Advancement of Science (1993), talks about using computer simulations "to form a scientific account of the universe" (page 65, Benchmarks for science literacy: Project 2061, 1993). Stratford (1997) presented evidence from earlier studies that student interactions with simulations confront learners with their (mis)conceptions of reality through the extent of the model imitating real-world events (Stratford, 1997). Gorsky and Finegold (1992) designed models using five force simulations to study students' conception of force and found that interacting with the simulations effectively elicited the understanding about forces acting on objects at rest and in motion (Gorsky & Finegold, 1992).

The enhanced learning also relates to meeting the industry expectations from the graduates. Pusca et al. (2017) described ideal engineering education as an "agile system" that can accommodate the changes in technological advancements to ensure graduates are equipped with and exposed to the understanding of the industry's requirements (Pusca et al., 2017). The authors argued that student activities focused on "learning by doing," followed by a reflective understanding of why it was done, prepare students through student-centered, hands-on learning. Anderson et al. (2005) discussed computer-assisted active learning methods in a thermodynamics class to demonstrate better learning outcomes (Anderson et al., 2005). Klahr et al. (2007) noted that virtual, i.e., computer-aided hands-on learning, may not provide the same level of tactile or visual cues as a physical model; it can still offer unique opportunities for practical learning (Klahr et al., 2007). A recent study noted that active learning results in teamwork, problem-solving, and analysis development, leading to increased performance and retention rates (Hernández-de-Menéndez et al., 2019). Lima et al. (2016) discussed how learners construct knowledge based on meaningful activities (Lima et al., 2016).

It is evident that even though modes of active learning have been studied to demonstrate increased learning outcomes, there is a dearth of publications that provide empirical evidence of enhanced learning outcomes in the engineering curriculum. In response, a pilot study with pretest-posttest randomized experiment was designed to answer a) whether using a computer model results in better understanding and learning and b) whether the students find using the computer models helpful studying a 'difficult' course.

Methods

Experiment Design and Data Collection

A series of assessments were put in place to evaluate the effectiveness of interactive computer-generated models of problems in the engineering dynamics class on students' pedagogy. Subjects were 20 sophomore students enrolled in the Engineering Dynamics class. The class was divided into two groups of the same size (10 students in each group), where students were randomly assigned to the groups. Two 'additional' quizzes were defined as extra assignments so that students could decide not to take the quizzes without an impact on their grades. The simulations were created using an open-source application called Algadoo and mainly focused on two-dimensional dynamic systems of bodies connected via ropes, springs, and joints. These models were used to teach dynamics concepts such as force and momentum transfer, work and energy, and generic 2-D motions. The first quiz, which tested these concepts, accompanied one such simulation model. This time, the model was given to one of the groups to study whether the model enhances the student's understanding of the problem, and the other group was not assigned any model. Another set of models was developed to help teach impact, translation, and rotation in dynamic systems, and the question in quiz 2 utilized a model of this kind. To remove the effects of student academic background, the groups swapped for the next quiz such that the second group had access to the model, whereas the first group did not have access to the models. This way, it was ensured that every student could work with the simulations once. Students had the liberty of not using the models without any penalty.

The following assessment was designed in the final exam, where one of the exam problems asked questions from momentum transfer as well as from impact, translation, and rotational motion. Compared to the models developed for the quizzes, a slightly more complex simulation model was developed for this question and posted on Canvas. This final exam consisted of three other problems without any model to visualize the motion. Students were free to choose whether they wanted to study the model without any consequences on their grades. To relate the student performance on that problem to the effectiveness of the simulation, students were asked to report how much time they spent studying the model. Again, this was a self-report without any impact on their grades. This way, the experiments were designed as a pretest-posttest control group experimental design.

Eventually, an evaluation form was developed to appraise whether the simulations were helpful in the students' learning process. Example questions are provided in Annexure 1. The evaluation form comprised questions about the computer models. An introduction was placed on the front page of the evaluation form to describe the intent of the evaluation and issues regarding confidentiality and voluntary participation. No question was asked about the students' identifying information like academic records, including their GPA, rank in class, or the number of credits taken and passed.

As stated, this study was mainly designed to reinforce the idea that visualization and contextualization in engineering courses can foster students' pedagogy and learning outcomes. This research in the current status qualified for an 'exempt review' since it studied normal educational practices in commonly accepted educational settings. Since this project used some student outcome data, approval from the Internal Review Board (IRB) was obtained (IRB number: 20161116539EP, Project ID: 16539).

Data Analysis

18 out of 20 students chose to take the additional quizzes and participate in the subsequent assessment survey. First, the obtained points for the voluntary quizzes were recorded – once when each group did not use any model to answer the questions (pretest), and once when students studied the simulation model for the quiz (posttest). In this randomized pretest-posttest control group design, the comparison was to be made between the grades of the 18 students with and without access to the model to understand the effects of the treatment (i.e., the use of simulation models). Hence, to compare the sample means before and after the treatment was applied, a paired sampled t-test was performed.

Paired sampled t-test can only be used when the difference between the posttest score and pretest scores is normally distributed. Normality assumption can be made for a sample size greater than 30. But for this study, the total number of observations combining the two groups was 18, which did not conform to the normality assumption. A Shapiro-Wilk t-test was conducted on the difference in scores with and without access to the simulation model, testing the null hypothesis that the differences were normally distributed. The p-value obtained from the Shapiro-Wilk t-test was 0.1246, indicating that there was no significant deviation from normality considering a significance level of 0.05. Thus, it was ensured that paired sampled t-tests could be used to assess the efficacy of computer models in learning outcomes for the dynamics class by testing the null hypothesis - there were no significant differences in the mean score after using the model to answer the quiz compared to the mean score for the quiz without the model. One can argue that the difference in understanding of the material in that class until the quizzes were given might influence how the students perceived the models, which was a potential source of bias. To ensure that the two groups of students were not significantly different in terms of background knowledge, a paired t-test was conducted between the two pretest datasets, i.e., grades of both the groups before they used the simulation model for the quiz.

One problem (question 1) was accompanied by a simulation model for the final exam, and three other problems were without any model to study. Comparing the points obtained for question 1 and the other questions revealed whether the model aided in enhanced understanding of the first problem, which, in turn, resulted in a better score than in other questions. Question 1 also had a sub-question attached to it – time spent to study the model where respondents answered on a scale of 1 to 5. Spending no time on the model to answer question 1 was recorded as 1, spending less than 30 minutes was scaled at 2, spending less than an hour was marked as 3, studying the model for less than two hours were marked as 4, and spending more than two hours was recorded as 5. Correlating the student scores with the time spent on the model provided an idea of how helpful the model was in answering question 1. Each student's score for question 1 was sorted according to the duration of the model study by that student. The average scores for these groups were compared to see if spending more time studying the model resulted in a better outcome. Additionally, as students could have different levels of understanding of dynamic problems coming to the final exam, it might be a source of bias needed to be controlled. Hence, the pre-final grade of the students - excluding the additional two quizzes with simulation models were also used to perform an Analysis of Variance (ANOVA) test to shed light on whether the students who did not have very high grades coming to the final exam, benefitted from studying the model in detail. It is noteworthy that spending more time to study the model might not necessarily suggest a better understanding. Also, the sample size for this analysis was 18, which might not be sufficient to establish a relation between the dependent and independent variables conclusively.

Results and Discussion

Comparison of Pretest-Posttest Quiz Scores

A paired t-test was conducted on the pretest data, i.e., the scores of the two groups, when taking the quiz without any model to check for any bias originating from the understanding of dynamic concepts prior to taking the quizzes. Before running the t-test, the normality observation was checked using a Shapiro-Wilk t-test, resulting in a p-value of 0.08 (>0.05), confirming no significant deviation from normality. The result of the t-test that tested the null hypothesis mean difference in score between the groups is zero, indicates that there was no statistically significant difference between the two groups before applying the treatment, as the p-value (0.705) was greater than the significance level (0.05) for the two-tailed t-test.

As it was confirmed that the two groups were identical before taking the quizzes comprising the simulation models explaining the quiz problems, the scores of all the students from both the groups were compared. Figure 1 shows the distribution of scores for all 18 students. Pre-treatment scores indicate the grade for the quiz that any model did not accompany, and post-treatment scores are the grades for the quiz supplemented by a simulation model. The boxplot in Figure 2 demonstrates the difference in the scores pre-and post-treatment. The mean pre-treatment score was 65.8 with a standard deviation of 15.9, and the mean post-treatment score was 80.3 with a standard deviation of 18.4.

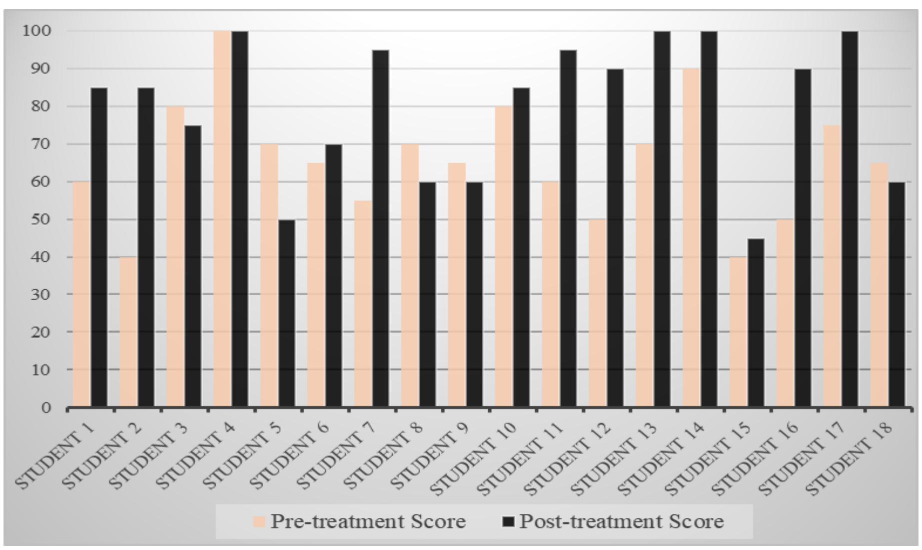

Figure 1: Distribution of Pre- and Post-treatment Scores

To test whether the mean difference in scores in the quizzes before and after the interactive model was provided to help the students visualize the problems, another paired t-test was conducted. The null hypothesis for this test was that the mean difference in scores before and after using the simulation model was zero, which was tested at a significance level of 0.05. The p-value (0.008) obtained from this test result was smaller than the significance level for a two-tailed t-test, indicating a statistically significant difference between the mean score of the two groups. The estimated increase in the average score for the quiz aided by the simulation model was more than 14 points, compared to the pre-treatment case. This finding clearly indicates that using the model was influential in the students' learning outcome, as it helped them understand the problem better. After visualizing the problem through the interactive model, on average, students were able to secure a higher grade than solving the problem using a stationary figure only.

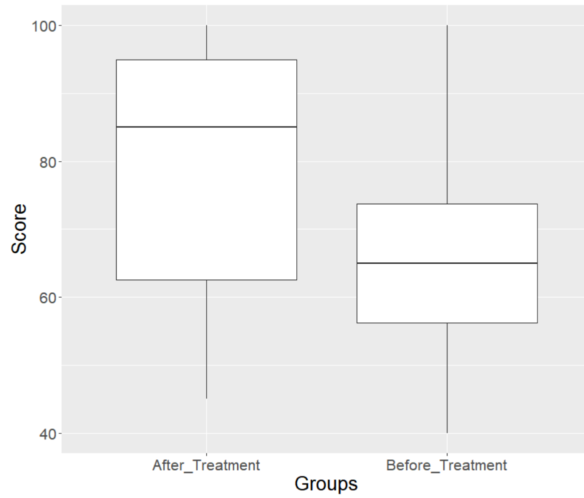

Figure 2: Boxplot of Pre- and Post-treatment Quiz Scores

Assessment of the Final Exam

19 out of 20 students had participated in the assessment associated with the final exam. Question 1 in the final exam was coupled with a simulation model that explained the dynamic motion of the system, which the students could voluntarily use to answer the question. In contrast, problems 2, 3, and 4 had only figures. Table 1 presents the comparison of scores of these questions. It is apparent that on average, question 1 scores were the highest, being the only question where the mean score was greater than 85%. The average scores for the other three questions were less than 70%. It is also noteworthy that the standard deviation of the question 1 scores was the lowest among all the questions, which suggests an enhanced benefit of using the model to solve dynamic problems.

Table 1: Comparison of Scores for Questions with/without Simulation Models

	Question 1	**Question 2**	**Question 3**	**Question 4**
Total Points	15	25	25	25
Average Score	12.84	15.55	13.66	17.21
Average Percentage	85.6%	62.2%	54.6%	68.8%
Standard Deviation	2.58	6.69	7.26	6.26

As mentioned earlier, additional information was requested from the students about the time used for studying the model to answer question 1. Table 2 shows the average grade of students for question 1, grouped according to the amount of time spent on the model. It is noticeable that students who used around 30 min to an hour working with the model had a higher average score in the question. Noticeably, no one spent more than two hours on the model, and only 3 out of 19 respondents chose not to use the model at all. Although this result provides an insight into the usefulness of carefully studying an interactive model to solve a dynamic problem, the generalizability of this finding is under question due to the limited number of observations and the potential bias from students' background knowledge gained from the Engineering Dynamics class throughout the semester.

Table 2: Question 1 score vs. time Spent on the Model

	Time Spent on the Model				
	1 (None)	2 (< 30 min)	3 (< 60 min)	4 (<120 min)	5 (>120 min)
No. of students	3	7	7	2	0
Average Score (out of 15)	10.67	12.72	14.14	12	0
Std. Dev.	5.13	2.21	1.21	1.41	0

To alleviate the generalizability threats on the question of whether the existing knowledge about dynamic problems had any role in the way students used (or did not use) the model in the final exam, pre-final grades - excluding that of the voluntary quizzes, were considered as the control. A two-way Analysis of Variance (ANOVA) was performed to determine if time utilized to go through the model and the pre-final grades were significantly related to the outcome, i.e., question 1 marks. Table 3 shows the result of the ANOVA, which suggests that neither the duration of model study nor the pre-final grades were significantly affected the score of question 1 at a significance level of 0.05. Time spent on the model impacts the outcome only when tested at the significance level of 0.1. Thus, these analyses show that even though it can be concluded that using dynamic simulation models for a problem was helpful, there is no evidence that spending more time on the model results in a better learning outcome.

Table 3: ANOVA Table - Effects of Model Study Duration and Pre-final Grade

	df	Sum of Squares	Mean of Sum of Squares	F-Statistic	p-value
Model Study Duration	3	24.87	8.29	2.783	0.08
Pre-final grades	1	0.58	0.58	0.195	0.67
Residuals	14	41.7	2.98		

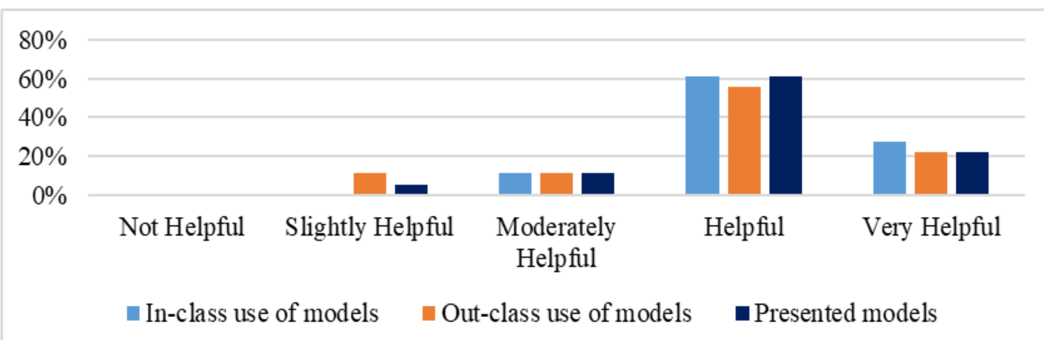

Figure 3: Summary of Assessment Survey

Assessment of Evaluation Survey

The assessment survey, followed by the final exam, was developed to get student feedback on whether using computer-generated models aided in understanding dynamic systems. As Figure 3 shows, in-class use of models for practice problems was hailed as helpful by 61% of the respondents, followed by 28% of the students who found the models extremely helpful. On the question of whether the use of simulation models outside of class was beneficial, 56% of the students agreed, while 22% of them thought the out-of-class use of models to be extremely helpful. Only two students thought using the models outside of the class without explanation was only slightly useful. Integrating models with the lectures was valuable by the majority of the students (11 out of 19), and 4 of them reported that using models with the class lectures was very helpful for them to grasp the concept.

Conclusion and Limitation

This study assessed the effects of active learning through computer-generated dynamic simulation models in students' learning outcomes. Observational and statistical methods were applied to understand whether using simulation models was efficient to bolster student experience and understanding in an introductory Engineering Dynamics class.

It was demonstrated that interactive simulation models result in better learning outcomes, measured in terms of obtained grades in specifically designed problems. The simulation models supposedly helped with visualizing moving systems. The evidence of improvement in learning outcomes was derived by comparing the grades of the same group of learners when they used computer-generated virtual models and when they solved similar problems from a stationary figure of the system at rest. Even though there was no conclusive proof, substantiated by statistical measures, that spending increased time to work with the models was more effective, it was evident that judicious use of the dynamic models helped in increasing the grades for problems concerning bodies in motion.

This was a preliminary pilot study with certain limitations. The small class size consequently affected the power of statistical tests. Still, dividing the students into two groups enabled an increased number of observations for pretest-posttest comparison. Only three simplistic models were derived for this study. More comprehensive models could be developed in the future, involving students in model creation instead of providing the models to them. This study was deemed a pilot study to gain insights into the concept of effectiveness, not to generalize the findings. More comprehensive research involving more students in diverse courses from different universities is planned for subsequent studies related to teaching effectiveness through active learning.

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Annexure 1 – Snippets of the Survey Questions

a. Have you ever used any educational computer models in your courses before?
   1) Yes 2) No
   If yes, for what course(s) and what kind of model(s)?
b. How useful do you find the in-class use of computer-based educational models in helping you understand the concepts of Dynamics course?
   1) Not helpful at all 2) Slightly helpful 3) Moderately helpful 4) Helpful 5) Very Helpful
c. How useful do you find the out-class use of computer-based educational models in helping you understand the concepts of Dynamics course?
   1) Not helpful at all 2) Slightly helpful 3) Moderately helpful 4) Helpful 5) Very Helpful
d. How useful did you find the dynamic models, presented by the instructor throughout the semester, in helping you grasp the fundamental concepts of dynamics?
   1) Not helpful at all 2) Slightly helpful 3) Moderately helpful 4) Helpful 5)Very Helpful
e. If the instructor provides you with some educational models, what would be your preferred way of running those models? (sort the statements using a number from 1 to 4, 1 being the most preferred way and 4 being the least preferred way)
   ___ on any web browser on laptops, cellphones, tablet (limitation: you have to have access to the internet)
   ___ on my windows/mac (limitation: you must install the corresponding software first to run the model)
   ___ on your windows/mac (limitation: you have to download the file as a self-executable file)
   ___ on universities' machine (limitation: you have access to the models on-campus only)