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Introduction to Interactive Simulations for Dynamics Education (InSiDE)

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Introduction to Interactive Simulations for Dynamics Education (InSiDE)

Abstract

We have developed a set of Interactive Simulations for Dynamics Education (InSiDE). The goal is to improve students' intuitive understanding of motion for complex dynamical systems. We held a workshop to introduce InSiDE to other Dynamics instructors. We have assessed the impact of these simulations through multiple means: comparing students' performance in a treatment and control class, analyzing students' surveys, and analyzing faculty workshop participant surveys.

1. Introduction and Motivations

We developed a set of Interactive Simulations for Dynamics Education (InSiDE)[1] to enhance student understanding and encourage active learning. Simulations are used in various disciplines, allowing for visual representation of difficult concepts and interactivity. For example, students enter values in a simulation, view the resulting animated action, and receive immediate feedback. Based on the feedback, students can adjust their learning, review their course materials to address any gaps in knowledge, and then continue using the simulation until they are confident with that concept. We used these simulations to teach Vector Dynamics (ARO 2150) in Spring 2024.

Vector Dynamics is required in several Engineering majors, including Mechanical and Aerospace Engineering. This course has a high non-passing grade across different departments at the California System Universities (CSUs), with a considerable equity gap. Table 1 shows the Dynamics courses offered at California Polytechnic University, Pomona (CPP, or Cal Poly Pomona), one of the prominent polytechnic CSU campuses. This data is gathered from the CSU faculty dashboard from 2020 to 2023. The Aerospace and Mechanical Engineering courses (ARO 2150 and ME 2150) are more advanced than the Engineering Technology course (ETM2111). The non-passing rate for the Aerospace and Mechanical courses is 19% and 36%, respectively. The Aerospace course is in a flipped format, compared to the traditional lecture format of the Mechanical Engineering course. Over 1300 students took Cal Poly Pomona's required Dynamics course between 2020 and 2023. The Mechanical Engineering Dynamics course (ME 2150), with 927 students, has the highest non-passing rate among the Mechanical Engineering courses.

In this study, we investigate how InSiDE provided to students taking a course in Vector Dynamics might improve their academic outcomes. We used a control and a treatment class. The control class only had access to InSiDE through a module in Canvas Learning Management

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[1] Created by Dr. Sotoudeh, Professor in the Aerospace Engineering Department at CPP, and Dr. Enger, Assistant Professor in the Computer Science Department at CPP (at the time of developing InSiDE).

system. In the control class, we did not use these simulations during the lecture, did not incorporate them in homework, but did introduce them to students and provide an access link at the beginning of the semester. In the treatment class, we explicitly and actively incorporated the simulation in the lecture and class activities. We compared student performance on Chapter tests between the control class and the treatment class. Finally, we gathered data on students' perceptions of the simulations, and any feedback for improvement.

Table 1: List of Dynamics courses offered at Cal Poly Pomona

Campus	Course Name	Department/ Course Number	Enrollment	Non-passing rate
Pomona	Vector Dynamics	Aerospace Eng. /2150	338	19%
Pomona	Vector Dynamics	Mechanical Eng /2150	927	36%
Pomona	Applied Dynamics	Eng. Technology/ 2111	121	2%

Additionally, we held a faculty workshop for instructors across the CSU system who teach Vector Dynamics and may use these simulations in their own classrooms. We introduced InSiDE and provided examples of how to implement them in instructional materials. Faculty were surveyed on their perceptions of the simulations and whether they might use them in their own instruction.

2. Background

Research in engineering education investigates ways to move beyond the typical instructional strategies to focus on more student-centered learning, by promoting online instructional experiences [1]. Blended learning entails a combination of face-to-face instruction and online components [2], meant to motivate students, enhance the learning experience, and improve student academic outcomes. Previous studies have explored the use of videos [3], animations [4], virtual reality [5], and simulations [6] to aid instruction and improve student learning. These technological tools allow for visual representation of complex concepts that may be difficult to convey in a traditional lecture setting [7]. Especially for undergraduate students in engineering programs, visual aids and step-by-step problem-solving are particularly important in instructional materials [8].

Some examples of topics taught in a Vector Dynamics course include rectilinear and curvilinear motion of particles; planar motion of rigid bodies in an inertial reference frame using Cartesian, normal-tangential and polar coordinate systems; mass moments of inertia; and fixed-axis rotation and general plane motion of rigid bodies. Such varied and complex motions may be hard for students to grasp solely through traditional teaching methods of lecturing, practice problems, and reading the textbook. Simulations are a way for students to practically apply their knowledge of how various motions may affect a system and see real-time results. Animated simulations can help students visualize how the relationship between variables changes in magnitude and direction [9]. Especially for students from historically underrepresented groups (particularly for our institution, Latinx and first-generation students) online resources are valuable because underrepresented students tend to use them more, and they appreciate being able go at their own pace [3].

Simulations have long been used for teaching students in health-related programs, but are now becoming more prevalent in Science, Technology, Engineering, and Mathematics (STEM) subjects as well [10]. Simulations can be a way for students to practice "what-if" analysis – they can enter various numbers in a provided slot and view the resulting motion, something that would be difficult to visualize in the classroom [6]. Instructors act as facilitators as they introduce how to use the simulations, and students take responsibility for their own learning while interacting with the provided simulations [6]. The immediate feedback provided by the simulation allows students to apply concepts they are learning and make any necessary adjustments to their understanding [7].

An interactive computer simulation learning module on projectile motion was introduced to over 300 undergraduate engineering students enrolled in a Dynamics course [11]. Students could adjust the initial velocity and initial launch angle and view how various other variables changed as a result. Students completed pre- and post-tests and attitude surveys after participating in the learning module and interacting with the simulations. Results indicate that students had higher post-test scores and thus made learning gains after using the simulations, and that students reported using the simulations was a positive experience [11]. Though students' scores were compared to their pre-test scores, there was no control group of students in this study who did not use the simulation learning module. Additionally, this study focused on one specific dynamics topic – projectile motion – rather than providing multiple opportunities for students to learn using simulations.

A later study introduced students to interactive computer simulations on rigid body dynamics while a comparison group of students received only traditional instruction [12]. Findings show that students who used the computer simulations did have a statistically significant increase in knowledge and conceptual understanding of rigid body dynamics when testing on these topics, compared to the group who did not use the simulations. Researchers also found that using the simulation modules increased students' confidence in learning the material, though it did not increase their motivation [12].

Another research study involved implementing video tutorials as well as simulations in a Vector Dynamics engineering course [13]. However, when compared to a class of students who did not use these tools, academic outcomes were inconclusive and researchers could not determine that the course with simulations would result in greater academic success than a control class. Within the class where all students were offered video tutorials and simulations, those who did not watch any of the videos received poor grades, suggesting that students' level of participation in the hands-on activities could predict their future exam performance [13]. It is important to continue investigating the use of simulations in engineering education, particularly in vector dynamics, to improve student outcomes.

3. InSiDE Development – Simulation Creation and Topics

The InSiDE were developed in the game engine/middleware Unity[2]. Unity provides functionality to create 3D scenes with custom logic to animate and move objects. It is primarily used for the development of video games, but has also found applications in engineering, simulation and

[2] https://unity.com/

education. For our project one particularly appealing feature of Unity is its built-in capability to export the simulations to WebGL, making them playable directly in a standard web browser without the need for any additional plugins.

We created a total of 16 web applications, split into two categories: Simulations and Practice Problems. The simulations provide an animated view of a problem or collection of problems, where students are tasked with calculating a value in a problem, and can use the simulation to visualize their solution and verify their results. In contrast, the practice problems guide students through a problem step by step, prompting them for intermediate thoughts/results. Both types of application were created the same way in Unity. Throughout this paper, we are referring to and focusing on the first category of web applications – the simulations. To create a consistent look and feel across all simulations, we also created a repository of assets, including a textured grid indicating distances. Simulations include appropriate camera controls, including the ability to switch to a purely two-dimensional view. Each simulation also contains a copy of the instructions. Students can try different scenarios and see the behavior of the dynamical system for each case. It should be noted that, while Unity provides physics simulation, this simulation is geared towards gaming, with a focus on calculation speed, and not necessarily accurate dynamic modeling. We therefore calculate all movement ourselves in the code. However, in some simulations, we let the Unity physics simulation take over after some time to provide a livelier simulation.

Figure 1 shows two screenshots from two different simulations in InSIDE, to illustrate the simulation environment. We encourage readers to explore the simulations at: https://cpp-inside.github.io/.

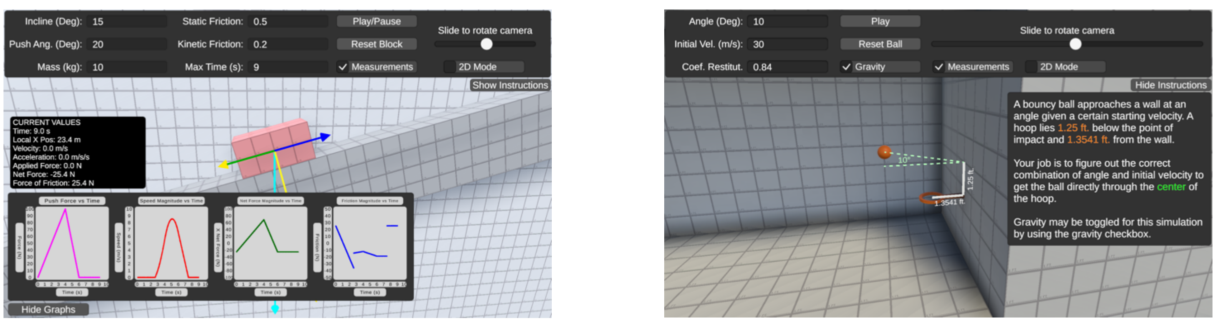

Figure 1: Two example simulations in InSIDE

While adding new simulations still involves the creation of the specifics of the problem, our common repository of assets, UI layouts and workflow greatly eases the effort required to create additional simulations.

To facilitate the assessment efforts, during Spring of 2024, in addition to the publicly available simulations, we also created versions that require students to enter a unique ID number. In these versions, every action of a student is sent to a server, running a custom Python Flask application, that records that student’s actions. Additionally, a periodic signal is sent as long as the student has the application open to keep track of their time using it. These private versions of the simulations were used to collect usage statistics for the purpose of assessment.

4. Assessments

4.1 A Quasi-experimental Design: Methodology, Procedure, and Assessments

Participants were 58 undergraduate students from Cal Poly Pomona. The participants were enrolled in one of two sections of ARO 2150 – Vector Dynamics, in Spring 2024. Fifty-six of the participants were Aerospace Engineering majors, one student majored in Mathematics (transferring to Aerospace), and one student was from Open University at CPP. We informed our students of the research at the beginning of the semester and received informed consent from all participants. Students received course credit for completing chapter tests and chapter surveys, regardless of whether they agreed to have their data used for research as part of their coursework.

Dr. Sotoudeh taught two class sections of ARO 2150 - Vector Dynamics in Spring 2024. One entire course section was randomly assigned as the treatment class and the other as the control class, making this a quasi-experimental design. Dr. Sotoudeh taught both classes in a flipped format [14]. This method provides students with instructional material, mostly videos, to study before lecture time. During the lecture, most of the time is used for problem-solving and activities using active learning techniques [15].

We provided students in both classes with a webpage containing InSiDE. The InSiDE were used as part of class activities in the treatment class. For the control class, the same activities were used but without the use of InSiDE. In addition, in the treatment class, simulations are actively embedded in discussions, used during class lectures, and when the course instructor solves example problems for students in class. The students were also encouraged to use them for review. However, in the control class, students were only introduced to InSiDE once during the introduction of this research when they were given the informed consent form. They had access to all the simulations in one Canvas module, Dr. Sotoudeh did not mention InSiDE during the lecture time, and students were not regularly reminded to use the simulations

Students completed a test after finishing each chapter. Certain questions in each chapter test were related to simulations provided by InSiDE (Table 1 of Appendix A). Students received a grade for each chapter test question depending on whether their answer was correct (full marks – 2), partially correct (part marks, e.g. 1, 1.25, etc.), incorrect (zero), or not attempted (zero). Time data was also gathered, indicating how long students spent on each test question. Activity log data was collected for each simulation, indicating which students accessed each simulation.

Participants in the research also completed an End-of-Semester survey, asking them about their perceptions of the interactive simulations, whether they thought they aided in their learning, what aspects of the simulations were effective in helping them understand course material, any suggestions for improvement, and any other comments they had regarding the simulations.

4.2 Faculty Workshop

In the Summer of 2024, we held a faculty workshop and invited instructors from across the California State University system who teach Dynamics courses. Our two-hour online workshop aimed to showcase InSiDE and suggest ways to incorporate them into classroom instruction, encouraging active learning. The 13 faculty participants had access to a Canvas course we made as a repository for instructional techniques useful for Dynamics instructors and a link to the

InSiDE simulations. As a part of their participation in the workshop and $200 stipend eligibility, participants completed a survey about the InSiDE simulations. They completed a course plan indicating how they might incorporate the simulations into their teaching. Participants engaged in collaborative discussions during the workshop to exchange ideas and insights about teaching Dynamics. The workshop material is accessible through https://canvas.cpp.edu/courses/112452

5. Results and Discussion

5.1 Analyzing Students' test scores

We used unique ID codes and monitored when students logged into the system and used the simulations. We used this information to eliminate those students who did not use the simulations from the treatment group and those who did use the simulations from the control group, and the remaining students are used in our statistical analyses. To determine whether using the simulations led to better test scores than not using the simulations, students' performance on chapter tests was compared between the treatment and control classes. An independent samples t-test was conducted for students' mean scores for each question in Chapter Tests 2, 3, 5, and 6 to determine whether there was a statistically detectable difference in performance between the treatment and control class. We did not see any relationship between students' performance on tests and the use of simulation. Appendix B shows the detailed results.

5.2 Results of End-of-Semester Student Survey

Students in the treatment and control groups were asked questions about their perceptions of the simulations. Students in the control group were asked if they were aware of the simulations, and if 'No' was selected, they were directed to the end of the survey. Thus, data was collected from those in the control group who had some awareness of InSiDE. 16 students from the treatment class and 18 from the control class responded to the end-of-semester survey.

Table 2 displays each group's response percentage of Agree or Strongly Agree and Disagree or Strongly Disagree to statements about the InSiDE simulations. Table 3 exhibits students' perceptions of the quality of the simulations.

Students in each group were asked an open-ended question, "What aspects of the InSiDE simulations did you find most helpful or effective in helping you understand the material?"

In the Treatment group, the three most common themes that emerged in responses were:

- Having the visualization / visual aid to learn the concept (8 responses)
- Being able to plug in different numbers for the variables and see the effect on the motion of the system - the interactivity (5 responses)
- Being able to practice problem-solving (2 responses)

In the Control group, the two most common themes that emerged in responses were:

- Having a visual representation to learn the concept (7 responses)
- Having an interactive simulation; being able to adjust parameters and see what happens (4 responses)

Table 2: Students' level of agreement to statements from the End of Semester Student Survey

Statement from Survey	Agree or Strongly Agree (%)		Disagree or Strongly Disagree (%)	
	Treatment (*n*=16)	Control (*n*=18)	Treatment (*n*=16)	Control (*n*=18)
I found the InSiDE simulations engaging (i.e., interesting to use).	75%	71%	25%	29%
The feedback provided by the InSiDE simulations was helpful.	56%	82%	44%	18%
It was easy to figure out how to use the InSiDE simulations.	75%	80%	25%	20%
I wish other courses would include similar interactive simulations.	69%	73%	31%	27%
The InSiDE simulations help me understand the concepts and physics of vector dynamics problems.	81%	76%	19%	24%

Table 3: How students rated the quality of the InSiDE simulations

I would rate the overall quality of the simulation modules as…	Treatment (*n*=16)	Control *n*=18)
Low	3	0
Average	12	15
High	1	3

Finally, students were asked to rank various course resources in order of importance in helping them learn in the course (Table 4). The treatment group found practice problems most helpful, and the control group found homework most useful. The two groups rated InSiDE low – 5th, and 6th, respectively.

Table 4: Students' rankings of course resources from 1 (most helpful) to 7 (least helpful).

Please rank these resources in helping you learn the objectives of this course	Treatment Group Ranking	Control Group Ranking
Practice problems	1	2
In-class problem-solving	2	3
Pre-lecture videos	3	4
Homework	4	1
InSiDE simulations	5	6
Textbook	6	5
Other	7	7

5.3 Results of Faculty Survey and Course Plan

We collected faculty's course plans indicating how they might incorporate InSiDE into their courses. Faculty created specific learning objectives and devised ways to use the InSiDE in their teaching. We did not systematically analyze faculty's course plans, but we reviewed them. Most faculty designed a traditional lecture course, incorporating active learning techniques, while two faculty designed a flipped classroom approach.

The 13 faculty who attended our workshop came from four different CSU institutions. Ten teach in the Mechanical or Aerospace Engineering department at their institution, two are in Electromechanical Engineering Technology, and one is a Civil Engineering instructor.

Faculty were asked, "What are the challenges you experience when teaching Dynamics?" Each response contained multiple themes, summarized in Table 5, where the frequency column shows how many times each theme was mentioned. The most popular response from faculty, mentioned six times, was students' lack of adequate background knowledge in math and physics. The next popular response, mentioned five times, was that it is a challenge for students to visualize dynamic systems. One instructor also mentioned that they have insufficient interactive resources to teach Dynamics. These challenges could be addressed by providing simulations to help visualize dynamic systems and allow interactivity. Simulations could also address the challenge of lack of time – students can use the simulations in advance of class time so they can gain an understanding of complex concepts before the lecture.

Table 5: Challenges identified by faculty when teaching Dynamics courses

Themes emerging from faculty's (*n*=13) responses to "What are the challenges you experience when teaching Dynamics?"	Frequency
Students' lack of adequate background knowledge in math and physics	6
Visualization of dynamic systems	5
Lack of time	4
Low student effort	3
Students have difficulty understanding the material/solving problems	2
Insufficient interactive resources	1

Faculty were asked if they plan to implement InSiDE simulations in their course. Nine faculty chose 'yes', and the remaining four chose 'maybe'.

Table 6 summarizes the workshop participants' responses to the rest of the survey questions.

Table 6: Faculty's level of agreement to statements from the Faculty Workshop Survey

Statement from Survey	Agree or Strongly Agree (%)	Disagree or Strongly Disagree (%)

I found the InSiDE simulations engaging (i.e., interesting to use).	100%	0
The InSiDE will help my students to learn vector dynamics more efficiently.	92%	8%
The InSiDE will give my students a deeper understanding of vector dynamics.	92%	8%
I will recommend the use of these simulations to other Dynamics instructors in my department.	100%	0

6. Discussion

Overall, looking at students' scores for 17 test questions across four Chapter tests between the two classes (Appendix B), there was only one test question where students who used InSiDE simulations had higher performance. Additionally, there was one question where students using simulations performed *worse* than the control class. Pass rates were similar between the control and treatment classes, and similar to previous semesters. Thus, it is not possible to conclude from these results whether the InSiDE contributes to improvement in the academic performance as measured by test scores.

However, the reason may be in our interpretation of the relation of test questions to a simulation. In future iterations, we will include more directly related questions to the simulation to be able to better assess the impact of using the simulations. In addition, Dr. Sotoudeh, the course instructor, could create class activities to convey the concept of simulations for the control class. The results of our experiments show that these class activities were as effective as simulations. However, creating these class activities without the use of simulations were more difficult and required more experience on the side of instructor; therefore, the simulations may be helpful for less-experienced instructors or larger classrooms to create an engaging and impactful course plan.

When asking students about their perceptions of the InSiDE, responses were mostly positive (see Table 2). Students found the simulations engaging and easy-to-use, and felt that they helped to understand the concepts in vector dynamics. Only about half of the students in the treatment group who used the simulations agreed that the feedback provided by the simulations was helpful. Perhaps students wanted more in-depth feedback about their responses rather than simply feedback on the correctness of the responses. It is worth noting that we also developed several practice problems with step-by-step guidance. However, we did not implement them in Spring 2024 or assess their impact.

As the semester progressed, the number of students who accessed the simulations in the treatment class declined – i.e., 27 students used the simulation before the Chapter 2 test, 24 students used the simulations for the Chapter 3 test, 20 students accessed simulations before the Chapter 5 test, and only 16 students in the treatment group used the Chapter 6 simulations. Towards the end of the semester, there are a lot of projects for students to complete in other courses in their program. Thus, limited time may have caused a decrease in participation in the provided simulations.

Students in both classes rated the quality of the simulations as average. When asked what was most helpful about the InSiDE, most students appreciated having a visual representation to learn the dynamics concepts. This aligns with and addresses what faculty had mentioned in our workshop about it being challenging for students to visualize dynamic systems. From the faculty workshop, most faculty believed the simulations could help their students learn more efficiently and gain a deeper understanding of vector dynamics, and all would recommend the simulations to their colleagues.

7. Conclusion and Future Work

Based on students' scores on chapter test questions in Vector Dynamics, it is inconclusive whether the InSiDE resulted in increased academic performance. There may have been other factors affecting students' test performance, including course load, content difficulty, and perhaps how in-depth students were with their usage of the simulations. Our future work will include pre-post tests for students who use the simulations and more in-class instruction using the InSiDE so students can become more familiar with and comfortable using them. We are also interested in seeing how other faculty members who teach Dynamics will introduce the InSiDE in their courses. Overall, students had a positive reception to using the simulations, so we are interested in incorporating them more into Vector Dynamics instruction.

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Appendix A:

Table 7 displays questions in each chapter that were directly related to InSiDE, including the name of the simulation and a link to access the simulation.

Table 7: Questions in each chapter that were directly related to InSiDE

Question number	**Chapter 2**	**Chapter 3**	**Chapter 5**	**Chapter 6**
Q1	Projectile Simulation (https://cpp-inside.github.io/InSiDE-Projectile-WebGL-Build/)	Sliding Block Friction Simulation (https://cpp-inside.github.io/InSiDe-Block-Friction-WebGL-Build/)	-	-
Q2	-	-	Disk Bar Rotation Simulation (https://cpp-inside.github.io/InSiDE-Disk-Bar-Rotation-Build/)	-
Q3	-	-	-	-
Q4	-	-	Disk Bar Rotation Simulation (https://cpp-inside.github.io/InSiDE-Disk-Bar-Rotation-Build/)	Pendulum Simulation (https://cpp-inside.github.io/Pendulums-Build/)
Q5	-	-	Disk Bar Rotation Simulation (https://cpp-inside.github.io/InSiDE-Disk-Bar-Rotation-Build/)	-
Q6	-	-	-	-

Appendix B: Statistical Analysis of Students' Test Scores

An independent samples t-test was conducted for students' mean scores for each question in Chapter Tests 2, 3, 5, and 6 to determine whether there was a statistically detectable difference in performance between the treatment and control class. All t-tests were two-tailed unless otherwise indicated. For each chapter test, one or more of the test questions were directly related to a simulation provided by InSiDE (see Appendix A). Some questions were not directly related to the simulations.

Following are the results of the independent groups t-tests for each question of the Chapter tests, between the treatment and control groups. All assumptions of an independent samples t-test are met unless otherwise indicated. In any analysis where Levene's test for equality of variance (i.e., variances approximately equal across the two classes) assumption is not met, and the variance in the two groups differs, we use the values from the Welch t-test, where equal variances are not assumed.

Chapter 2 test

27 students in the treatment class completed the Chapter 2 test and accessed the Projectile simulation. 18 students in the control class completed the Chapter 2 test and did not access the Projectile simulation. Table 8 displays the t-test results for Chapter 2 test questions. For question four, students who used the simulation had higher test scores on this question than students who didn't use the simulation, even though both received similar instruction in class related to this problem. The effect size, measured by Cohen's d, was d = 0.60, indicating a medium effect.

Table 8: Scores on each Chapter 2 Test Question for the Treatment and Control Classes

	Treatment Class (*n*=27)		**Control Class (*n*=18)**					
	Mean	*SD*[1]	*Mean*	*SD*	*df*[2]	*t*	*p*	Cohen's *d*
Q1	.56	.85	.22	.65	42.11	1.493	.143	0.45
Q3	.65	.73	.69	.62	43	-.220	.383	0.06
Q4*[1]	.78	.97	.28	.67	42.93	2.041*	< .05*	0.60

*Indicates a statistically significant differences exists between the groups at the $p < 0.05$ level
[1]Welch test is reported because Levene's test indicated that the homogeneity of variances assumption was not met for this variable.
[2] Standard deviation
[3] Degrees of freedom

Chapter 3 test

24 students in the treatment class completed the Chapter 3 test and accessed the Sliding Block Friction simulation. 31 students in the control class completed the Chapter 3 test and did not access the Sliding Block Friction simulation. Table 9 displays the t-test results for Chapter 3 test questions. Interestingly, Question 1 and Question 2 scores were the same for both classes, though

Question 1 was related to a simulation taught in class, and Question 2 was only related to a homework problem

Table 9: Scores on each Chapter 3 Test Question for the Treatment and Control Classes

	Treatment Class (*n*=24)		**Control Class (*n*=31)**					
	Mean	*SD*[1]	*Mean*	*SD*	*df*[2]	*t*	*p*	Cohen's *d*
Q1	1.33	.87	1.35	.84	53	-.093	.766	0.023
Q2	1.33	.87	1.35	.84	53	-.093	.766	0.023
Q3	1.17	1.01	.97	1.02	53	.723	.389	0.20
Q4*	.58	.93	.32	.75	43.49	1.122*	.268	0.31

*Welch test is reported because Levene's test indicated that the homogeneity of variances assumption was not met for this variable.
[1] Standard deviation
[2] Degrees of freedom

Chapter 5 test

20 students in the treatment class completed the Chapter 5 test and accessed the Disk Bar Rotation simulation. 29 students in the control class completed the Chapter 5 test and did not access the Disk Bar Rotation simulation.

For all the Chapter 5 test questions, there was no statistically detectable difference in test scores between the Treatment and Control groups (Table 10). Both classes performed similarly, despite Questions 2, 4, and 5 being directly related to the Disk Bar Rotation simulation, which the Treatment group accessed.

Table 10: Scores on each Chapter 5 Test Question for the Treatment and Control Classes

	Treatment Class (*n*=20)		**Control Class (*n*=29)**					
	Mean	*SD*[1]	*Mean*	*SD*	*df*[2]	*t*	*p*	Cohen's *d*
Q1	1.45	.83	1.38	.85	47	.289	.795	0.083
Q2*	1.55	.83	1.24	.95	44.43	1.208	.233	0.35
Q3	1.75	.64	1.65	.77	47	.496	.320	0.14
Q4	1.57	.62	1.46	.72	47	.518	.498	0.16
Q5	1.45	.83	1.48	.78	47	-.141	.735	0.037
Q6	.70	.47	.69	.47	47	.076	.880	0.021

*Welch test is reported because Levene's test indicated that the homogeneity of variances assumption was not met for this variable.
[1] Standard deviation
[2] Degrees of freedom

Chapter 6 test

16 students in the treatment class completed the Chapter 6 test and accessed the Pendulum simulation. 30 students in the control class completed the Chapter 6 test and did not access the Pendulum simulation. Table 11 reveals the t-test results for Chapter 6 test questions. For Question 2, students not using the simulations performed better than those with access to a simulation. In this case, the question was related to the Pendulum simulation, but both groups received similar instruction in class without the instructor using the simulation. The effect size, measured by Cohen's d, was d = 0.64, indicating a medium effect.

Students usually have lower performance on this chapter because the content is more difficult than previous chapters. It is noteworthy that much fewer students in the Treatment class accessed the simulations for Chapter 6 (i.e., 16 students), than for previous chapters.

Table 11: Scores on each Chapter 6 Test Question for the Treatment and Control Classes

	Treatment Class (*n*=16)		**Control Class (*n*=30)**					
	Mean	*SD*[2]	*Mean*	*SD*	*Df*[3]	*t*	*p*	Cohen's *d*
Q1[1]	.55	1.02	.92	1.18	34.95	-1.109	.275	0.34
Q2*	.94	1.25	1.71	1.16	44	-2.090	< .05*	0.64
Q3	.78	1.20	.92	1.23	44	-.360	.721	0.12
Q4[1]	.47	1.01	.83	1.20	35.67	-1.092	.282	0.32

*Indicates a statistically significant differences exists between the groups at the $p < 0.05$ level
[1]Welch test is reported because Levene's test indicated that the homogeneity of variances assumption was not met for this variable.
[2] Standard deviation
[3] Degrees of freedom