Innovative Learning in Engineering Dynamics: The Impact of Simulation-Based projects

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ABSTRACT

Engineering Dynamics is a core course in mechanical engineering programs, often offered with or without lab components. Our program delivers this 4-credit course without lab sessions, relying solely on lectures to explain principles and provide examples. To enhance student engagement and learning, we previously implemented a paper design project where students created a tennis launch machine using engineering dynamics principles and SolidWorks. While this initiative fostered a dynamic learning environment, it proved unsustainable due to the significant out-of-class time required, leading to student complaints.

In response, we introduced simulation-based projects using 2D Working Model software. The objectives were to enhance student learning, apply engineering dynamics principles, and familiarize students with simulation tools. We developed four projects aligned with course topics: simulating free-flight and dependent motion, analyzing components' behaviors under loading, investigating work and energy, and simulating the crank-slide mechanism.

Students were tasked with creating simulation models and verifying results against theoretical calculations. This approach significantly increased engagement and interest in course content, creating an active learning environment. Throughout the implementation, we collected student feedback to refine our methods. Initially, we provided online tutorials for 2D Working Model, but many students struggled with self-directed learning, prompting us to adapt our strategy. We allocated lecture time to demonstrate the software fundamentals, which proved effective.

End-of-semester surveys indicated that students found the simulation projects beneficial, particularly in comparing simulation outcomes with theoretical predictions. This paper details the implementation of these design projects and analyzes survey results, demonstrating their positive impact on student learning in our Engineering Dynamics course.

1. INTRODUCTION

Engineering Dynamics is a required course in mechanical engineering programs and is known to be one of the most difficult and challenging courses for undergraduate students [1,2,3]. This difficulty arises not only from the complex topics and concepts in engineering dynamics but also from the traditional teaching approach [4,5,6]. Typically, engineering dynamics is offered without a lab component. The conventional teaching method involves lectures where the instructor explains principles, demonstrates examples, assigns homework for students to apply what they've learned, and uses quizzes or exams to assess understanding. However, this approach often fails to establish connections between the course content and real-world applications and does not foster active learning.

Literature reviews highlight three types of additional activities that have been incorporated into engineering dynamics courses (without lab sections) to help students better grasp key principles and concepts:

a. **Teaching Method Innovations**: These include approaches such as flipped classrooms [7], challenge problems [8], supplemental materials [9], and clickers for real-time interaction [10]. The primary goal of these activities is to promote active learning and spark student interest in the course material. These activities typically do not require much out-of-class time, as they are either conducted during lectures or assigned as homework.
b. **Use of Devices, Instruments, and Software**: Some courses incorporate tools such as smartphones with accelerometers for measuring acceleration [4,11], motion capture technology [6], Pocket-lab sensors [3], IMU (inertial measurement units) technology [2], LEGO four-bar mechanisms [4], and hands-on experiments with physical models [1,9,12]. The software Working Model is commonly used for simulating dynamic properties in projects, such as aircraft landing gear simulations [13], experimental model-based control design using multibody codes [14], and applications in mechanical engineering technology [15]. These activities aim to link course content with real-world examples and provide opportunities for students to compare theoretical calculations with real-world data. These activities also do not demand substantial out-of-class time, as they rely on existing devices, instruments, or software.
c. **Physical Design Projects**: This type of activity requires students to design and build physical models, such as a golf ball launcher [16] or a Rube Goldberg machine to demonstrate specific types of motion [17]. These projects connect course content with practical applications and allow students to implement and validate what they have learned. However, they are time-consuming, as they require significant out-of-class effort to design, construct, and test the projects.

Our program offers an engineering dynamics course for junior mechanical engineering students without a lab section. To enhance the learning experience, we have introduced four simulation-based design projects. This paper presents the implementation of these projects and discusses the outcomes. Additionally, a survey was conducted at the end of the semester, and the paper also analyzes the survey results.

2. FOUR SIMULATION DESIGN PROJECTS

Engineering Dynamics is a required course in our mechanical engineering program, typically offered during the junior year in a fifteen-week semester. The course is a 4-0-4 credit class, meaning it includes four lecture hours and no lab component, totaling four credits. The primary textbook for the course is *Engineering Mechanics: Dynamics* by R.C. Hibbeler. The course, as outlined in the syllabus, covers the following chapters:

- Chapter 12: Kinematics of a Particle
- Chapter 13: Kinetics of a Particle: Force and Acceleration
- Chapter 14: Kinetics of a Particle: Work and Energy
- Chapter 15: Kinetics of a Particle: Impulse and Momentum

- Chapter 16: Planar Kinematics of a Rigid Body
- Chapter 17: Planar Kinetics of a Rigid Body: Force and Acceleration

Since the course does not include a lab section, the typical approach involved explaining the principles of engineering dynamics during lectures, demonstrating examples, and assigning homework for students to apply what they learned. Quizzes and exams were then used to assess students' understanding of the material. However, this traditional teaching method has been criticized by many educators [1,2,3,4,5,6], as it does not foster active learning or establish connections between course content and real-world applications. As a result, there is a clear need for changes to improve the learning experience.

To enhance student engagement, we introduced additional activities aimed at promoting active learning. Several years ago, we implemented a design project in which students were tasked with designing a tennis ball launcher. This project was introduced in week 7, following the completion of Chapter 13: *Kinetics of a Particle: Force and Acceleration*. Students formed design teams of two to four members, either by choice or with faculty assistance, and were required to complete the project by the end of week 14, before the final exam. Since the course lacked a lab section, teams had to collaborate outside of class for at least two hours per week to apply engineering dynamics principles, design the launcher, and create models and necessary drawings using SolidWorks. The project successfully stimulated class participation and increased student interest in the course. However, despite not requiring prototype construction, it placed a significant out-of-class time burden on students due to the absence of dedicated lab hours. Many students expressed concerns about the heavy time commitment, a challenge also reported in other engineering dynamics courses that incorporated physical design projects [17]. As a result, we ultimately discontinued the project, as it proved unsustainable for students.

After abandoning the physical design project, we decided to introduce simulation-based design projects using 2D Working Model software. The main reasons for choosing the 2D Working Model were its ability to quickly create virtual models and its capacity to measure dynamic properties such as displacement, velocity, acceleration, and forces. With the introduction of these simulation-based projects, the grading policy for the course was updated as follows:

- Homework: 30%
- Quizzes/Exams: 30%
- Final Exam: 25%
- Class Simulation Design Projects: 15%

The simulation-based design projects now represent a significant portion of the final grade. The objectives of these projects are to (1) engage students in active learning, (2) apply engineering dynamics principles to verify simulation results generated by 2D Working Model, and (3) familiarize students with new simulation software, particularly focusing on the behavior of components or mechanisms under loading. Four class design projects were carefully developed to align with the course topics, and these are explained and displayed in the following sections.

The simulation project one: Free-flight motion and Dependent Motion

The first design project was to simulate free-flight motion and dependent motion. This simulation project was for Chapter 12 Kinematics of a particle. This simulation project would provide an additional platform to visualize free-flight motion and dependent motions by using virtual models and simulations. Students were asked to verify the simulation results by theoretical calculations. It consists of three questions. The first simulation project is listed in Appendix A.

The simulation project two: Kinetics of particles

The second design project is to simulate a component's behaviors such as displacement, velocity, and acceleration under a loading. It was for Chapter 13 Kinetics of particles: Force and Acceleration. This simulation project provided a platform to visualize the displacement, velocity, and acceleration vs time. Students could gain a deeper understanding of kinetics of particles. The second simulation project consisted of three questions and is listed in Appendix B.

The simulation project three: Work and Energy

The third simulation project was for Chapter 14 Kinetics of a particle: Work and energy. It consisted of two questions. They could reinforce students' understanding of work and energy and visualize the principle of work and energy. The simulation project three is listed in Appendix C.

The simulation project four: Crank-slider mechanism

The last class simulation project was to simulate the behavior of a crank-slide mechanism. This was for Chapter 17 Planar Kinetics of a rigid body: Force and Acceleration. This project consisted of one question only. The comparison between simulation and theoretical calculation would significantly improve students' understanding of crank-slider mechanism and visualize the motion of the crank-slider mechanism. Simulation project four is listed in Appendix D.

For each class simulation project, students were asked to create simulation models, display, and export simulation data such as displacement, velocity, acceleration, and force, and then verify the simulation results through theoretical calculations. These activities significantly activated students learning and increased their interest in the course contents and created an active learning environment.

3. IMPLEMENTATION OF THE PROJECTS

We have implemented simulation design projects in our Engineering Dynamics course for several years. This paper focuses on the implementation during the 2024 summer semester, a standard 15-week term.

The simulation design projects were designed as team assignments, with each team consisting of two to four members. While teamwork was encouraged, students were allowed to work individually on the projects in certain special cases, since the projects involved simulations and no physical prototypes.

The release schedule for the 2024 summer semester projects is as follows:

- **Week 4**: After covering "Dependent and Relative Motion," the first simulation project—*Free-flight Motion and Dependent Motion*—was released.

- **Week 7**: After completing Chapter 13 on *Kinetics of a Particle: Force and Acceleration*, the second simulation project—*Kinetics of Particles*—was released.
- **Week 9**: After completing Chapter 14 on *Kinetics of a Particle: Work and Energy*, the third simulation project—*Work and Energy*—was released.
- **Week 12**: After completing Chapter 16 on *Planar Kinematics of a Rigid Body* and beginning Chapter 17 on *Planar Kinetics of a Rigid Body: Force and Acceleration*, the fourth simulation project—*Crank-Slider Mechanism*—was released.

We used 2D Working Model, a motion simulation CAE and conceptual design tool, to allow students to create simulations that verify concepts and analytical calculations without building physical prototypes.

Throughout the implementation of these design projects, we consistently gathered feedback from students to refine our approach. Initially, we provided students with tutorial websites for 2D Working Model, hoping they would learn the software independently. However, we found that this approach led to many questions and complaints from students, particularly regarding difficulties in starting the design projects. As a result, we modified our approach. In the previous year, we allocated one lecture hour to explain the basic fundamentals of 2D Working Model before releasing the first project. This adjustment proved to be successful.

Since 2D Working Model was new to most students, we implemented the following activities to help them familiarize themselves with the software:

- **Week 2**: Two weeks before the first project was released, we informed students that a 2D Working Model would be used for simulation design projects. We encouraged them to install the software and explore online tutorials, providing several useful websites such as Design Simulation.
- **Week 4**: When the first simulation project was released, we dedicated one lecture hour to introduce 2D Working Model. During this session, we explained the software's basic functions and conducted live demonstrations to help students begin using the software. We also held a Q&A session to address any issues. The following topics were covered during the lecture, as shown in Figure 1:
    - Creating objects with different shapes and determining the position of their centers using the Shape toolbar.
    - Specifying links between objects using the Joint toolbar.
    - Specifying constraints between objects and the ground using the Constraint toolbar.
    - Adding external forces, velocity, rotation, springs, pulleys, and other functions using the Function toolbar.
    - Modifying properties such as mass, velocity, and position using the "Properties" tab under the "Window" menu.
    - Creating measurements for dynamic properties (position, velocity, acceleration) using the "Measure" tab in the menu.
    - Adjusting simulation settings, such as time intervals and simulation duration, via the "Accuracy" and "Pause Control" subtabs under the "World" menu.

- Exporting measurement data through the "Export" subtab under the "File" menu, enabling students to save and open the data in Excel.

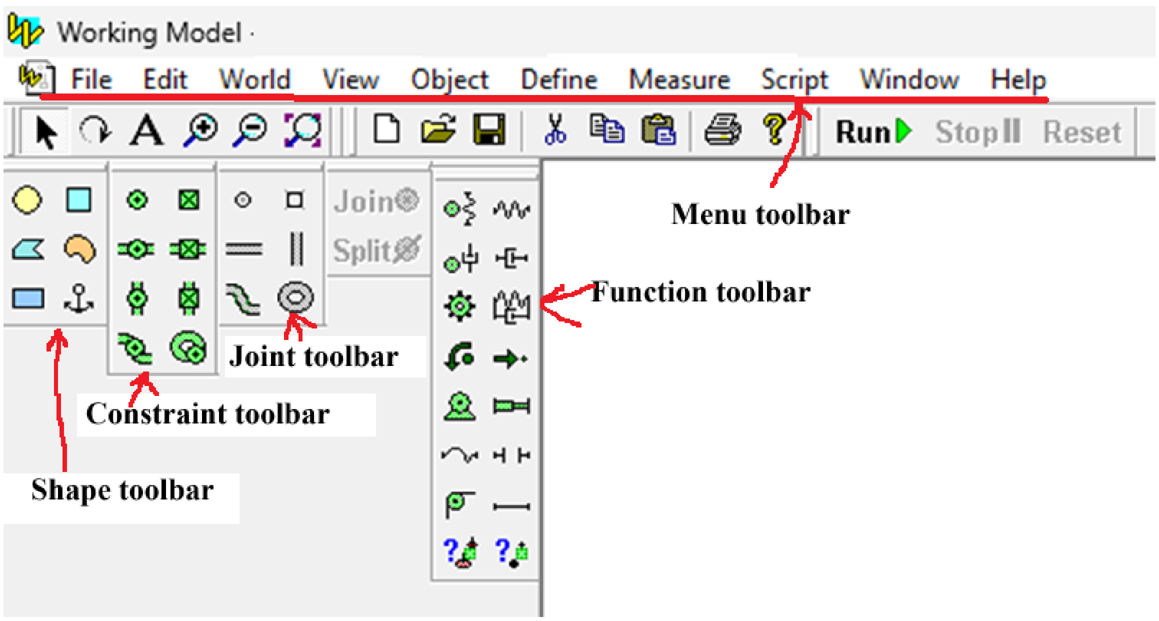

Figure 1 The interface of 2D Working Model

One week before each project was due, we organized a 10-minute Q&A session to address any project-related issues.

From our interactions during these Q&A sessions and office hours, we observed the following:

- Some students did not like the 2D Working Model, believing it was not sufficiently advanced.
- A significant amount of time was spent comparing simulation results to theoretical calculations, particularly when discrepancies arose. In most cases, these differences were due to improper settings in the software, such as incorrect mass, velocity, or friction coefficient specifications.

We were pleased to observe that no students complained about the workload associated with these four simulation projects. This time, we provided two one-hour lectures to explain the fundamentals of the WorkingModel software and offered short 10 to 15-minute Q&A sessions specifically for simulation projects. Based on interactions with students, they typically required an average of two hours to complete each simulation project.

4. CLASS SURVEY AND DATA ANALYSIS

The class survey data presented in this paper was from one section of engineering dynamics with a total of twenty-one students. At the end of the 2024 summer semester, a survey was conducted to assess simulation design projects. We received sixteen responses with a responding rate of 72.6 percent. The survey contained five questions, and the results are presented in Table 1.

Table 1 Survey questions and survey data

Q#1:To what extent did the simulation projects enhance your understanding of engineering dynamics concepts?				
Not at all	Somewhat	Neutral	Very Much	Extremely
0	2	3	8	3
Q#2: In all simulation assignments, you are asked to compare the simulation results with hand calculations, did you find it beneficial?				
Not at all	Somewhat	Neutral	Very Much	Extremely
0	3	5	4	4
Q#3:The simulation projects help me to have a better visualization of engineering dynamics theory.				
Not at all	Somewhat	Neutral	Very Much	Extremely
0	2	2	7	5
Q#4: How do you think including class projects, like simulation projects, in the engineering dynamics course would impact your learning experience?				
Not beneficial at all	Somewhat challenging	Neutral	Somehow beneficial	Extremely beneficial
0	3	1	7	5
Q#5: How would you rate your overall experience with the simulation assignments?				
Very Dissatisfied	Dissatisfied	Neutral	Satisfied	Very Satisfied
0	1	4	6	5

The survey results on question #1 are depicted in Figure 2. A total of 69% of students agreed that the simulation projects contributed to their understanding of these concepts.

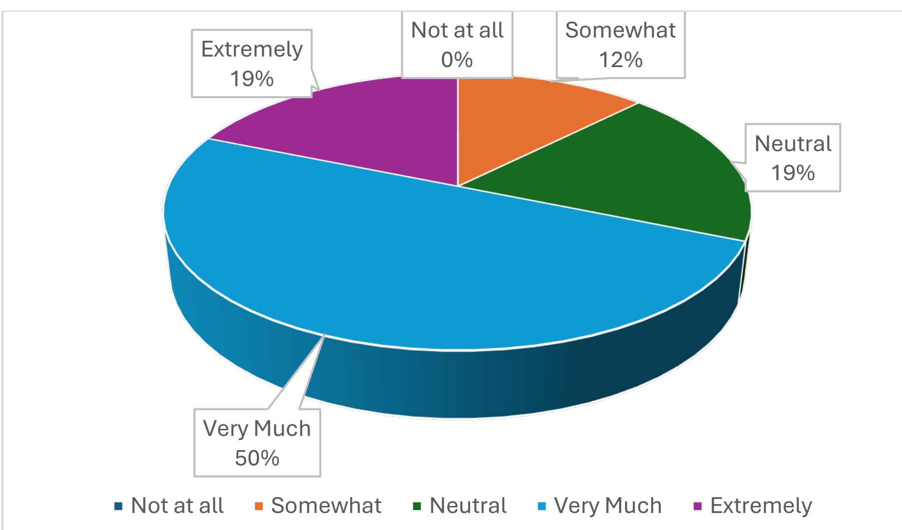

Figure 2 The survey results on question #1: To what extent did the simulation projects enhance your understanding of engineering dynamics concepts?

In traditional homework assignments, which consisted of well-defined problems from the textbook, students followed a set approach to arrive at an answer, which may or may not have been correct. However, in the simulation design projects, students ran simulations to obtain answers and were then required to verify these results through theoretical calculations. When the simulation results did not match the theoretical calculations, students were prompted to investigate and identify potential errors in either the simulation or the calculations. The survey results on question #2 are depicted in Figure 3. While we hoped that this comparison would provide significant learning benefits, only 50% of students agreed that this process was beneficial.

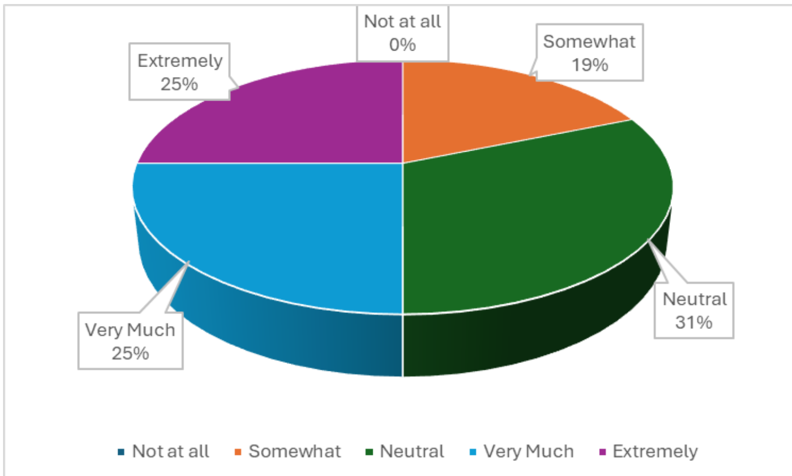

Figure 3 the survey results on question #2: In all simulation assignments, you are asked to compare the simulation results with hand calculations, did you find it beneficial?

The simulation design projects used virtual models to help students visualize dynamic motions. The survey results on question #3 are depicted in Figure 4. According to the survey, 75% of students agreed that the simulations helped them better visualize engineering dynamics concepts.

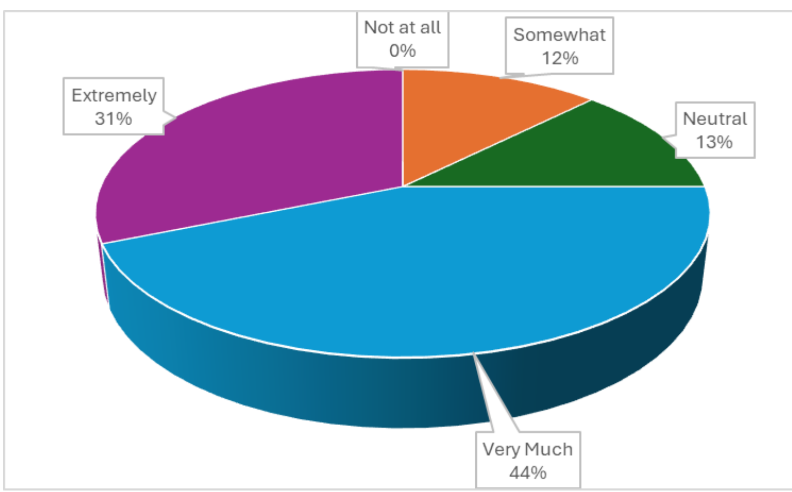

Figure 4 the survey results on question #3: The simulation projects help me to have a better visualization of engineering dynamics theory.

As noted in the introduction, many educators believe that additional activities can enhance the traditional lecture-homework-exam approach, and our survey data supported this view. The survey results on question #4 are depicted in Figure 5. The results showed that 75% of students agreed that the simulation projects in the engineering dynamics course enriched and impacted their learning experience.

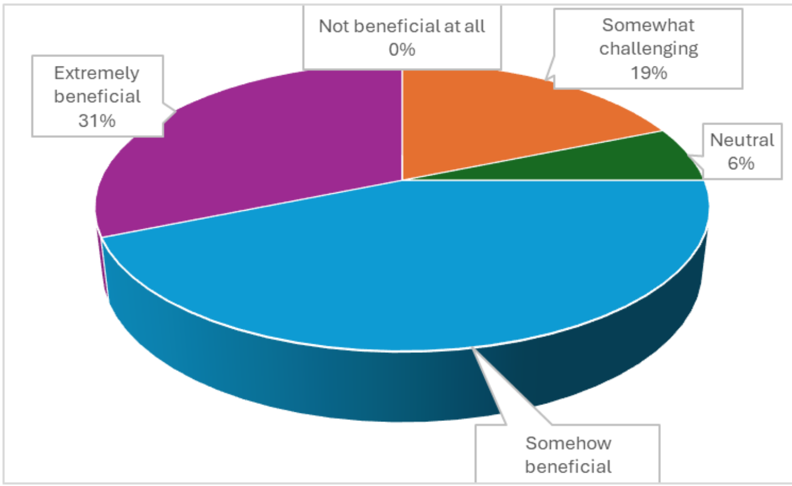

Figure 5 The survey results on Question #4: How do you think including class projects, like simulation projects, in the engineering dynamics course would impact your learning experience?

Finally, when asked to rate their overall experience with the simulation projects. The survey results are depicted in Figure 6. According to the survey, 69% of students reported a positive experience.

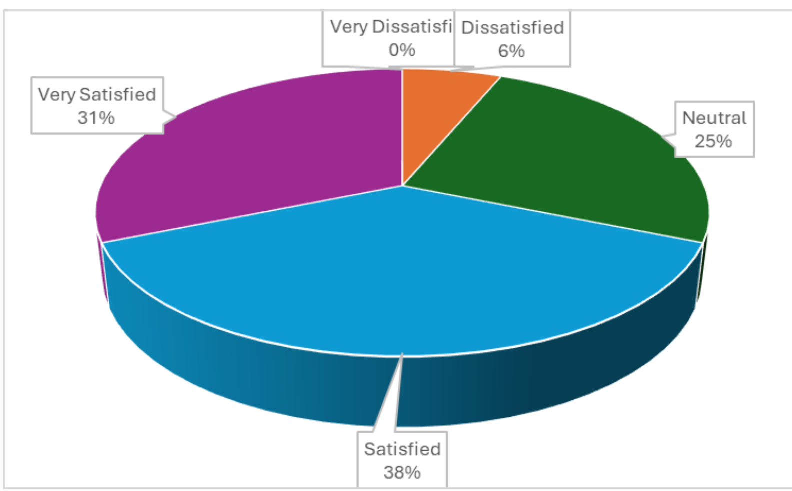

Figure 6 The survey results on Question #5: How would you rate your overall experience with the simulation assignments?

At the end of the course, we also asked students to provide additional feedback. Some of the comments are listed below:

- “I think the simulation projects are a great part of the course; they definitely help with overall understanding and boost grades.”

- "Having the simulation assignments as part of the course is very helpful for visualizing the problems we are solving using dynamics theories."
- "The simulations, used as an engineering tool for analysis and visualization, were useful as they allowed students to work on projects they found interesting and observe the effects of various dynamics principles in action."
- "I believe the simulations gave me a clearer understanding of the assignments we were completing on Pearson, and they provided a nice challenge."
- "I liked the simulation projects, but I wasn't a fan of the program."
- "Using newer and better simulation programs, like SolidWorks, would be very beneficial for students and would give them essential experience for their future careers."
- "Consider using a different software since this one is outdated."

From the students' comments, it was clear that several students were dissatisfied with the 2D Working Model due to its outdated nature. They expressed frustration with its limitations and the lack of support, which impacted their overall experience.

5. DISCUSSIONS AND CONCLUSIONS

Our Engineering Dynamics course is a core requirement in the mechanical engineering curriculum and is typically taught as a lecture-based course without a lab section. To enhance student learning, we incorporated simulation design projects as supplementary activities, allowing students to gain a deeper understanding of course concepts. According to a student survey, 69% agreed that these projects improved their comprehension of engineering dynamics. Additionally, 75% felt the simulations helped them better visualize theoretical concepts, and another 75% believed the projects enriched and positively impacted their learning experience. Overall, 69% of students reported a positive experience with the simulation design projects.

One surprising finding from the survey and our observations was related to the value of comparing simulation results with hand calculations. As instructors, we strongly believed this comparison was crucial for deepening students' understanding. However, only 50% of students agreed it was beneficial, meaning half did not find this aspect of the projects valuable. This result was unexpected, as we assumed these comparisons would strengthen their grasp of the material.

We also found that many students expressed dissatisfaction with the 2D Working Model software, with some requesting the use of more advanced alternatives. Their main concern was the lack of supporting information and the outdated nature of the software. As instructors, we believed the 2D Working Model was effective because it allowed for quick model creation based on dynamic properties, rather than the shapes and dimensions of physical models. This approach helped reduce the burden on students, as the course did not include a lab section.

In conclusion, the simulation projects were generally well-received, enhancing students' understanding of engineering dynamics and providing a valuable tool for visualization. However, we will continue refining our approach based on student feedback and explore better simulation software to further support student learning in future courses.

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Appendix A: The simulation project one: Free-flight motion and Dependent Motion

Question #1: A ball with a mass of 0.2 kg has an initial velocity of $V_{x0} = 5(\frac{m}{s})$ and $V_{y0} = 10(\frac{m}{s})$. The center of the ball is located at the coordinate $x = 0\ (m)$ and $y = 20\ (m)$, as shown in Figure 7. Using simulation, determine the time and the y-component velocity of the ball when the ball hits the ground.

In the submission, include the following:

- The screen shot of the working model and the meter graphs (y-position and V_y)
- The simulation curves for vertical position and velocity of the ball are created by Excel.
- Verify the simulation results of the time and the y-component velocity of the ball when the ball hits the ground by analytical theoretical calculation.

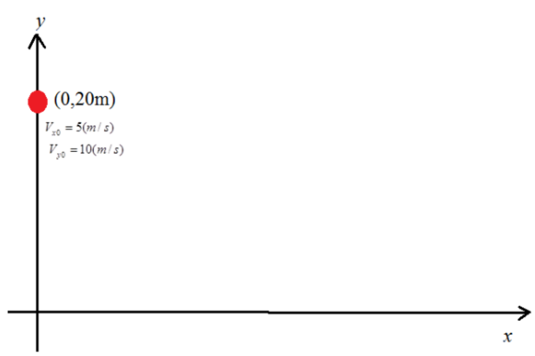


Figure 7 The schematic for question #1

Question # 2: It is concluded that for a free-flight motion, when the angle of the initial velocity with the horizontal axis is 45^0, the flight distance of the object in the horizontal direction is maximized. To verify this conclusion, use the Working Model to simulate three cases, as shown in Figure 8, with angles $\alpha= 30^0$, 45^0 and 60^0.

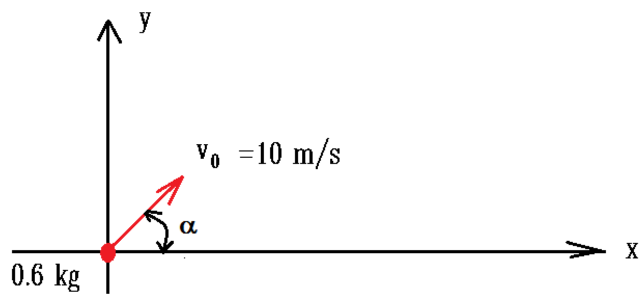


Figure 8 The schematics for question #2

Question #3: Construct the equations that relate the velocities of the blocks in the pulley system shown in Figure 9. For the system with zero initial velocities, we have: $m_A = 6(kg)$ and $m_C = 2(kg)$. Determine the velocity of each block at t = 0.5 second.

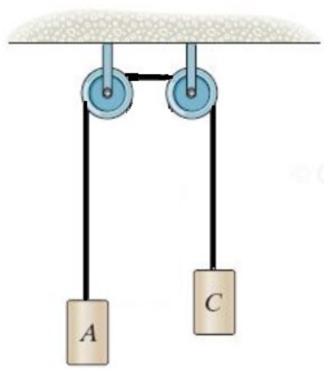


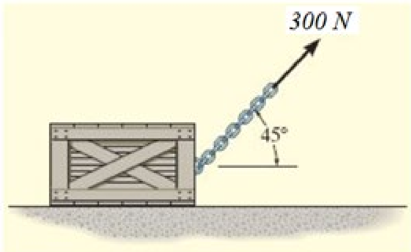
Figure 9 The schematic for question #3

In the submission, include the following:

- The screen shot of the working model for the model with the meter graphs (vertical position, velocity, and acceleration of the block C).
- The simulation curves for vertical position, velocity and acceleration of the block C created by Excel.
- Verify the simulation results of the vertical position, velocity, and acceleration at t=0.5 (s) by analytical theoretical calculation.

Appendix Two: The simulation project two: Kinetics of particles

Question #1: Determine the acceleration, velocity, and position of the block as shown in Figure 10.



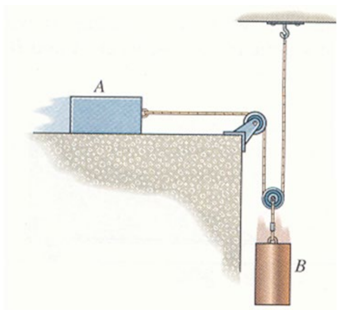
$$\mu_k = 0.2$$
$$\mu_s = 0.3$$
$$m = 60(kg)$$

Figure 10 The schematic for question #1

In the submission, include the following:

- The screen shot of the working model for the model and the meter graphs (x-position V_x and a_x)
- The simulation curves for position, velocity, and acceleration of the block created by Excel for the time range of 0~2 (s).
- Verify the simulation results of the position, velocity, and acceleration of the block at t=2 (s) by analytical theoretical calculation.

Question #2: For the two block systems shown in Figure 11, determine the acceleration of each block and the tension in the cord.



$$\mu_k = 0.2$$
$$\mu_s = 0.3$$
$$m_A = 20(kg)$$
$$m_B = 30(kg)$$

Figure 11 The schematic for question #2

In the submission, include the following:

- The screen shot of the working model for the model and the meter graphs (velocity and acceleration of each block)
- The simulation curves for position, velocity, and acceleration of each block created by Excel for the time range of 0~2 (s).
- Verify the simulation results of the acceleration of each block by analytical theoretical calculation.

Question #3: The spring has a stiffness $k = 200N/m$ and is upstretched when the 25-kg block is at position A as shown in Figure 12. The contact surface between the block and the plane is smooth. Run the simulation to determine the acceleration of the block when s=0.4 m.

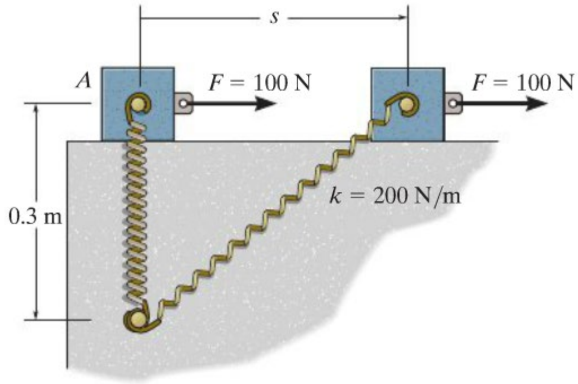


Figure 12 The schematic for question #3

In the submission, include the following:

- The screen shot of the working model for the model and the meter graphs (velocity and acceleration of the block)
- The simulation curves for position, velocity, and acceleration of the block created by Excel for the time range of 0~2 (s).
- Verify the simulation results of the acceleration of the block by analytical theoretical calculation.

Appendix C The simulation project three: Work and Energy

Question #1: The collar has a mass of 2 kg and is released from rest at position A and slides up the smooth rod under the action of a constant force with a magnitude of 50-N as shown in Figure 13. Determine the velocity, and acceleration of the collar as it passes position B. Note that the spring is un-stretched at position A.

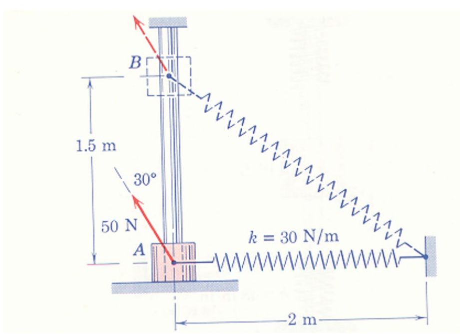


Figure 13 the schematic for question #1

In the submission, include the following:

- The screen shot of the working model for the model and the meter graphs (position, velocity, and acceleration of collar)
- The simulation curves for position, velocity, and acceleration of the collar created by the Excel for the time range of 0~2 (s).
- Verify the simulation results of the velocity and acceleration of the collar when passing position B by analytical theoretical calculation.

Question #2: Determine the speed of the 10-kg block A after it has moved 0.1m to the right under the action of the 80-N constant force as shown in Figure 14. The contact surfaces between blocks and the ground are smooth.

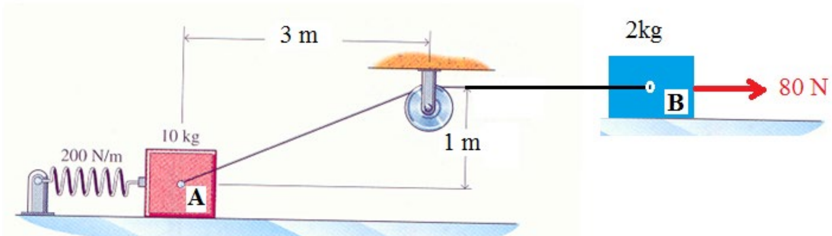


Figure 14 The Schematic for question #2

In the submission, include the following:

- Screen shot of the simulation problem with the meter graphs (position, velocity and acceleration of block A, and the tension of the rope).
- The simulation curves for position, velocity, and acceleration of block A, and the tension of the rope created by the Excel.
- Solve the problem analytically and compare the velocity of block A after it has moved 0.1 m to the right with the simulation by a table with % of error.

Appendix D The simulation project four: Crank-slider mechanism

Question #1: In the position shown crank AB has a constant angular velocity of 6 rad/s as shown in Figure 15. Determine the velocity of the slider D for two positions of θ = 45° and θ = 90°. Start the simulation at θ = 0°.

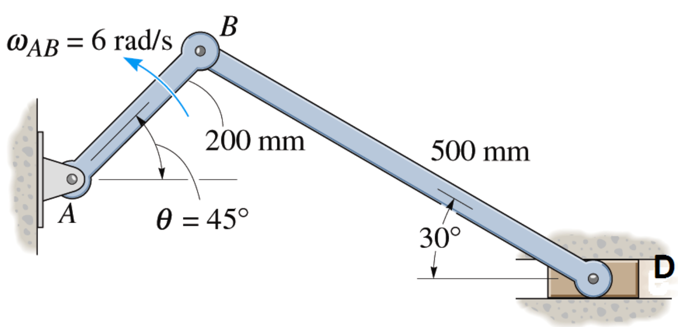


Figure 15 the Schematic for question #1

In the submission, include the following:

- The screen shot of the working model for the model and the meter graphs (position and velocity of the slider D)
- The simulation curves for position and velocity of the slider D created by Excel for the time range of 0~2 (s).
- Verify the simulation results of the velocity of the slider D when θ = 45° and θ = 90° by analytical theoretical calculation.
- Attach the working model file.