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Enhancement of Student Learning in an Engineering Course Through Hands-on Pedagogical Approaches

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Abstract

This study focused on enhancing student learning in the gateway engineering dynamics course by modifying the instructional design and incorporating hands-on learning activities. This research targeted Mechanical Engineering (ME) undergraduate students, for whom ME 252: Engineering Dynamics is a required foundational course. The research goals were to improve students' understanding of engineering dynamics principles, increase the passing rate in ME 252, and prepare them for higher-level courses. While being a prerequisite course, the ME 252 course serves as a key building block in developing the ME students' understanding of Fluid Mechanics, Computational & Experimental Methods, and Control Systems in the ME curriculum. Thus, for students to enjoy success throughout the ME curriculum, they must develop a solid understanding in ME 252 as it is one of the foundational engineering specific courses to which ME students are exposed. The need to improve their understanding is crucial because every semester, nearly 25% of the students in ME 252 earn a "D", "F", or "W" grade and must repeat the class. Moreover, statistics from the past several semesters showed that on average, 30% of students in ME 252 earn a "C" grade, which means that these students leave the course with an incomplete knowledge of how to connect theoretical concepts to applications in dynamics. Therefore, during the first day of class, the importance of ME 252 as a prerequisite to other ME courses is explained, emphasizing how the course's key concepts are used in future courses. Also, the hands-on learning methodology and the upcoming problem-solving approach were outlined on the first day of class. These new approaches to teaching the dynamics course were followed through the remainder of the semester, and students' feedback was collected and analyzed at the end. The results indicate that using such pedagogical approaches has yielded a positive effect on student performance and will thus be repeated/evaluated in the ME 252 course in the subsequent semesters for continuous improvement.

Goals and Objectives

Figure 1 shows that ME 252: Engineering Dynamics course is a prerequisite to ME 356: Fluid Mechanics, ME 384: Computational Method, and ME 460: Controls. These courses are prerequisites to other Mechanical Engineering (ME) courses such as ME 411, ME 420, ME 458, ME 480, and ME 481. Thus, for students to attain success throughout the Mechanical Engineering curriculum, they must develop a solid understanding in ME 252. The need to improve their knowledge is highly crucial because every semester, nearly 25% of students in this course earn a "D", "F" or "W" grade and must repeat the class. Additionally, statistics from the past several semesters show that approximately 30% of students in ME 252 earn a "C" grade. This indicates that these students leave the course with an incomplete knowledge of connecting theoretical concepts to applications in dynamics (such as the kinematics of particles and rigid bodies; kinetics of particles and rigid bodies; force and acceleration; work and energy; impulse and momentum application to practical problems).

The goal of this instructional redesign is thus to reduce the failure rate and improve students' mastery of the core materials in dynamics so that they can have more success in the other ME courses. Students' feedback from the last several semesters shows that computer simulations and visualizations (alternative teaching methods to enhance learning) are not substitutes for hands-on and active learning experiences. Instead, it suggests that hands-on, activity-based teaching does improve student learning.

Therefore, the objectives of this study included replacing traditional teaching methods (lecture with textbook or computer simulations and visualizations) with a combination of lectures followed by the students manipulating physical objects to demonstrate the theoretical principles. These objects (e.g., bow and arrow set, yo-yo, toy airplanes, pulleys, etc.) enabled the instructor to conduct pedagogical demonstrations in class to illustrate dynamic concepts such as kinematics and kinetics of particles, work and energy principles, impulse and momentum principles applied on particles and rigid bodies, etc. These activities are assigned to small groups, thereby increasing students' level of participation and encouraging the development of teamwork. A second major objective is to gather formative assessments of students' learning, which enabled the instructor to give short post-activity quizzes to assess (in real-time) their understanding of the principles they just learned. As this course lays the foundation for mathematically illustrating the motions of objects, understanding the effect of forces/moments on such motions through practical examples is expected to be highly effective for the students.

Background and Context

The ME 252: Engineering Dynamics is a 3.0 credit hours Mechanical Engineering (ME) core/foundation course which is a prerequisite for ME 356: Fluid Mechanics, ME 384: Computational Method, and ME 460: Controls as mentioned earlier. This course is a basic building block for the mechanics portion of the ME program. This course provides students the opportunity to develop an ability to identify, formulate, and solve engineering dynamics problems by applying engineering, science, and mathematics principles. The course focuses on applying basic concepts and principles of dynamics with the primary application of moving conditions involving particles and rigid bodies. Students learn to differentiate between kinematics and kinetics problems. They can compute the position, velocity, and acceleration of a particle and rigid body using cartesian, normal-tangential, and polar coordinate systems. They also learn how to use equations of motion with free body diagrams to solve kinetic problems involving force, work, and impulse on particles and rigid bodies.

In each semester, only one section of ME 252 is offered. That means the total number of sections is two for each academic year. The ME department enrolls 90-100 new students every year who are required to take this core course along with ME 251: Engineering Statics, and several basic math and physics courses. This course is for either sophomore or junior level students. Based on their performance in these core courses (ME 251 and ME 252), students will decide either to stay in the Bachelor of Science in Mechanical Engineering (BSME) program or to transfer to Engineering Technology Management (ETM) program within the Mechanical Engineering (ME) department.

This project provides benefits to multiple areas of the ME program. From the students' perspective, this study seeks to reduce "D", "F" and "W" grades and helps students to improve their grades more towards "A" and "B" by increasing their learning. Also, with this experience, in the long run, this transformation of the traditional classroom to an active learning environment can be extended to other courses like Fluids Mechanics, Controls, Machine Design, etc. Moreover, this learning approach promises to increase student success in a core course like dynamics, which should positively impact students' performance in subsequent courses in the ME department.

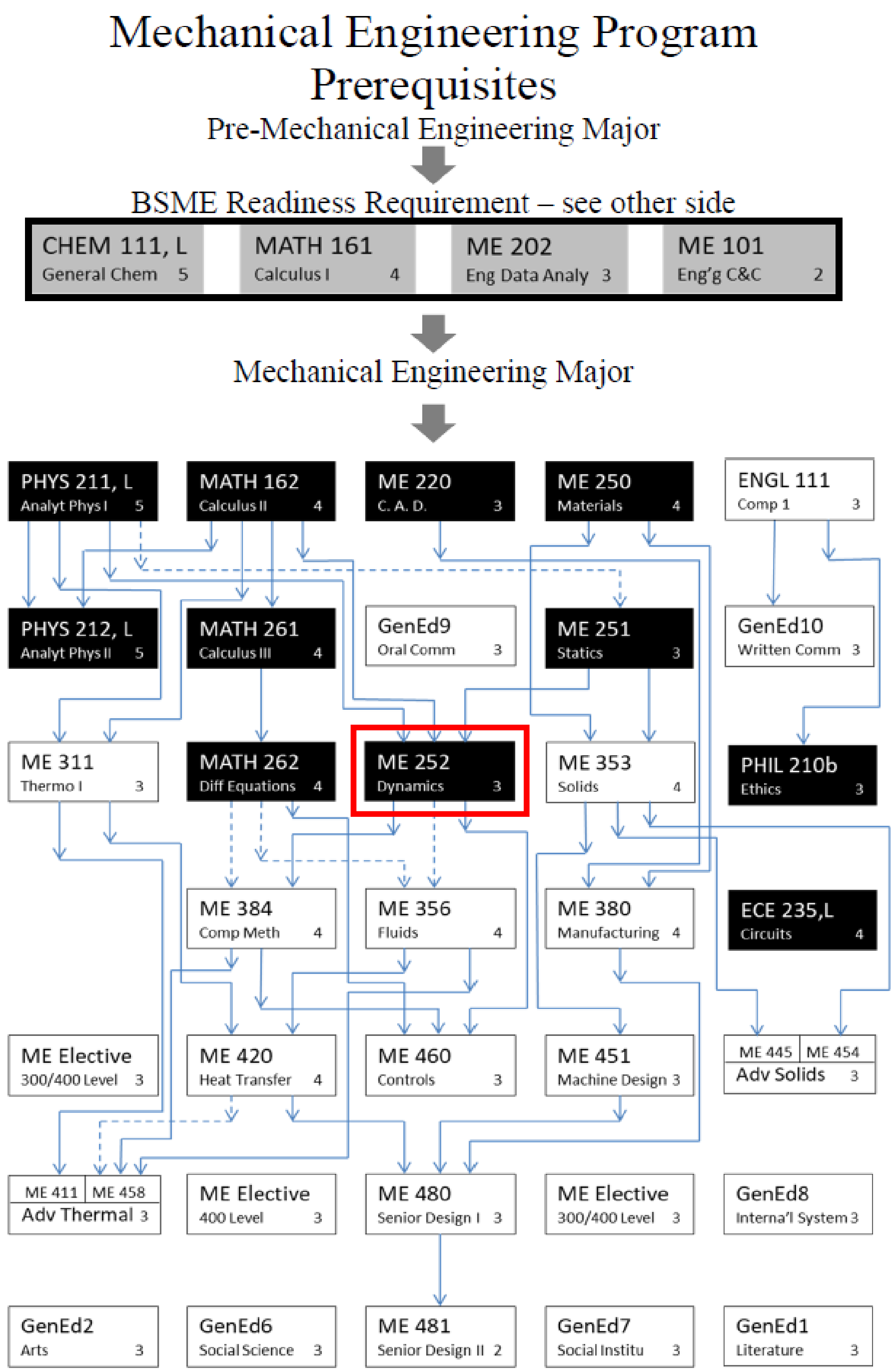

Fig 1: Mechanical Engineering program course hierarchy demonstrating the interaction of all courses with ME 252: Engineering Dynamics.

Approach and Methodology

A well-organized syllabus of ME 252 course has been prepared with a class schedule and grading rubrics. It involves numerous laws of physics and mathematical formulas. The current instructional method in ME 252 is split into several portions. First, theories are discussed with active interactions with pedagogical demonstration and real-life importance. Second, numerous problems using the step-by-step problem-solving methods are presented to show real world correlations and applications. In the end, a class participation problem is assigned to the students to solve in each class. The following key rules are mentioned in the ME 252 syllabus:

- *Class participation/Homework:* Several assignments (in the form of active class participation and homework) are given throughout the semester. The assignments are due on or before the due date and need to be turned in online through the Canvas provided link. All homework assignments are given through Pearson Mastering of Engineering. The website randomizes the variables of homework problems which eliminates the chance that students copy the answers from one another.
- *Quizzes/Exams:* Four quizzes, three exams, and a comprehensive final exam are given throughout the semester. The quizzes are intended to encourage preparation for the upcoming exams. The quizzes/exams are closed books and closed notes. For reference, a formula sheet is provided with the quizzes and exams. The schedule of all quizzes and exams is provided in the syllabus.
- *Calculator and Electronic Devices:* Students must bring only scientific calculators to the class and must be prepared to work on problems during class. No graphing calculators are allowed during quizzes/exams. Examples of scientific calculators are TI-34 or CASIO fx-300ES models. Cell phones, PDA's, pagers, handheld computers, and other electronic devices must be turned off and stored away during quizzes/exams. All calculator cases/covers must be stored away as well. The syllabus also mentioned that the failure to comply with those policies is treated as a violation of academic integrity.

It has long been known that student achievement rises significantly when teachers regularly assign homework and students do it [1-2]. In this course, homework is itemized in the syllabus to strengthen a specific key concept and their applicability to solve real-world problems. Assignments require students to think and foster their desire to learn [3-5]. The homework problems for students to think about the problem-solving methodology are provided later (described below). However, the main drivers in engaging the students to develop their problem-solving methodology are the active interactions and demonstration of real-life importance. Based on work done by [6-8], how students are motivated plays a significant part in their desire to learn a new subject. This work aims to implement strategies with pedagogical demonstration (few examples are shown below), which would positively influence the overall passing rate in ME 252, while keeping course integrity and consistency intact.

Learning

It is explained to the student that learning is a time-intensive process. Therefore, all students should schedule several hours each day to review class notes, practice examples, read the textbook, work on homework, and prepare for this class. Students need to use the following flow chart to get the most out of the studying (Fig. 2).

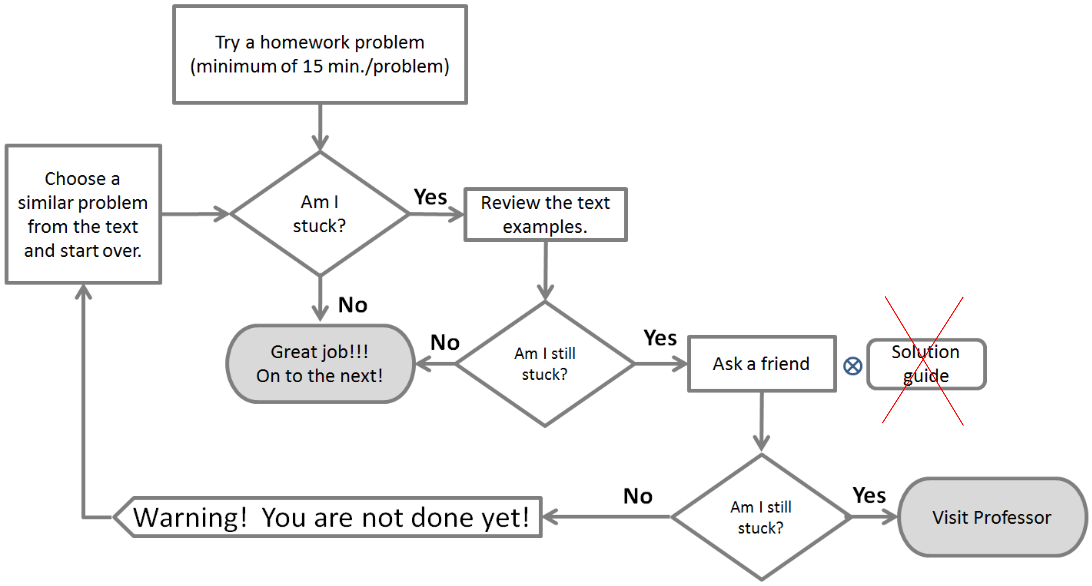

Fig 2: ME 252: Engineering Dynamics flow chart of learning.

Problem Solving Methodology

One of the goals of the ME 252 course is to develop engineering problem-solving skills. The problem-solving methodology is an organized and consistent way of working through dynamics problems and is included in the syllabus. These skills are mastered through class participation and homework. There is a preferred approach to problem-solving that is characterized by a systematic procedure consisting of the following steps:

1. *Known:* After carefully reading the problem, state briefly and concisely what is known about the problem. Do not repeat the problem statement.
2. *Find:* State briefly and concisely what is to be found.
3. *Free Body Diagram:* Draw a free body diagram of the physical system to show all forces involved and the direction of motions.
4. *Assumptions:* List all pertinent assumptions needed to simplify the problem.
5. *Analysis:* Begin analysis by applying appropriate physical laws. Develop the analysis as completely as possible before substituting numerical values. In other words, devise a solution strategy before punching keys on a calculator.
6. *Calculations:* Perform the calculation (using a scientific calculator) needed to obtain the desired results. Clearly identify your results.
7. *Units:* Exercise care when dealing with units. Answers without appropriate units are ambiguous.

The “step 5: analysis” in problem-solving methodology is applicable from the most basic to highly advanced dynamics problems. For example, the procedure of problems involved in dynamics as “equation of motion” are:

a) Select a convenient inertial coordinate system; rectangular (x, y), normal/tangential (n, t), or cylindrical (r, θ) coordinates.

b) Draw a free-body diagram and resolve forces into their appropriate components.
c) Draw a kinetic diagram to show the inertial force, m***a***. Then, resolve this vector into its appropriate components.
d) Apply the equations of motion (EoM) in their scalar component form and solve these equations for the unknowns.
e) When necessary, apply the proper kinematic relations to generate additional equations to solve for all unknowns.

Pedagogical Demonstration

One of the curvilinear motions often studied in terms of its rectangular components by free-flight projectile motion is shown in Fig. 3. As the air resistance is neglected in this problem, the only force acting on the projectile is its self-weight, which causes the projectile to have a constant downward acceleration and constant velocity at the horizontal direction. This phenomenon can be easily demonstrated by throwing a football. Such that a football was brought to a large classroom and two students were volunteer to throw the football to each other (as Fig. 3). The learning outcome for sudetns is that the football is coming down to earth although it was throw to sky due to “acceleration due to gravity” which is the integral part of projectile motion.

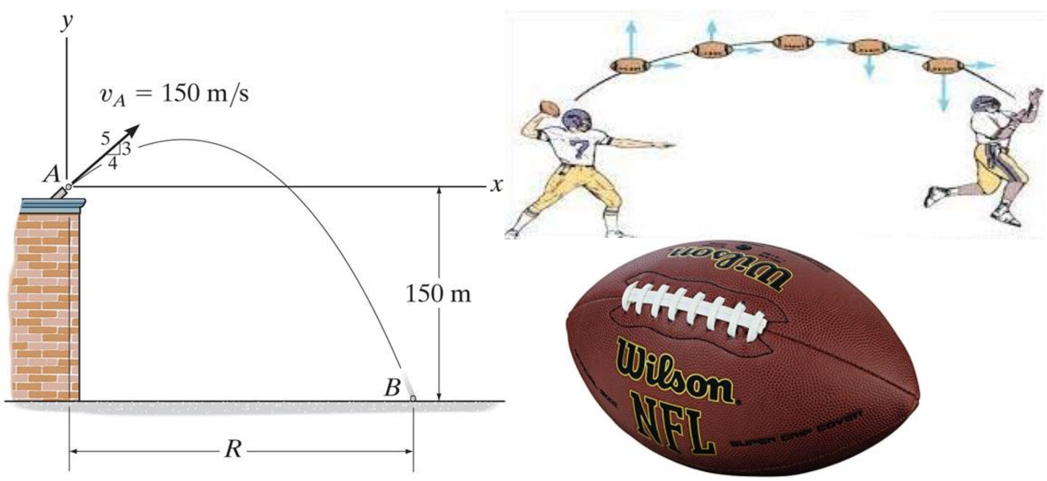

Fig 3: Demosntration of Projectile Motion (left) with a ‘curvilinear kinematics of rectangular components’ problem that can be easily explained by showing the motion of a football (right) when it is hit by a player.

In dynamics, there are types of problems involving the motion of one particle that depends on the corresponding motion of another particle, known as the absolute dependent motion of these particles, shown in Fig. 4. This example shows this dependency, where a bucket being considered a particle is interconnected by inextensible ropes wrapped around the pulleys. In this demonstration, four pulleys were brought to class and hanged by rigging ropes from cantilever beam. One student was come forward to hold the rope (as Fig. 4) and pulled down. Students were able to comprehend that when rope was pull down by a student then the metal bucket was going upward, which means their motion were depended on each other.

Fig 4: Demonstration of an Absolute Dependent Motion Analysis (left) through a pulley mechanism that can be easily explained by building a simple setup using (right) rigging ropes, a metal bucket, and a pulley.

In dynamics, the branch that deals with the relationship between the change in motion of a particle and the forces that cause this change is called kinetics. Newton's Second Law is the basis of kinetics, which states that when an unbalanced force acts on a particle, the particle will accelerate in the direction of the force with a magnitude that is proportional to the force. When a particle moves along a curved path, the equation of motion for the particle can be written in both the normal and tangential coordinates. This can be demonstrated by having a softball hanging by a rope, like a pendulum moving back and forth, as shown in Fig. 5. The learning outcome for sudetns is that when a softball hanging from a cantilever beam by a rope (as Fig. 5) then it moves in a curved path due to application of force on it.

Using the concepts of work and energy the motion of particles can be analyzed. The resulting equations will be useful for solving problems that involve force, velocity, and displacement. A force does work on a particle only when the particle undergoes a displacement in the direction of the force. The capacity of doing work is called energy. The work done by a spring force depends on the elongation or compression of the spring only. When an elastic spring is elongated or compressed a distance from its unstretched position, elastic potential energy is stored in the spring, which is always positive. The spring force, which has the capacity or potential to always do positive work on a particle, can be clearly understood by demonstrating the compression and expansion of a spring shown in Fig. 6. Two springs were brought to the classroom to explain the difference between compression and expansion of a spring, and shown the unstretched location of spring. This understanding is important for spring related problem.

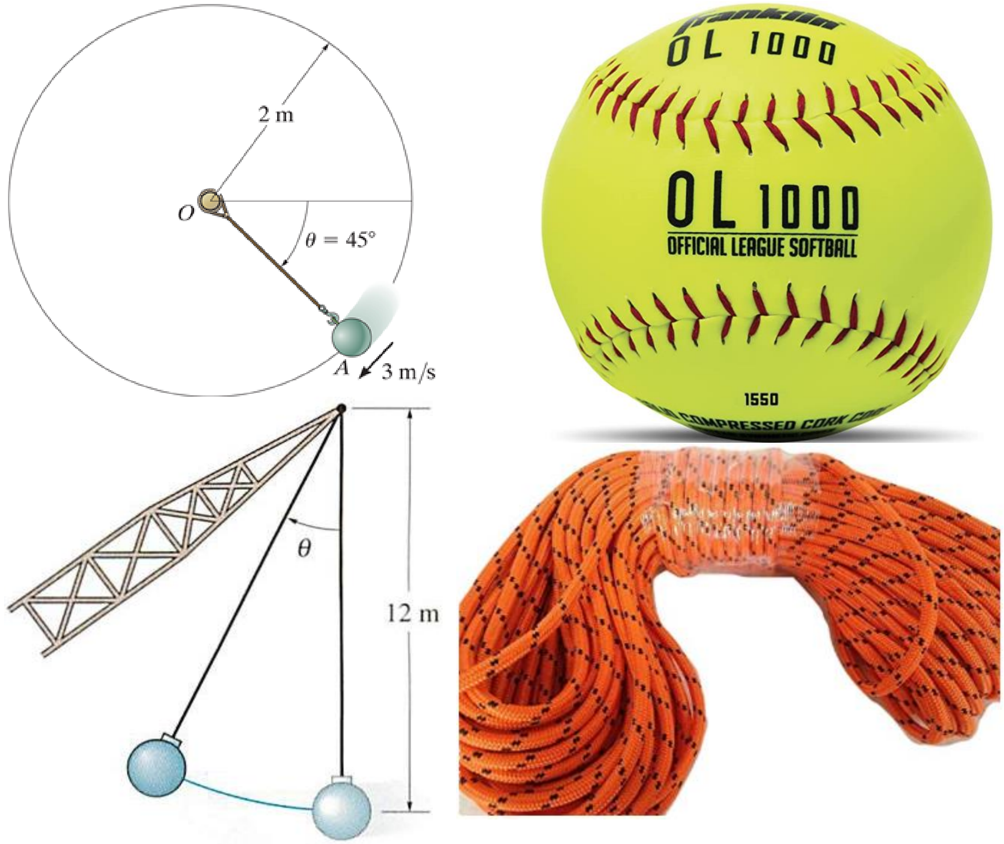

Fig 5: Demonstration of Newton's Second Law of Motion (left) with normal and tangential coordinates problems can be easily explained by hanging (right) a softball by a rope and applying a force onto it.

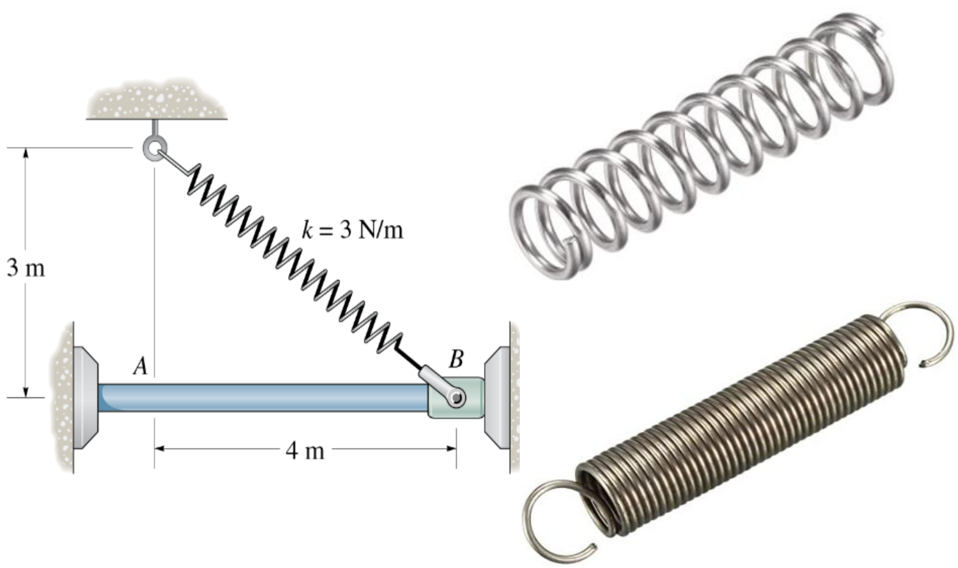

Fig 6: Demonstration of Work and Energy Principle (left) with an elastic potential energy problem can be easily explained using (right) a compression and expansion spring.

Using the principle of impulse and momentum, the equation of motion of particles with respect to time can be analyzed. The resulting equations will be useful for solving problems that involve force, velocity, and time. This principle is simply a time integration of the equation of motion. It provides a direct means of obtaining the particle's final velocity after a specified period when the initial velocity is known, considering the forces acting on the particle as a function of time. This analysis has been demonstrated as a projectile motion of a golf ball hit by a golf club, as shown in Fig. 7. A golf club and golf ball were brought to the classroom to visualize this phenomenon by all students.

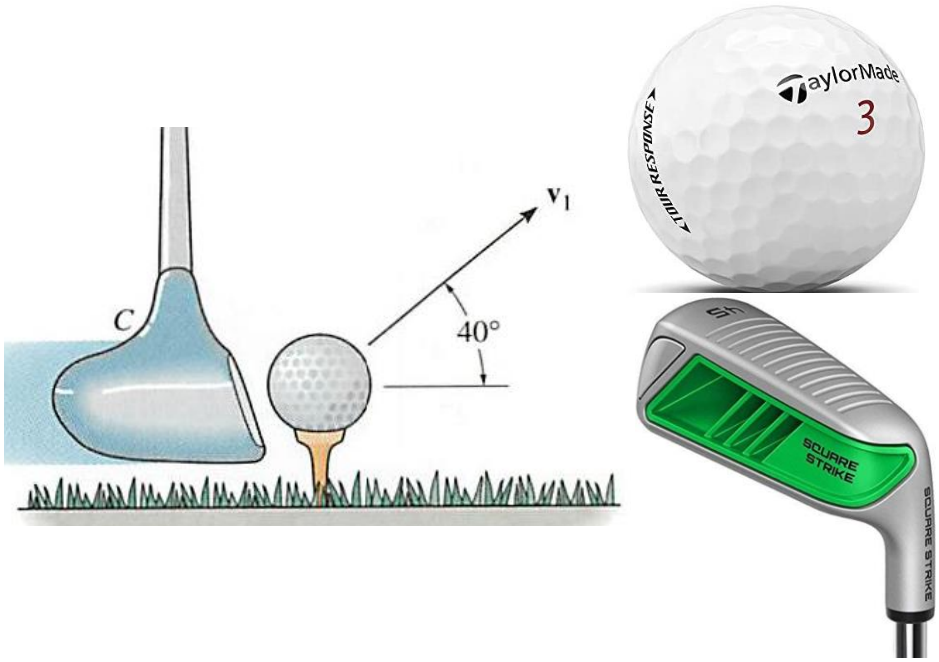

Fig 7: Demonstration of Impulse and Momentum Principle (left) with a projectile motion problem that can be easily explained by showing (right) the motion of a golf ball when hit by a golf club.

The planar motion of a body occurs when all the particles of a rigid body move along the equidistant paths from a fixed plane or surface. There are three types of rigid body planar motion. They are translation, rotation about a fixed axis, and general plane motion. The translational equation of motion of a rigid body states that the sum of all the external forces acting on the body is equal to the body’s mass times the acceleration of its mass center. When the rigid body undergoes a translation, all the particles of the body have the same acceleration shown in Fig. 8. In this case, the rotational equation of motion applied at point G reduces to zero. These concepts were explained by a toy airplane brought to the classroom. It was shown that although three tires of airplane were rotating, the body of airplane was translating due to the acceleration of its mass center by an applied force. Students grasp that this is how rigid body moves (as Fig. 8).

Fig 8: Demonstration of Planar Kinetic Equations of Motion (left) with a translation of rigid body problem that can be easily explained by using (right) a toy airplane.

Results

The primary measure of success includes the evaluation of the percentage of passing the class exams, the comprehensive final exam, and the evaluation of the overall exam average. In all instances, 70% or more exam scores are considered the percentage of passing with no curving. Figure 9 reviews the passing percentage for all exams for the past two years. The overall exam passing average is based on achieving 70%, or more for the syllabus weighted average of three class exams combined with the comprehensive final exam. The Fall 2021 exams percentage of passing has been found to be better than previous years.

It is worth to point out that Fall 2020 and 2021 were under COVID-19 pandemic, however, this course was taught in face-to-face format in a very large room where all students were able to attend and pedagogical demestrations were achieved. Also due to pandemic, videos were created for every lectures/chapters of the course and uploaded them on Learning Management System (LMS).

Another measure of success is the percentage of total grades shown in Fig. 10. Again, the overall exam average is based on the syllabus weighted average of three class exams along with the comprehensive final exam. In all instances, the Fall 2021 students performed better than previous years' students.

Shown in Fig. 11, the grade distribution of Fall 2020 and Fall 2021 also indicates the success of two year's students by comparing them. It shows that this study reduced the number of "C", "D", and "F" grades and improved students' grades more towards "A" and "B" by increasing their learning. This learning approach promises to increase student success in subsequent courses in the ME department.

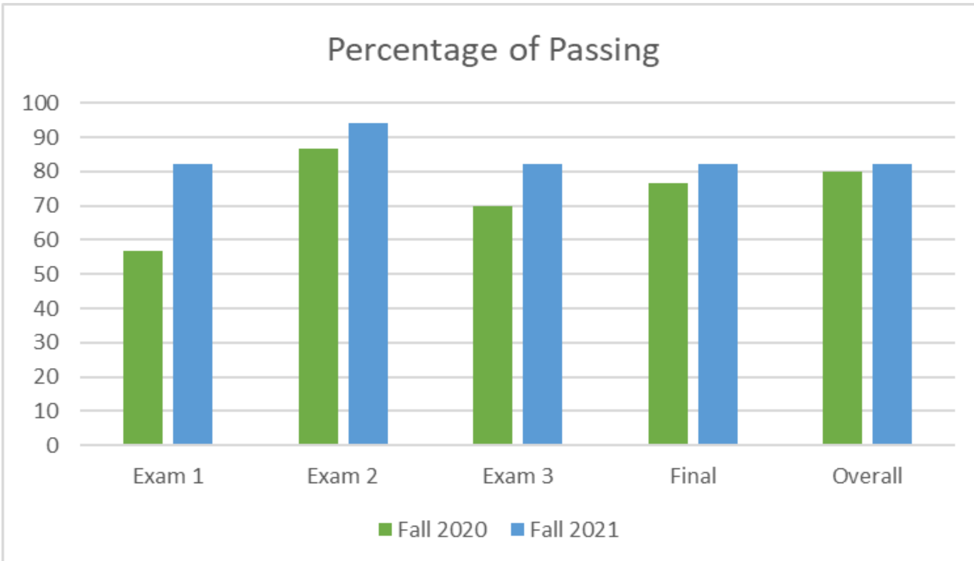

Fig 9: Percentage of passing students who achieved 70% or more for each ME 252 exam.

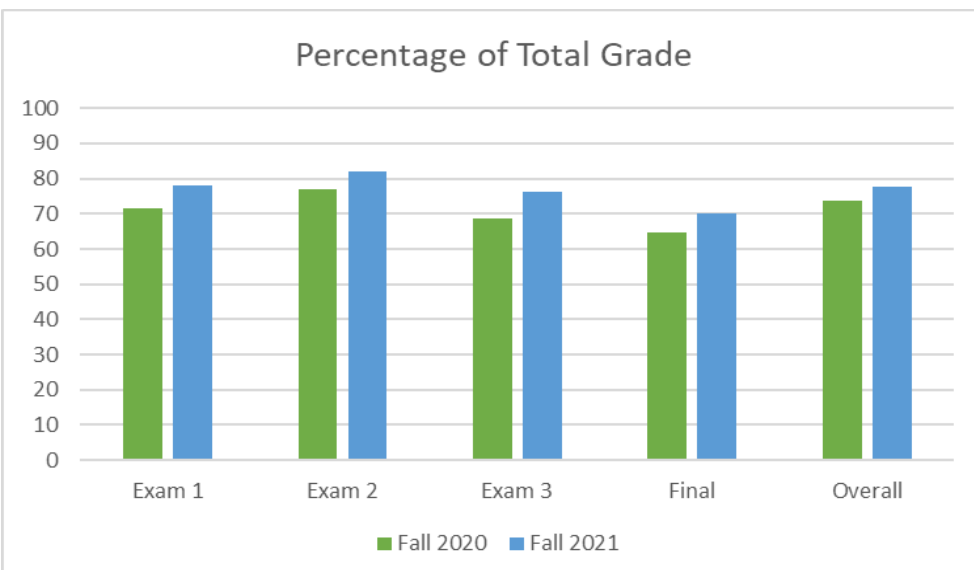

Fig 10: Students' percentage of the total score for each ME 252 exam.

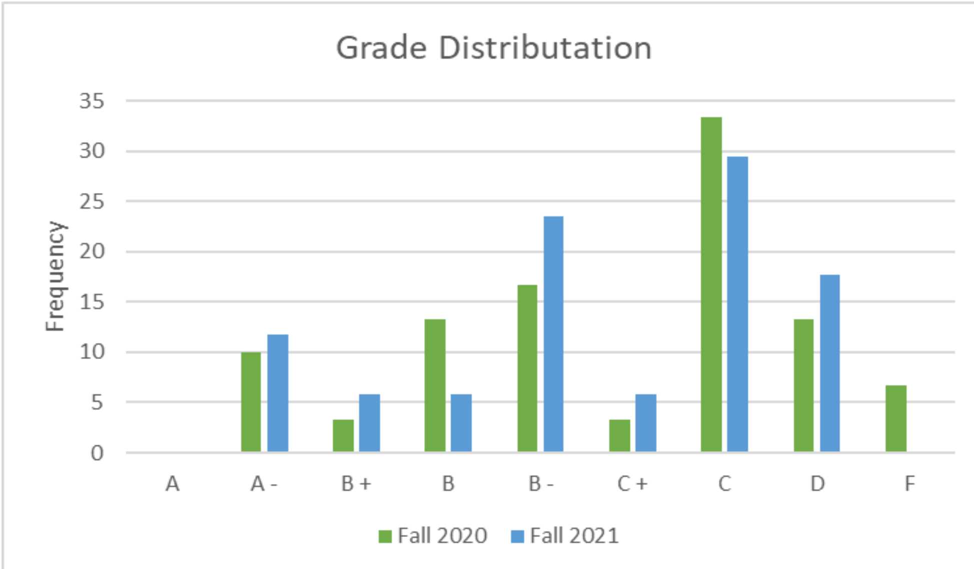

Fig 11: Comparing the grade distribution of ME 252 for Fall 2020 and Fall 2021.

Near the end of each semester, students are asked anonymously to write down the key to their success in ME 252 to comprehend how well they are performing in this class. Almost all students mentioned the problem-solving methodology (mentioned as “example problems” or “explain equations”) and pedagogical demonstration (mentioned as “props” or “tools”) in their response and its importance to learn, practice, and understand the subject materials.

Example of anonymous feedback for problem-solving methodology:

“I liked the way the professor explained the equations then used examples to help us understand the concept.”

“I thought that the instructor used the equations very well in his examples and it helped the understanding of how to use them and prepared us very well for the quizzes and tests.”

“I enjoy you going through the example problems, it is helpful for learning the material.”

“I enjoyed how the examples were worked out on the white board instead of just having the solutions on the PowerPoints as well as having the recorded lectures.”

Example of anonymously feedback for pedagogical demonstration:

“The "tools" brought in for examples was helpful, the online lecture videos being available was helpful for review when it was not clear in class.”

“Props helped a lot the couple times they were used, and the videos were very well made.”

“I like that he brought in props that corresponded with the teaching material.”

This evidence suggests that the students understand that there is a methodology that they are introduced to ensure their success instead of just practicing homework problems and trying to match in exams. This critical methodology of solving engineering problems is a significant upgrade from the traditional approach.

Conclusions

There are many aspects that influence how students choose to prepare and perform on quizzes/exams. This study focused on teaching and interaction strategies intended to motivate students to implement their understanding and follow a detailed problem-solving methodology. Based on the results from the year of 2021 and earlier classes, it is perceived that effective implementation of student-selected study habits positively improved quizzes/exams passing rates, improved quizzes/exams grade percentage, and improved overall course success rate. Such a novel teaching methodology and pedagogical demonstration helped the students to follow a comprehensible problem-solving approach. It is anticipated that the students' understanding of the concepts in dynamics will result in better preparation for the ME program in general. This instructional technique of pedagogical demonstration towards the problem-solving approach that helped students improve their quizzes/exams performance will be designed and applied to other ME courses. This is expected to result in similar positive student outcomes in the future.

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