Course-Related Undergraduate Projects for Dynamics

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Abstract:

The Engineering Technology (ET) program at Middle Tennessee State University (MTSU) has approximately 450 students. Our Mechanical Engineering Technology (MET) concentration was started in 2004 fall and currently it has 220 majors. The author teaches Dynamics every spring and all MET students are required to take this course. Dynamics is a lecture course and we cover kinematics and kinetics of particles and rigid bodies in this calculus-based course. We felt it is necessary to have some hands-on projects that will help students better understand the principles and applications. The author developed the egg drop project in which the students work in teams and following the guidelines build two structures using balsa wood sticks, place an egg inside and drop the unit from a certain height so as to land on the target placed on the ground. They build two such units with and without a parachute. They are required to write a report that included the construction method, calculations and graphical presentation of the unit's height as a function of time. They also compare the calculated time of fall with the measured value and explain any discrepancy. The author derived the equation of motion and the height-time relationship for the case with a parachute as these are not readily available in our Dynamics textbook. The egg drop project of each team is judged based on the compliance to the guidelines, structure's weight condition of the egg/structure after landing, distance from the target to the egg/structure, and aesthetics of the structure. This project was a great success and students had fun working together and competing with other teams. The author briefly discussed in the class a hands-on project that would help students better understand the motion of a projectile in a two-dimensional space. Three students showed a great interest in the project and that very weekend they purchased a paintball gun and conducted some experiments at a barn. Their paintball has the capability of giving the velocity of the paintball at the barrel exit which is the initial velocity of the projectile. They built some fixture to allow the tilting of the gun so that they can measure the angle made by the initial velocity of the projectile. They were able compare the calculated range and height of the target with the corresponding measured values and compute the accuracy of their device. They were also able to make a video of their experiments. The trio made a presentation of their experiments in the class and in collaboration with the author they also participated at the MTSU's annual undergraduate symposium. Three of our Dynamics students were inspired by the Paintball Gun project and decided to build a golf ball shooter for their capstone project. These students applied their knowledge of CADD, Fluid Power, Machine Tool Technology and Dynamics, and successfully completed the project. There are numerous application-oriented publications in the area of Engineering Mechanics and we have cited two of them in this paper.[1, 2] We hope our course related hands-on project will inspire the ET faculty community further and many more interesting projects will be presented at the future ASEE conferences.

Introduction:

Middle Tennessee State University is one of the fastest growing universities in the United States. We have about 28,000 students and our Engineering Technology (ET) is one of the ten departments in the college of Basic and Applied Sciences. The ET program has Computer,

Electro-Mechanical and Mechanical concentrations with approximately 450 students. The Mechanical Engineering Technology (MET) concentration has approximately 220 majors. The MET program, started in the fall of 2004, has grown well and we are fortunate to be located in a highly industrialized area. Our MET students are required to take several junior and senior level classes such as Statics, Dynamics and Strength of Materials, and Design of Machine Elements, Fluid Power, Heating, Ventilation and Air Conditioning (HVAC), Robotics, and Vibration. ET 3840 - Dynamics is also a required course for our pre-engineering students and some aerospace majors and it is offered in the spring semester. In this course we teach the kinematics and kinetics of a particle and a rigid body.[3] In kinematics the rectilinear motion and curvilinear motion (with emphasis on motion of a projectile in a rectangular coordinate system, and motion of a particle in the normal & tangential, and cylindrical coordinates) are discussed. In kinetics the application of Newton's Second Law to particles and rigid bodies in motion are discussed. Topics such as the work and energy principle and, the linear impulse and momentum principle are also discussed under kinetics. We teach calculus-based Dynamics and the author developed some course-related hands-on activities to help students better understand the principles and applications.

Egg Drop Project:

The author derived the equation of motion and the height-time relationship for the case with a parachute as these are not readily available in our Dynamics textbook. The unit with egg can be modeled as a particle (Case-1) and it corresponds to the kinematics of a freely falling particle. The unit with the structure, egg and parachute can be modeled as a particle (Case-2) and it corresponds to the kinetics of a freely falling body under the action of its own weight and the drag force.

Equation for Case-1:

The constant acceleration of a moving particle is given by

$$a_c = dv/dt,$$

which can be rearranged to give

$$dv = a_c \, dt.$$

Integrating both sides between the appropriate limits we get

$$v = v_0 + a_c \, t, \quad\quad\quad\quad\quad (i)$$

where v = instantaneous velocity,
v_0 = initial velocity,
t = time.

Substituting $v = ds/dt$, where s = instantaneous position, into Equation (i) and rearranging the terms we get

$$d\text{s} = (v_0 + a_\text{c}\, t)\, dt.$$

Integrating both sides between the appropriate limits we get

$$s = s_0 + v_0\, t + \tfrac{1}{2}\, a_\text{c}\, t^2, \qquad\qquad \text{(ii)}$$

where s_0 = initial position.

In the case of a freely falling particle,

$$v_0 = 0,$$
$$a_\text{c} = -g, \text{ the gravity.}$$

Therefore, Equation (ii) can be written as

$$s = s_0 - \tfrac{1}{2}\, g\, t^2 \qquad\qquad \text{(iii)}$$

Equation for Case-2:

The equation of motion for a freely falling particle under the action of its own weight and the drag is given by

$$W - F_\text{d} = 0, \qquad\qquad \text{(iv)}$$

where $W = mg$, the weight,
$F_\text{d} = \tfrac{1}{2}\, C_\text{D}\, \rho\, v^2 A$, the drag force.

Substituting for W and F_d into Equation (iv) and rearranging the terms gives

$$v = [mg/(\tfrac{1}{2}\, C_\text{D}\, \rho\, A]^{1/2}.$$

Substituting $v = ds/dt$, into the above equation, rearranging the terms and integrating both sides between the appropriate limits we get

$$s = s_0 - \sqrt{\frac{2mg}{C_d \rho A}}\; t \;, \text{ where}$$

s_0 = initial height
m = mass,
g = gravity,
C_d = drag coefficient,
ρ = air density,
A = area.

In the case of a unit with the structure, egg and parachute, the area A corresponds to the parachute area.

Project Details:

Contest guidelines were posted on the Desire2Learn (D2L) site for Dynamics and the students were shown MPEG videos of the previous contests to give them a good understanding of the project. These videos and pictures of the structures that survived the fall (Figure 1) were also made available on the course site. A maximum of four students were allowed in a team and each team had to build two structures with and without a parachute using balsa wood and glue following the guidelines. An egg had to be placed inside the structure so that it was supported at three points only. The egg drop project of each team was judged for the compliance to the guidelines, structure's weight, condition of the egg/structure after landing, distance from target to the egg/structure and aesthetics of the structure. This project was a great success and students had fun working together and competing with other teams.

We had three judges from the ET faculty and graduate students (Figure 2). The contest was conducted indoors at our Alumni Memorial Gym arena for consistency and to avoid the undesirable cold and windy conditions. The structure and egg with and without a parachute attached were dropped (Figures 3 and 4) from a height of fifteen feet. Each team was required to submit a written (MS Word/ Excel) report. The report format included Introduction, Design, Fabrication, Testing, Calculations and Graphs, Discussion of Results, and Bibliography. They were especially asked to compare the measured and calculated time for the two freely-falling units and explain any discrepancy.
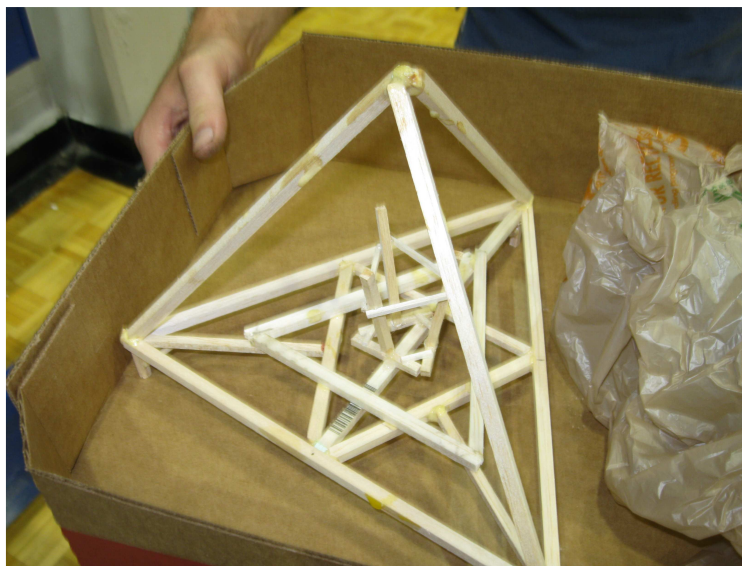

Figure 1. A typical balsa wood structure that survived the fall.

Figure 2. The three judges, first, second and third from right, are seen in action.

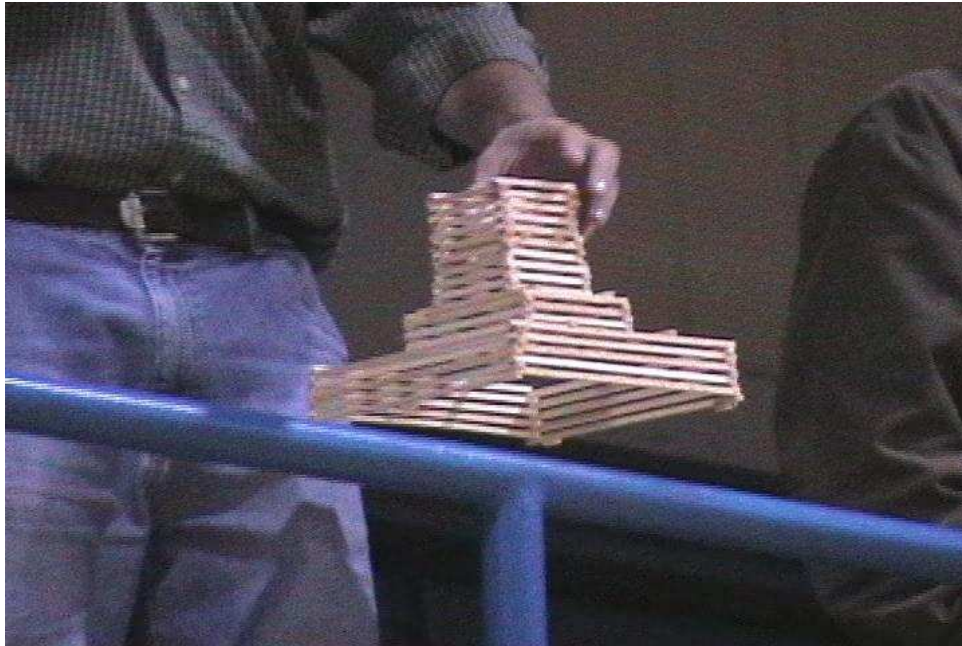Figure 3. A structure with egg and parachute is about to be dropped.

Figure 4. A structure with egg and no parachute is just dropped.

The author also conducts the egg drop contest on MTSU campus at other annual events such as the Expanding Your Horizons in Science and Engineering (EYH) for girl scouts, and the Regional Science Olympiad participants.

Student Projects:

1. Paintball Gun Project:

We discuss curvilinear motion of a particle under kinematics and derive the equations for the trajectory of a projectile in an *x-y* coordinate system. The author briefly discussed in the class a hands-on project that would help students better understand the motion of a projectile in a two-dimensional space. Three students showed a great interest in the project and that very weekend they purchased a paintball gun and conducted some experiments at a barn. Their paintball gun has the capability of giving the velocity of the paintball at the barrel exit which is the initial velocity of the projectile. They built a fixture to allow the tilting of the gun so that they can measure the angle made by the initial velocity of the projectile. They were able compare the calculated range and height of the target with the corresponding measured values and compute the accuracy of their device. They were also able to make a video of their experiments. The trio made a presentation of their experiments to our Dynamics class and in collaboration with the author they also participated at the MTSU's annual undergraduate symposium.[4] Currently we don't have any pictures of these students' project because currently the university is closed for the Holidays. We hope to include some pictures and experimental results in the final version of this paper.

2. Golf Ball Shooter Project:

A golf ball, tennis ball, basketball or volley ball can be treated as a projectile. Three of our Dynamics students were inspired by the Paintball Gun project and decided to build a golf ball shooter for their capstone project.[5] These students applied their knowledge of CADD, Fluid Power, Machine Tool Technology and Dynamics and successfully completed this project. The front, top and isometric views of their 3D model are shown in Figures 5-7.
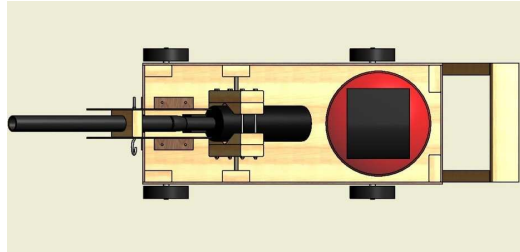

Figure 5. Top view of the golf ball shooter created using AutoDesk Inventor
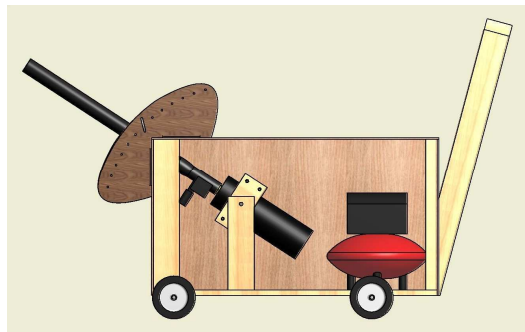

Figure 6. Front view of the golf ball shooter created using AutoDesk Inventor

Figure 7. Isometric view of the golf ball shooter created using AutoDesk Inventor

The golf ball shooter (Figure 8) consists of a 110- volt compressor that can deliver three gallons of air to a reservoir, a pressure regulator connected to the air reservoir, a 0.7-gallon accumulator connected to the regulator, a 24-volt and 120 psi valve connected to the accumulator, a high velocity nozzle connected to the valve, and a barrel connected to the valve. The golf ball is loaded into the barrel and after the required pressure is built up in the accumulator a momentary switch or electronic push button that has a 24 volts supply battery pack is pushed. At this moment the circuit is completed and the solenoid opens the valve letting the 0.7 gallons of air at the set pressure to the nozzle which propels the ball out of the barrel.

Figure 8. Photograph of the golf ball shooter.

As we know the curvilinear motion of a projectile in an *x-y* coordinate system can be treated as two rectilinear motions in the *x* and *y* directions. The resulting kinematic equations are coupled by the projectile's initial velocity, the angle made by the initial velocity with the *x* axis and the time.[1] Our students calibrated the golf ball shooter by launching the ball for a certain barrel angle and measuring the horizontal distance (range) and the height of the ball while recording the time taken for the ball to reach the target. They were able to use this information to calculate for the given angle the initial velocity of the ball which remains constant for a given air pressure. Later they ran several tests for different barrel angles and computed the range and height and prepared a ready reckoner table. They also changed the air pressure thereby changing the initial velocity and prepared a table for a series of range values as a function of the air pressure and barrel angle. These students provided weekly updates to the author, successfully completed the project and submitted a written report on time.

Course Objectives and Student Learning Outcomes Related to ET 3840 - Dynamics:

At MTSU Dynamics is a three-credit lecture course and we developed three course objectives for this course and five discipline specific criteria for our MET program to compliment the ABET *a-k* criteria.

Objectives:
1. Understanding the concepts of position, displacement, velocity, and acceleration.
2. To investigate particle and rigid body motion along a straight line and a curved path using different coordinate systems.
3. To analyze the accelerated motion of a particle and a rigid body using the equations of motion with different coordinate systems. To develop the principle of work and energy and apply it to solve problems that involve force, velocity, and displacement.

Student Learning Outcomes – ABET Criteria for Dynamics:

a. An ability to select and apply the knowledge, techniques, skills, and modern tools of the discipline to broadly-defined engineering technology activities
d. An ability to design systems, components, or processes for broadly-defined engineering technology problems appropriate to program educational objectives
f. An ability to identify, analyze, and solve broadly-defined engineering technology problems

Student Learning Outcomes – MET Specific Criteria for Dynamics:

2. The essential tools to analyze systems in motion, and calculate the velocity, acceleration, inertial forces, torque, power, and mechanical efficiency as required to solving engineering problems.

As has been done at several U.S. universities, we use the tests, final exam, homework and laboratory activities as direct methods to evaluate the learning outcomes. The major field test (MFT), exit interview (oral and anonymous questionnaire) and employer and/or employee survey are used as the indirect methods to evaluate the learning outcomes. In Dynamics the author gives two tests and one final exam, and they carry 80% of the final grade. The egg drop project contributes 20% towards the final grade. The project report carries 30% of the project grade. The hands-on projects address the course objectives listed above and we use them to help students better understand the principles and applications of Dynamics. The projects promote team work among the students and address the following outcomes even though there is no ABET requirement for a lecture course.

-   An ability to conduct standard tests and measurements; to conduct, analyze, and interpret experiments; and to apply experimental results to improve processes.
-   An ability to function effectively as a member or leader on a technical team.

We conduct the MET major field test (MFT) in the fall and spring semesters. Our MFT consists of one hundred questions with five questions from each MET course. Regarding the Dynamics questions there are two questions on the kinematics of a particle, one question on the relative

velocity of two particles and two questions on the kinematics of a rigid body. In our analysis of the MFT results we used the criterion that at least 70% of the student who took the test should get the correct answer. We modified or replaced the questions that did not meet this criterion noting that we can replace only 5% of the questions in a year.

Conclusions:

Middle Tennessee State University is located in a very industrialized area. Nissan which is a major automobile manufacturer and many other related industries are located within a twenty-mile radius from our campus. These companies hire a lot of our graduates and expect them to have team work experience. The egg drop project has been a great success and it not only helped our students better understand the kinematics of a particle but also provided them team work experience. We developed a brand new MET - MFT in 2011 fall because the previous test did not include questions from some MET courses. In the 2011-12 academic year twelve MET majors took the MFT and our analysis shows that all of them got the right answer to the kinematics of a particle related questions. In the case of one question related to kinematics of a rigid body, less than or equal to 25% of the students got the right answer. The average MFT scores for Dynamics were 33% in 2011 spring and 45% in 2012 spring. Although both of these scores are less than our benchmark value of 50% we see the improvement in the scores are encouraging and continue to modify or change the questions as necessary. At this point we are not sure how much the egg drop contest has contributed to this increase the MFT score but we will continue to study the trend and introduce questions directly related to the egg drop contest. The author introduced the egg drop project in 2010 spring. The purpose of this project was to help the students better understand the subject and also give an opportunity to improve their grade. The normalized mean and median values of the final scores are 85 and 86, 82 and 88, and 84.8 and 84.3 for the years 2010, 2011 and 2012, respectively. If the egg drop project scores are excluded, then these values will be 65 and 64, 61 and 64, and 70 and 68 for the years 2010, 2011 and 2012, respectively.

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