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Lesson Plan
Engineering Design: 10-12
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0. Abstract

I. Standards/Skills/Objectives/Assessment

1. Focal Standard or Skill: * Required
2. Measurable Objective(s): * Required
3. Assessment: * Required
4. Additional Standards (Optional)

II. Fellowship Connections

1. 21st Century Skill(s):* Required (Exempt ,if you did Focal Standard/Skill 1a)
2. 21st Century Skill(s) Application:* Required (Exempt, if you did Focal Standard/Skill 1a)
3. Fellowship Description:* Required
4. Fellowship Connection to School/Classroom: * Required

III. Instruction

1. Instructional Plan: * Required
2. Additional Instructional Context: (Optional)
3. Supply List: * Required
4. Bibliography:* Required
5. Keywords: (Optional)

IV. Attachments

Calculation-based Engineering Design Applied to a Spring-Powered Mechanism



0. Abstract

This lesson is designed for the Gunn HS engineering/robotics class or similar (e.g. a Project Lead the Way capstone course). The lesson demonstrates the use of mathematical simulation in design decisions, specifically designing a launch mechanism based on mechanical springs. The lesson has students using first-order kinetic and potential energy calculations, calculating the transformation of potential energy to kinetic energy, calculating spring constants based on a desired projectile launch, and then testing out their spring design on a simple launch mechanism. Launch objects are assumed to be spheres (balls) and the desired motion restricted to a vertical plane (i.e. launch target locations will have only horizontal and vertical displacement relative to the original position). The lesson assumes that students have completed Algebra 1 and know the definitions of trigonometric functions sine, cosine and tangent; however, no high school physics is assumed.

I. Standards/Skills/Objectives/Assessment

1. Focal Standard or Skill:

From the California Career Technical Education Model Curriculum Standards,
Engineering and Design:

D5.0 Students understand the design process and how to solve analysis and design problems:

D5.3 Choose between alternate solutions in solving a problem and be able to justify the choices made in determining a solution.

2. Measurable Objective(s):

1. Students will use equations to calculate kinetic and potential energy values, and use the concept of energy transfer and conservation of energy to calculate resulting velocity, spring displacement, etc. in mechanical energy transfer problems.
2. Students will use equations to calculate the spring constant theoretically required to achieve a specified launch target based on the mass of the object being launched, [the launch angle], the displacement of the launching spring, and the location of the target. Note: Students will first evaluate situations with only a horizontal (0 degree) launch angle; only students who are successful with this first case will be challenged with situations requiring non-zero launch angles.
3. Students will compare calculated predictions versus experimental results, and recognize that the actual final displacement falls short of the target (with the amount of error a function of the spring system, mass and surface area of the projectile sphere, etc.).

3. Assessment:

Assessment of objective 1 (formative) will have students completing a worksheet of calculations for projectile trajectory and energy transfer. The worksheet has space for documenting sample problems completed in the lesson, and for additional “try on your own” practice problems.

Assessment of objective 2 (formative) will have students measuring the horizontal and vertical distance vectors from a physical test launch mechanism to a target location, weighing the given launch objects, and calculating the spring constant and displacement required to reach the target location. Target locations requiring a non-zero launch angle will be assigned to any students who complete objective 2 well ahead of the remainder of the class.

Assessment of objective 3 (summative) will have students completing an experiment write-up. The write-up will include the results of their calculations, justification of their

physical spring selection, the results of their experimental launches, and some analysis and discussion of their results relative to their modeled predictions.

4. Additional Standards (Optional)

From the eight NGSS Framework practices of science and engineering essential for all students to learn:

- 5. Using mathematics and computational thinking
 - 6. Constructing explanations (for science) and designing solutions (for engineering)
 - 8. Obtaining, evaluating, and communicating information
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II. Fellowship Connections

1. 21st Century Skill(s):

Critical Thinking and Problem Solving

- Exercising sound reasoning in understanding
- Making complex choices and decisions
- Understanding the interconnections among systems
- Identifying and asking significant questions that clarify various points of view and lead to better solutions
- Framing, analyzing and synthesizing information in order to solve problems and answer questions

2. 21st Century Skill(s) Application:

- Students will demonstrate their understanding and reasoning by appropriately measuring and applying physical attributes (mass, distance) of the launch object and target position to projectile motion and energy transfer equations related to the test launch mechanism.
- Students will make complex choices by selecting the appropriate physical spring based on their calculations.

- Students will demonstrate their understanding of the interconnection between the spring potential energy system and the launch object velocity by calculating the necessary spring constant to reach the target.
- Students will ask, analyze and answer two significant questions: Are the given requirements achievable? and Which spring will create the necessary potential energy to meet the requirements?

3. Fellowship Description:

The Camarillo Lab at Stanford studies the correlation between sudden head accelerations (both linear and rotational accelerations, in sports and elsewhere) and traumatic brain injury. My project is to design, build and test a device to induce concussion in ferrets. The skills required for this project include 3D modeling (CAD), knowledge of physics (potential and kinetic energy, conservation of momentum, moment of inertia, etc.), knowledge of mechanical devices, set-up of simple simulations (using Excel), fabrication (machining, assembly) and design evaluation and rework based on test results. In the lab I am working among mechanical engineers, biomechanical engineers, and software engineers in a multi-disciplinary environment. My sponsor is developing a reliable mouth-guard/sensor system to monitor potential trauma brain injury (TBI) events.

4. Fellowship Connection to School/Classroom:

My fellowship definitely required the 21st century skill of systems thinking to analyze how various components would interact with each other to produce outcomes in a complex mechanism. I will share my fellowship experience with my students informally during lessons on the design process and CAD skills, and formally in this two-day design lessons in the fall semester of the class. The lesson will engage students in an important part of the engineering process that is very relevant to our annual FIRST robotics competition design work (focus of our spring semester), as most competition design prompts result in the development of one or more spring-loaded mechanisms. In the past students have designed mechanisms to meet geometric constraints (fitting within the required robot perimeter, meeting dimensional and weight limits, etc.) but specific components (springs, motors, etc.) have typically been selected using a “guess and check” process that is time-consuming and that often does not result in adequate performance once we enter into competitions. Introducing the concept of evaluating mechanical designs using physics and engineering principles will improve the students’

knowledge of, and skill with, engineering design, and potentially help them meet FIRST competition deadlines, and improve competition performance of their robots (very motivating for the students!).

III. Instruction

1. Instructional Plan:

Time required: (two 70-minute periods)

Opening/Hook

1. Play video clips of 3 FIRST competition robots that use a spring force mechanism to launch a projectile.
2. Working in groups, students discuss each of the spring force mechanisms and then share with the class.

Lecture Part 1 – Sample Application Problems

[Follow the PowerPoint presentation “Calculation-based Engineering Design Applied to a Spring-Powered Mechanism”; students should have worksheet #1.]

1. Ask if students to define “energy” (answer: the capacity or power to do work, e.g. to move an object by applying a force).
2. Ask students what types of energy they are familiar with (possible answers: electrical, mechanical, chemical, thermal, nuclear, students who have had physics may answer kinetic, potential, gravitational).
3. Define kinetic energy (energy of motion, calculated $KE = \frac{1}{2} mv^2$), potential energy (energy of position, gravitational $PE = mgh$ and elastic $PE = \frac{1}{2} kx^2$).
4. Briefly discuss units of energy and relate back to equations. Yes, if you are teaching this in the U.S. you have to discuss both metric and US customary units!).

Guided Practice 1

Demonstrate three application problems (students complete on worksheet #1).

Lecture presentation Part 2 – Transforming Energy

1. Discuss the transformability of different types of energy. Ask students to share examples from daily life (possible answers: chemical energy in battery to electrical energy to run cell phones, etc.).
2. Show students Road Runner video clip.
3. Discuss efficiency as a calculation of % energy transformed.
4. Give a sample calculation equating two different forms of energy: $\frac{1}{2} kx^2 = \frac{1}{2} mv^2$

Guided Practice 2

Demonstrate the application problem (students complete on worksheet #1).

Lecture presentation Part 3 – Motion in Gravitational Field

1. Ask students to predict what happens when:
 - Keys are dropped
 - Keys are tossed across the room
2. Discuss how Earth's gravity routinely creates situations where gravitational PE is transformed into KE.
3. Show video clip of bowling ball v. feather drop.
4. Ask students to hypothesize why video clip does not match our experience (answer: air resistance!)
5. Discuss how gravity affects vertical vs. horizontal motion; introduce the concept of velocity vectors using horizontal and vertical speed as legs of a right triangle.
6. [If students ask, introduce the concept of using trigonometry to identify horizontal and vertical components of an angled vector. This concept may be used by students who have more math and/or physics background during the experimentation.]

Guided Practice 3

Demonstrate the application problem (students complete on worksheet #1).

Lecture presentation part 4 – Spring Mechanism Design

1. Discuss the design set-up: a pinball launcher mechanism that will use a spring plunger to transfer potential energy to a launch object with the goal of hitting a target placed on the floor below the mechanism.
2. Discuss types of springs and physical characteristics.
3. Demonstrate how to perform a spring component search on the Lee Spring website (www.leespring.com). Make sure students know how to convert units using Google.

Independent Practice: Activity

1. Following the steps on worksheet #2, students calculate the required spring constant and plunger displacement to hit the launch target.
2. Students locate three possible spring components in the McMaster-Carr or Lee Spring product lines that will provide the required force.
3. Students select one of six available springs, recalculate required plunger displacement, and complete three attempts of the launch experiment, recording the resulting distance from the target for each attempt.
4. Students write a paragraph answering the worksheet prompt regarding spring selection, experimental observations, accuracy of their calculated predictions, possible reasons for deviation from 100% efficiency.

Follow-up Discussion (this should occur after student work the assessment is completed, graded and returned)

1. Ask students to share something learned from the project with the class. Note: All results should fall somewhat short of the desired target, but heavier launch objects should come closer to the theoretical prediction. Bring this to the attention of the class if none of the students do.
2. Ask students how they would change their test set-up to improve their results.
3. Solidify observations and comments into a method for designing a general spring mechanism for the robotics competition. (This might include: measurement and calculation of relative launch/target locations, calculation of required spring potential energy minimum value, design for a range of scenarios – especially for prototyping, design iteration for commercially available springs, etc.)

3. Supply List:

- **Student worksheet #1 class and practice problems**
- **Student worksheet #2 spring mechanism design activity**
- **Powerpoint presentation with lecture notes and illustrations**
- Several **Lee Spring catalogs**
- access to **computers** for on-line website searches
- One **Pinball launch device** per group
either home-made or
“Newton’s Second Law” device #3153622 from Edmund Scientific (~\$23).

This device comes with a single spring
($\frac{3}{8}$ ” diameter x 3” length) and three 1” diameter steel balls.

The device may be disassembled so that other springs selected by your students can be installed.

If you have taken apart and reassembled a box-cutter, this device uses a similar spring and latch mechanism.

The hardware is fairly cheap, so you may want to invest in better quality bolts, washers and hex nuts so the disassembly/reassembly is easier.)

- **Various springs** (~6) with different k values; length should match the pinball launch device
- **Launch objects** of similar shape but differing in weight, e.g. steel ball, wooden ball, ping-pong ball
- **10’ butcher paper and markers** to draw targets
- **12’ tape measure**

4. Bibliography:

FIRST robot designs using spring mechanisms:

www.youtube.com/watch?v=md67kiDS9cE

www.youtube.com/watch?v=PtRewwr59d8

www.youtube.com/watch?v=WwUhGqWIUzE

Wile E. Coyote + Road Runner: <https://www.youtube.com/watch?v=Jnj8mc04r9E>

Bowling ball + feather drop: <https://www.youtube.com/watch?v=E43-CfukEgs>

5. Keywords: (Optional)

Enter up to **10** keywords/meta tags separated by commas, so it can be easily searched.

Kinetic energy, potential energy, gravitational potential energy, elastic potential energy, springs, spring constant, mechanism design

IV. Attachments

1. Worksheet #1 - class and homework problems

<https://drive.google.com/file/d/0B4jyPUEVKwEednpXb0t1NkV3MHM/view?usp=sharing>

2. Worksheet #1 answers

<https://drive.google.com/file/d/0B4jyPUEVKwEeYUdFVTvKS01oMUk/view?usp=sharing>

3. Worksheet #2 - class activity

<https://drive.google.com/file/d/0B4jyPUEVKwEeNk90c1ZaNE14Vjg/view?usp=sharing>

4. Spring Lessons PowerPoint

<https://drive.google.com/file/d/0B4jyPUEVKwEeZnRhRGNqai1PSFU/view?usp=sharing>