NEXT ENGINEERS

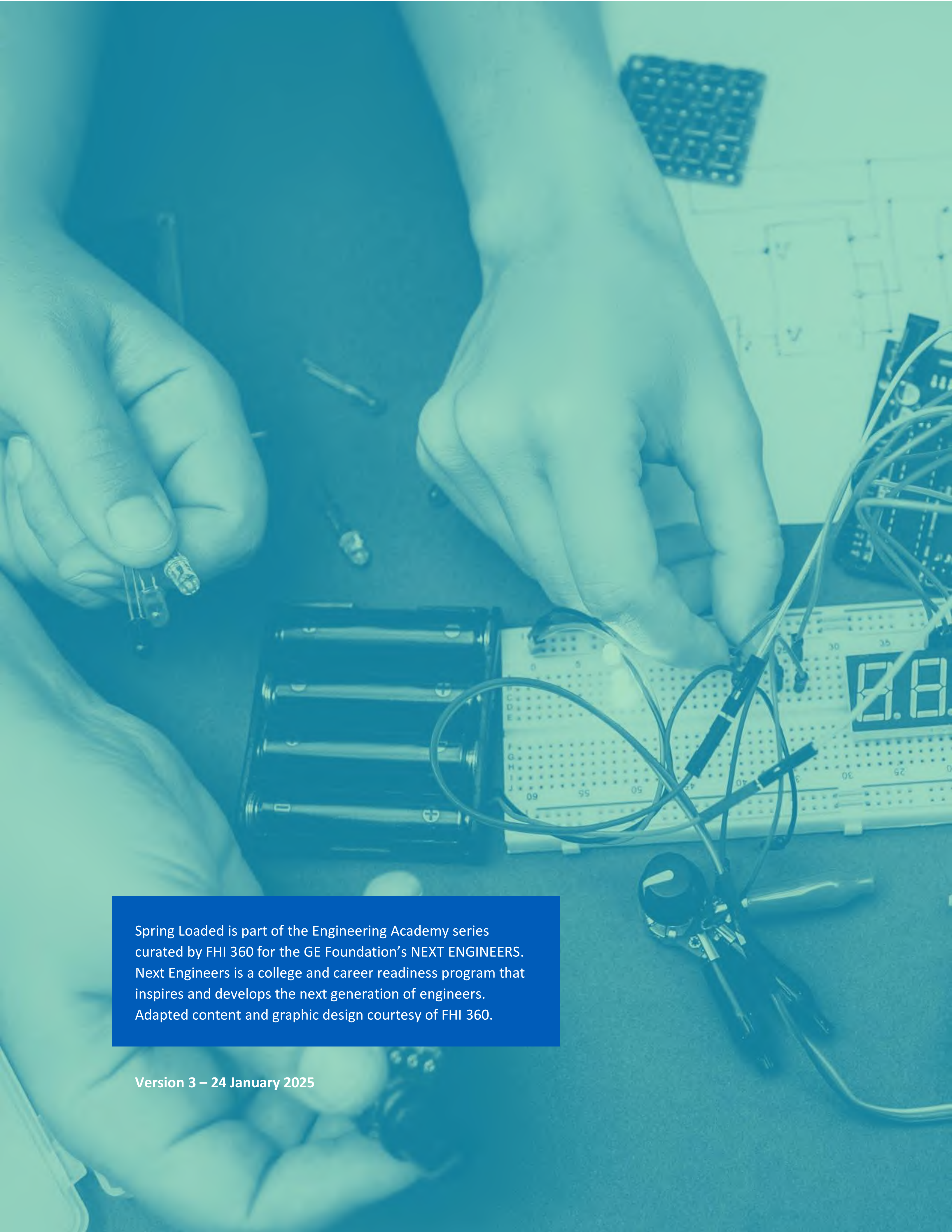
ENGINEERING ACADEMY

Difficulty Level 4

Spring Loaded

Mechanical Engineering

NEXT ENGINEERS



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Spring Loaded

Today, people and goods can travel farther, more quickly, more safely, and more economically than ever before. Modern transportation has greatly increased the economic potential and productivity of millions of people, and access to work opportunities has lifted millions more out of poverty.

In addition, foods and other essentials are now available more reliably and at less cost to more people than ever before. In short, modern transportation has accelerated human economic development.

This remarkable progress has been driven by fossil fuels. Over the years, major improvements to the internal combustion engine and catalytic converters have resulted in cleaner and more efficient vehicles. But burning fossil fuels does still come at a cost.

Globally, transportation accounts for about 16.2% of all CO_2 emissions[1]. Almost 75% of this is due to road vehicles, with passenger vehicles making up the majority[2]. This means that about 9.5% of all CO_2 emissions are because of the cars we drive.

Reducing emissions from cars (and transport in general) can result in sizable cuts in global CO_2 emissions and reductions in environmental pollution. Electric vehicles are often touted as a key driver in this regard. But is this really the case?

Electric vehicles require electricity and, currently, only about 35% of electricity is produced from low-carbon sources (especially nuclear and renewables)[3]. Indeed, the energy required to manufacture the batteries for electric vehicles (most often from fossil fuels) means that it reaches the showroom floor having been responsible for about double the CO_2 emissions of an ordinary vehicle. By some estimations, an electric vehicle would need to be driven for more than 200 000 miles (about 320 000 km) before the ordinary vehicle becomes 'dirtier'. Instead of solving the problem, electric vehicles often just move it.

This is a systemic problem, and it requires a systemic response. We cannot afford to become fixated on any single intervention. We need to be doing lots of things at the same time and we need to be mindful of the impact that each action has on the entire system and on the economic well-being of ordinary people, especially those in the developing world.

NOTES

[1] https://ourworldindata.org/emissions-by-sector. Accessed 10 September 2021
[2] https://ourworldindata.org/co2-emissions-from-transport. Accessed 10 September 2021
[3] https://ourworldindata.org/grapher/electricity-prod-source-stacked

Reducing emissions from transportation, for example, requires a multipronged response including all the following:

- **Fuel switching** - Using fuels that emit less CO_2 like hydrogen fuel cells and electricity from low-carbon sources, such as wind, solar, and nuclear.
- **Improving fuel efficiencies** - Using better and more advanced vehicle and drive train designs, materials, and technologies. Hybrids have an important role to play here.
- **Improving operating practices** - Adopting practices that minimize fuel use, including improved driving practices and vehicle maintenance.
- **Reducing travel demand** - Adopting urban planning that reduces the number of kilometers that people need to travel each day, making biking and walking more feasible, as well as implementing effective and efficient public transport.

Three of the four strategies above are efficiency-based, using the energy available to achieve more. Improving energy efficiency is all too often overlooked.

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The design challenge

Students will work in teams to design and build a vehicle that uses the elastic potential energy stored in a mousetrap for propulsion.

- Success criteria
  - The vehicle must have at least three wheels.
  - The vehicle must be able to cover a minimum distance of 10 m (32.8 ft) on a single 'charge'.
- Constraints
  - No push starts of vehicles are allowed.
  - Students must work within a given time.

Before you begin the design challenge, decide what budget you will make available to each team. A budget of about US$10 – US$15 per team is recommended (excluding the mousetrap).

Note that you can change the criterion that vehicles need to travel 10 m on a single 'charge'. You can extend or reduce this to suit the design sophistication of your group.

Also, before you begin, you need to select a test track on which all vehicles need to meet the criteria. This should be as straight, flat, and smooth as possible.

To make the challenge more exciting, it is suggested that you host a public race day along with the final presentations and consider both of these race categories.

- An **endurance** race to see which vehicle can cover the greatest distance on a single 'charge'.
- A **speed** race to see which vehicle is fastest over a specific distance (5 m – 6 m (16 ft – 20 ft) is suggested).

While you can award prizes for each race, you should also consider a grand prize for the best overall performer in both races.

You can also demarcate race lanes on the track using rope or tongue depressors stuck to the ground with temporary adhesive putty (e.g., Prestick© or Blu Tack©) and penalize teams whose vehicles leave their lanes.

EXTENSION

Besides a distance and speed race, you can also add the following challenges:

- Having the vehicle stop as close to a designated finish line as possible (e.g., 6 m (20 ft)).
- Reversing the vehicle after a set distance and having it stop as close to its starting position as possible.

Key outcomes

By the end of this design challenge students will be able to:

- Define energy.
- Explain the difference between kinetic energy and potential energy.
- Calculate kinetic energy.
- Calculate elastic potential energy.
- Define and identify instances of friction and air resistance.
- Define and explain mechanical advantage.
- Calculate the overall energy efficiency of their mousetrap vehicle.

Essential questions

- What are potential energy and kinetic energy and how can we efficiently convert potential energy into kinetic energy?

- What is mechanical advantage?
- What is the effect of mechanical advantage on making our vehicle go farther or faster?
- What are friction and air resistance?
- How can we minimize friction and air resistance?
- What is traction?
- How can we improve the traction of our wheels?
- How do we measure speed and distance?
- How can we improve our vehicle's acceleration?

The public presentation

At the end of the design challenge, each design team will be required to present their mousetrap vehicle to a public audience. The exact composition of this audience is left to you to define, although it is suggested that it includes at least other teams and GE Volunteers. You can include parents, students' teachers, your program staff, other GE engineers, and other engineering partners if you wish.

Teams must describe the process they went through to design, test, and refine their vehicle. In addition, teams must present answers to the following questions:

- What problems related to friction did they encounter and how did they overcome these?
- What kind of wheels did they use? Why did they choose them?
- What was the total approximate elastic potential energy stored in their mousetrap?
- What was the total mechanical advantage of their vehicle?
- What was the acceleration of their vehicle while under power?
- What was the maximum velocity achieved by their mousetrap vehicle?
- How did the theoretical distance their vehicle might have covered compare to the actual distance it covered and what was responsible for this difference?
- What was the force of friction acting in the opposite direction to the motion of their vehicle?
- What was the overall efficiency of their vehicle in converting potential energy to kinetic energy? How might this be improved through additional optimization?

Teams must also be prepared to answer questions on their design and the process they followed from members of the audience.

Make sure that you secure a date and venue for the presentations as soon as possible and send out the relevant invitations.

Teams may create and use any type of digital media including images, videos, and presentations. **Each presentation should be no more than 10 minutes long.**

!

FACILITATOR NOTE

Encourage teams to keep detailed notes in their workbook and to take videos and photos at each step of their process so that they have information and media to refer back to and draw on when they design their presentation.

Time required

This design challenge will require approximately **18 hours** to complete (excluding the presentations and student reflection). You may decide how to structure and organize this time.

Activity	Duration
1. Can a Mousetrap be a Battery?	**1 hour**
2. Identify and Define the Problem	**2 hours**
3. Gather Information	**2 hours**
4. Generate Possible Solutions	**2 hours**
5. Create a Prototype	
6. Test and Evaluate the Prototype	**9 hours**
7. Refine and/or Redesign the Solution	
8. Present the Solution: Prepare	**2 hours**
Total	**18 hours**

A mousetrap
https://commons.wikimedia.org/wiki/File:Victor-Mousetrap.jpg

Facilitation equipment and materials

- A presenter computer and projector (with sound for playing videos)
- A flipchart and colored markers
- Internet access
- An internet-capable device for each team that has word processing, spreadsheet, and presentation software. **Google Docs** is a free resource that will give students online access to this software as well to store and share documents
- A document storage and sharing platform
- A copy of the Student Workbook for each student
- An engineering design notebook for each student of about 50 pages in which they can take notes, jot down thoughts, draw design sketches and prototypes, and record data.

FACILITATOR NOTE

You can either run this challenge by providing a set collection of materials for all teams to build with or you can allow teams to determine what materials they would like to use within a set budget. The latter allows more design options but is more complicated to manage. A useful strategy can be to provide some basic materials for teams to test and iterate with but also give then the option of adding their own materials to this set.

Design equipment and materials

Wherever possible, teams should be encouraged to source their own materials either from home (including recycled sources) or from stores with budget you provide. However, here is a list of common materials that are quite likely to be required by most teams.

- A mousetrap – any type that uses a torsion spring as shown alongside
- Cable ties (smaller is usually better)
- String and/or nylon thread (nylon dental floss can be very useful)
- Plastic straws
- Dowels (a range from about 3 mm to 6 mm (0.125 in to 0.25 in) diameter)
- Skewers
- Ice-cream/popsicle sticks and/or craft sticks
- Wooden craft cubes
- Balsa wood
- Pliers

- Saws
- Scissors
- Glue guns and glue sticks
- Electrical tape
- Masking tape
- Wheels – you can supply a table of possible wheels or encourage teams to identify and supply their own wheels. Here are some suggestions for a supply table.
  - CDs or DVDs
  - Spools
  - Bottle caps
  - Metal or plastic lids from jars or cans
  - Wheels from Legos or other toys
  - Wooden wheels (available at craft stores)
  - Large buttons
- Rulers
- A spring scale to measure the force of the mousetrap arm
- A scale with which to measure the mass of the vehicles
- A measuring tape to measure distances travelled
- Other suggested materials
  - Bearings
  - Lubricants (oil or graphite powder)
  - Washers of different sizes

Supporting resources

A set of supporting resources are made available with this design challenge guide to support you in facilitating the challenge with students. These are all available at www.NextEngineers.org as part of the **Spring Loaded** design challenge package.

1. *Spring Loaded Facilitator Presentation.pptx* – a presentation version of the facilitation guide with embedded videos that can be used to step students through the challenge
2. *Spring Loaded Student Workbook.pdf* – a workbook that can be given to students electronically or on paper that provides additional support, guidance, and direction for completing the challenge successfully
3. *Decision matrix tool.pdf* – a tool to help teams evaluate and then select the best design ideas
4. *Decision matrix tool.xlsx* – an editable spreadsheet version of the decision matrix tool
5. *How to use the decision matrix tool.pdf* – a short explanation for how to use the decision matrix tool
6. *Design brief template.pdf* – a template to help teams create their design briefs
7. *Design brief template.pptx* – an editable presentation version of the design brief template
8. *The engineering design process.pdf* – a short explanation of the steps involved in the engineering design process
9. *Section 3 Worked Solution.mp4* – a short video that shows how to do the calculations contained in **Section 3** of the Student Workbook
10. *Section 14 Worked Solution.mp4* – a short video that shows how to do the calculations contained in **Section 14** of the Student Workbook
11. *Spring Loaded Volunteer Guide.pdf* – a guide to introduce and orientate GE volunteers to the design challenge to help them support its implementation

12. *Spring Loaded Parents Guide.pdf* – a guide to introduce and orientate parents to the design challenge so they can support and encourage their children.

Background resources

Here are some background resources that you should review prior to starting the design challenge with students. You may also choose to provide these resources to students if you feel they require additional support.

- ***Emissions by sector***: an article exploring and explaining the contribution of various sectors to global greenhouse gas emissions https://ourworldindata.org/emissions-by-sector
- ***Cars, planes, trains: where do CO2 emissions from transport come from?***: an article presenting key data about the contribution of various forms of transportation to CO_2 emissions https://ourworldindata.org/co2-emissions-from-transport:
- ***Electricity production by source***: an interactive graph showing the proportion of the different sources of electricity https://ourworldindata.org/grapher/electricity-prod-source-stacked
- ***Global primary energy consumption by source***: an interactive graph showing the proportion of total energy consumed by source https://ourworldindata.org/grapher/global-energy-substitution
- ***The Future of Energy Storage Beyond Lithium Ion***: an excellent video summarizing the alternative chemical and non-chemical grid-scale energy storage technologies in development https://www.youtube.com/watch?v=EoTVtB-cSps
- ***Mousetrap Racers***: An entire website devoted to all things mousetrap vehicles https://www.docfizzix.com/topics/
- ***Newton's laws of motion***: a Wikipedia article summarizing the laws of motion https://en.wikipedia.org/wiki/Newton%27s_laws_of_motion
- ***Newton's laws of motion***: a Britannica article summarizing the laws of motion https://www.britannica.com/science/Newtons-laws-of-motion#ref348017
- ***Elastic potential energy***: an article explaining elastic potential energy and elastic and plastic deformation https://energyeducation.ca/encyclopedia/Elastic_potential_energy
- ***Elasticity vs plasticity***: an article explaining elasticity and plasticity https://energyeducation.ca/encyclopedia/Elasticity_vs_plasticity
- ***Chapter 4: Springs generate force and store energy***: a textbook chapter explaining parallel and series compound springs https://web.pa.msu.edu/courses/2002spring/ISP209/course_pack/chapters/Ch_04.pdf
- ***Mousetrap Car – Explained***: An Instructables article outlining how to build a mousetrap vehicle as well as some of the physics behind it https://www.instructables.com/Mousetrap-Car-Explained/
- ***Mousetraps in Motion***: A step-by-step guide to building a mousetrap vehicle https://www.stevespanglerscience.com/lab/experiments/mousetraps-in-motion/
- ***Work, Energy, and the Mousetrap Car***: A video explaining some of the physics concepts regarding work, energy, and power behind a mousetrap vehicle https://www.youtube.com/watch?v=HXyKvoGvV1g
- ***1st place Mousetrap Car Ideas***: An excellent video demonstrating many of the principles involved in designing and building distance and speed mousetrap

vehicles
https://www.youtube.com/watch?v=b7zWwo9dbiU

Activity 1: Can a Mousetrap be a Battery?

1 HOUR

INTRODUCTION:

We most often think of batteries as the cylindrical objects we put into devices like torches or flashlights. But in principle, a battery can be any device that can store energy to be used later.

In this case, when a mousetrap is set, energy (elastic potential energy) is stored in the spring which is released as soon as the mousetrap is triggered. The question becomes whether we can utilize this stored energy to drive a vehicle?

OBJECTIVE:

Students will consider what a battery is and whether the energy stored in a mousetrap can be used to drive a vehicle.

EQUIPMENT AND MATERIALS:

- A presenter computer and projector (with sound for playing videos)
- Flipchart paper and colored markers
- Student workbooks
- A variety of batteries
- Mousetrap

ONLINE RESOURCES:

- ***The world's biggest battery looks nothing like a battery*** (5:15) Video https://www.youtube.com/watch?v=r4OWMSG4Agg

WHAT TO DO:

1. Start by asking the group to describe and explain what a battery is. One of the most common definitions is that a battery is a device that converts stored chemical energy directly into electric energy by means of a chemical reaction. Show the group the variety of batteries you have on hand.
2. Now ask the group what they think the world's biggest battery is. Where is it? What does it look like? How much power can it store?
3. Play the video called *The world's biggest battery looks nothing like a battery* (5:15) which describes pumped hydro schemes as the world's biggest batteries.
4. Now show the group a mousetrap and demonstrate how it works. Ask them whether they think this mousetrap can be thought of as a battery. Why or why not? You can facilitate this discussion using the following questions.
   a. What do batteries basically do? (*They store energy.)*
   b. What do you have to do to set the mousetrap? (*You have to use energy to push against the spring and set the trap.)*
   c. What happens if you trigger the mousetrap? (*The energy stored in the spring is released and the trap snaps shut*.)
5. Explain that a mousetrap can be thought of as a battery. Batteries are basically just energy storage devices. We put energy into the battery, and it stays there until we release it. We must put energy in to bend the spring and set the mousetrap. This energy stays inside the spring until the mousetrap is triggered. Then all this energy is released very quickly as the trap snaps shut.

CAN A SPRING BE A BATTERY?

- What are springs?
- How do springs store energy?
- How much energy can a spring store?

CREATING TEAMS

- Try to have students work in different teams for each design challenge.
- As far as possible, keep teams to no more than five students. Three students per team is ideal.
- Make sure there is a good mix of students in each team.
- Assign roles or allow teams to determine and designate their own roles. Some roles you can suggest teams consider are Project Lead, Research Lead, Design Lead, Resource Manager, and Finance Manager.

6. Split the group into their teams for this challenge and ask them to think about the following questions. They can note their answers in **Section 1** of their workbooks.
   a. If we can use a mousetrap as a battery, what else could we use as a battery? Where or how would the energy be stored?
   b. Could we design a car that runs on a mousetrap battery? What kinds of problems would we need to solve to make this possible?
   c. What else might we power with a mousetrap battery?
7. After about 10 min bring students back together and have them share and discuss their answers.
8. Tell students that they are going to design and build a vehicle powered by a mousetrap. Describe the criteria and the constraints for the challenge and have teams write these down in **Section 2** of their workbooks.
   a. Success criteria
      i. The vehicle must have at least three wheels.
      ii. The vehicle must be able to cover a minimum distance of 10 m (32.8 ft) on a single 'charge'.
   b. Constraints
      i. No push starts of vehicles are allowed.
      ii. Students must design and build their vehicles within the given time.
9. Tell students that they will follow the engineering design process. If your students have never used the engineering design process before, hand out a copy of *The Engineering Design Process* to each team and take some time to explain the process and its steps.
10. Explain that teams will compete in races against other teams:
    a. An **endurance** race where prizes will be awarded for the vehicle that covers the greatest distance on a single 'charge'.
    b. A **speed** race where prizes will be awarded for the fastest vehicle over a specific distance.
11. Explain that teams will also present their vehicles to a public audience. This will include them telling the story of their design, testing, and redesign process and presenting answers to the following questions:
    a. What problems related to friction did they encounter and how did they overcome these?
    b. What kind of wheels did they use? Why did they choose them?
    c. What was the total approximate elastic potential energy stored in their mousetrap?
    d. What was the total mechanical advantage of their vehicle?
    e. What was the work done by their vehicle in overcoming friction?
    f. What was the acceleration of their vehicle while under power?
    g. What was the maximum velocity achieved by their mousetrap vehicle?
    h. How did the theoretical distance their vehicle might have covered compare to the actual distance it covered and what was responsible for this difference?
    i. What was the force of friction acting in the opposite direction to the motion of their vehicle?
    j. What was the overall efficiency of their vehicle in converting potential energy to kinetic energy? How might this be improved through additional optimization?

CRITERIA AND CONSTRAINTS

Success criteria are the conditions the design must satisfy to be considered successful.

Constraints are the limitations within which the team's design must remain.

You are at liberty to adjust or change the criteria and constraints to tailor the scope and complexity of the challenge to your group of students.

Before you start the challenge decide on the budget and time constraints.

FACILITATOR NOTE

If possible, show teams the location where the race events will be held and describe over what distance the speed race will be held.

If necessary, you can also elect to only conduct one of the race events.

Teams must also be prepared to answer questions on their design and the process they followed from members of the audience.

This presentation must be no more than **10 minutes**.

12. Encourage teams to take pictures, record videos, and keep detailed notes of what they do and how they do it throughout the challenge. All this media and information will be especially useful come time to create their presentation.

Activity 2: Identify and Define the Problem

1.5 HOUR

INTRODUCTION:

The essential problem students are solving is to find the best way to convert the elastic potential energy stored in their mousetraps into the kinetic energy of their vehicles.

To start to solve this problem, students need to understand what energy and work are, the different forms of energy, and the fact that energy can neither be created of destroyed but only converted from one form into another.

Key to understanding the motion of their vehicle is to understand the important role that friction plays in all motion and how it gradually converts kinetic energy into heat and sound energy that is then lost by the vehicle causing it to slow down and eventually stop.

Reducing friction will be one of the key challenges teams will need to overcome.

OBJECTIVE:

Students will learn about energy and energy transfer and the basics of motion.

EQUIPMENT AND MATERIALS:

- A presenter computer and projector (with sound for playing videos)
- Flipchart paper and colored markers
- Student workbooks
- Student computers or tablet/mobile devices with internet access
- A small ball
- Two magnets or a magnet and a small metal object

ONLINE RESOURCES:

- ***STEMonstrations: Newton's 2nd Law of Motion*** (2:39) Video
  https://www.youtube.com/watch?v=sPZ2bjW53c8
- ***4 Ton Wrecking Ball in Slow Motion*** (from 7:31) Video
  https://www.youtube.com/watch?v=D7sj7L1uLiw&t=451s
- ***Force and Motion: Basics*** Interactive simulation
  https://phet.colorado.edu/sims/html/forces-and-motion-basics/latest/forces-and-motion-basics_en.html

WHAT TO DO:

1. Start by facilitating a discussion with the group about what is needed to make an object move. Demonstrate this by having a student push a chair (or another object) across the floor. Say that to move the chair, the student must do work and to do work, the student needs to expend energy. Therefore, energy is defined as the "ability to do work". The more work that must be done to move something, the more energy is needed.
2. Explain that there are two main forms of energy – kinetic energy and potential energy.
   a. **Kinetic energy** is the energy of a moving object like a wrecking ball swinging into a house. It has enough kinetic energy to destroy a building.

Demonstrate that a ball thrown through the air also has kinetic energy. If thrown at a window, it might have enough energy to break the window. Have the group give other everyday examples of things with kinetic energy.

   b. **Potential energy** is the energy that is stored because of the position or arrangement of matter. An example is a stationary wrecking ball held above a car. It is not doing any work on the car but sure has the potential to do some work if released. This is called **gravitational potential energy** (the potential energy of an object because of its position in Earth's gravitational field). Demonstrate that a ball held above the ground also has gravitational potential energy that gets converted into kinetic energy when released. Other types of potential energy include:
      i. **Chemical potential energy** is the energy stored in the chemical bonds between atoms and molecules. Have the group give examples of everyday substances we use because of their chemical potential energy.
      ii. **Elastic potential energy** is the energy stored when an object, like a rubber band or spring is stretched or deformed. This energy is released when the object regains its normal shape. Have the group give other everyday examples of things able to store elastic potential energy.
      iii. **Electric (or electromagnetic) potential energy** is the energy stored because of a charged particle's position in an electric field or its position relative to another charged particle. Demonstrate this by holding two opposite magnetic poles apart. As soon as we let go, this potential energy is converted into the kinetic energy of the magnets as they move together.

3. Have teams read through **Section 3** in their workbooks and do the simple calculations on kinetic energy.
4. Spend a few minutes reviewing the answers to the questions from **Section 3** in the student workbook with the group to make sure everyone understands how to work with the kinetic energy formula. See the *Section 3 Worked Solutions* video in the Supporting Resources folder.
5. Explain that cars that use gasoline or petrol convert the chemical potential energy in the fuel into thermal energy in the cylinders which then gets converted into the kinetic energy of the pistons which ultimately turns the wheels and drives the car forward.
6. In this challenge we need to find a way to convert the elastic potential energy of a mousetrap into the kinetic energy of the vehicle.
7. Have teams read through **Section 4** of their workbooks and then answer the questions.
8. Go through the basic answers to the questions in Section 4 of the student workbook to make sure that everyone understands the basics of the laws of motion and friction. Here are some suggested answers for each question.
   a. An object, such as a car, at rest will remain at rest unless an external force acts on it.
   b. The reason moving cars don't keep moving is because friction (surface and fluid) is constantly converting the kinetic energy of the vehicle into heat and sound.
   c. If the engine of a car provides a force greater than friction (and air resistance), the car will accelerate and gain speed. The greater the net force, the greater the acceleration.

CHEMICAL POTENTIAL ENERGY

The energy stored in the chemical bonds between atoms or molecules.

ELASTIC POTENTIAL ENERGY

The energy stored in an elastic object when a force deforms it out of its natural shape.

d. Unless the engine continues to provide a force greater than friction (and air resistance), a car will slow down and eventually stop.
e. Cars that are lighter will experience greater acceleration than heavier cars when the same net force is applied to them, or will need a smaller net force to achieve the same acceleration.
f. The smaller the force of friction a car experiences, the smaller the force needed to accelerate the car (or change its motion).
g. The smaller the force of friction a car experiences, the less kinetic energy will be lost to heat and sound and the farther the car will travel with a given force.

Activity 3: Gather Information

2 HOURS

INTRODUCTION:

By this stage, students should understand what energy and work are and that work is the application of force over a distance. They should also understand that potential energy can be converted into kinetic energy as the energy stored in a spring is converted into the motion of a vehicle. However, friction will keep transforming some of this kinetic energy into heat and sound and so the vehicle will eventually lose all its kinetic energy and come to a stop. Therefore, friction needs to be reduced as far as possible.

The most important concept that students need to understand when designing their mousetrap vehicles is **mechanical advantage**. When a mousetrap is triggered, the trap arm snaps shut extremely quickly. If this rapid release of force was directly translated to the wheels, the wheels would most likely just spin and most of the energy would be wasted. Students need to achieve a far slower and more controlled release of the stored energy and its transfer to the wheels.

Another way of thinking about this is that the distance the mousetrap arm moves as it snaps shut is not very far, meaning that, when transferred directly to the wheels, will cause them to spin for only a very short period. Students need to extend the distance over which this arm moves so that their mousetrap vehicles can travel farther.

OBJECTIVE:

Students will learn about mechanical advantage and how different kinds of simple machines can be designed to change the magnitude of an output force and the distance over which it is applied.

EQUIPMENT AND MATERIALS:

- A presenter computer and projector (with sound for playing videos)
- Flipchart paper and colored markers
- Student workbooks
- Student computers or tablet/mobile devices with internet access
- For each team
  - A Mousetrap
  - A wooden dowel or skewer
  - Two cable ties or electrical tape
  - A ruler

ONLINE RESOURCES:

- ***The mighty mathematics of the lever*** (4:45) Video
  https://www.youtube.com/watch?v=YlYEi0PgG1g
- ***Balancing Act*** Interactive simulation
  https://phet.colorado.edu/sims/html/balancing-act/latest/balancing-act_en.html

WHAT TO DO:

1. Have students get into their teams and give each team its mousetrap for this challenge. Show students how to set and trigger the trap, being very clear about the following **safety rules**:
   a. Never leave the trap set
   b. Never trigger the trap while holding it. Always lay it on a surface.
   c. Never trigger the trap with your finger. Always use a pen, pencil, or other object.
2. Allow teams to practice setting and triggering the trap a few times making sure that everyone adheres to the three safety rules.
3. Ask teams to describe how the trap closes when triggered. Does it move quickly or slowly? Is the elastic potential energy in the spring released quickly of slowly? How far does the trap arm move when closing?
4. Have teams set and trigger their traps and ask them what would happen if they somehow connected the trap arms directly to the wheels of their vehicles. What do they think would happen? How far would their vehicles travel? How effective would this approach be?
5. Ask the group if anyone has any suggestions about how the elastic potential energy stored in the mousetrap can be released in a more controlled manner over a longer period.
6. Play the video called *The mighty mathematics of the lever* (4:45) to the group that introduces and explains the concepts of levers.
7. Emphasize that levers do not violate the laws of physics. We know that $W = F \times d$. If we extend the distance over which the force is applied to reduce the force, the total work is still the same. We have made a trade-off - reduced force but applied over a greater distance. Nothing is free! Work through the numerical example of this in the *facilitation presentation*.
8. Explain that mechanical advantage is a measure of this trade-off and is the ratio of the output force to the input force. For a lever, it can also be expressed as the ratio of the distance of the input force from the fulcrum to the distance of the output force from the fulcrum.
9. Explain that the distance can also be measured as the distance over which the input and output forces travel.
10. Explain that
    a. A mechanical advantage **greater than one** means that
       i. The output force is **greater than** the input force
       ii. The output force travels a **smaller distance** than the input force
    b. A mechanical advantage **less than one** means that
       i. The output force is **less than** the input force
       ii. The output force travels a **greater distance** than the input force
11. Explain that we can arrange a lever with both arms on the same side of the pivot. The force at the end of the shorter arm would be greater than the force at the end of the longer arm but it would travel through a smaller distance.
12. Give each team a wooden dowel or skewer, some cable ties or electrical tape, and a ruler and ask them to work through **Section 5** of their workbooks to explore how they can change the mechanical advantage of their mousetraps.
    a. Measure the length of your mousetrap spring arm in mm.
    b. Calculate the length of the arc through which the mousetrap arm travels as it closes. Remember that the circumference of a circle is $2\pi r$ where r is the radius of the circle.

!

FACILITATOR NOTE

If you would like students to get more practice working with levers and balancing the forces either side of the pivot, have them play with the interactive simulation called *Balancing Act* at https://phet.colorado.edu/sims/html/balancing-act/latest/balancing-act_en.html.

Note: some mousetraps do not operate over a full 180°. You may need to approximate the percentage of the semi-circle through which the arm does travel and multiply your answer by this amount. For example, if the arm travels through 90% of the semi-circle, multiply the answer by 0.9.

$$\text{Circumference}_{\text{semi-circle}} = \frac{\text{Circumference}_{\text{circle}}}{2}$$
$$\text{Circumference}_{\text{semi-circle}} = \frac{2\pi r}{2} = \pi r$$

c. If you connected the wheels of a vehicle directly to the mousetrap arm, what do you think would happen? How far would the vehicle travel?
The trap would snap shut very quickly, transferring its energy to the wheels very quickly. The wheels would accelerate rapidly but only for a very short period of time. It is likely that the wheels would just spin without driving the car forward very much, if at all.

d. Using the materials you have, create a device that will reduce the size of the output force and make it be applied over a greater distance.
Teams should figure out that if they extend the length of the mousetrap arm, they will increase the distance (and hence) time over which the force is applied and also decrease the force applied to the wheels.

e. If you have not yet done so, connect your dowel or skewer to the mousetrap arm with the cable ties or electrical tape. Which arm, the original arm or the extended arm, travels through a greater distance?
The extended arm travels through a greater distance. Encourage students to trace, on a piece of paper, the arcs made by the end of the original arm and the extended arm to see that this is the case.

f. Is the force greater at the end of the original arm or the extended arm? Why?
The force is greater at the end of the original arm. The force at the end of the extended arm is being applied over a greater distance. For the work being done at both points to still be the same, the force on the extended arm must be reduced. Students should be able to feel this is the case by moving the trap from the end of the original arm and the end of the extended arm.

g. Measure the length of the extended arm and calculate the arc length through which the end travels.

$$\text{Circumference}_{\text{semi-circle}} = \frac{2\pi r}{2} = \pi r$$

h. We can think of the original arm as the input arm and the extended arm as the output arm. Calculate the mechanical advantage of this simple machine.

$$\text{MA} = \frac{\text{r}_{\text{original arm}}}{\text{r}_{\text{extended arm}}}$$

i. By creating this simple lever machine with a mechanical advantage less than one, we increase the distance through which the output force is applied while decreasing the magnitude of this output force. How will this help us design a better mousetrap vehicle?

It will reduce the force applied by the mousetrap to the wheels, preventing them from slipping and the vehicle wheel spinning. This reduced force is also applied over a greater distance, meaning that we can drive the wheels for longer. While the vehicle will not accelerate very rapidly, it will travel much farther overall.

13. Go through the answers to the questions in **Section 5** of the student workbook, especially question 8. Do the calculation of the mechanical advantage based on the actual length of the mousetrap arm and dowels or skewers teams were working with.
14. Ask the group which other part of their vehicle design could help them achieve additional mechanical advantage to further reduce the magnitude of the output force but increase the distance over which it acts?
15. Explain that the same kind of mechanical advantage calculation can be done by comparing the radius of the axle to the radius of the wheels. The greater the difference, the greater the mechanical advantage (again, a reduction in force to gain a greater distance).

Activity 4: Generate Possible Solutions

2 HOURS

INTRODUCTION:

Now that students understand what mechanical advantage is, why achieving a mechanical advantage of less than one to reduce the output force but increase the distance over which it acts is advantageous, and how the mechanical advantage can be changed and calculated, it is time for teams to start designing their mousetrap vehicles.

OBJECTIVE:

Teams need to produce a detailed design brief describing and explaining their design.

EQUIPMENT AND MATERIALS:

- A presenter computer and projector (with sound for playing videos)
- Flipchart paper and colored markers (for facilitator and each team)
- Student workbooks
- Student computers or tablet/mobile devices with internet access

ONLINE RESOURCES:

- ***d.school brainstorming rules*** (2:31) Video
  https://www.youtube.com/watch?v=W1h5L_0rFz8
- ***how NOT to brainstorm*** (1:17) Video
  https://www.youtube.com/watch?v=ttWhK-NO4g8
- ***1st place Mousetrap Car Ideas- using SCIENCE*** (14:05)
  https://www.youtube.com/watch?v=b7zWwo9dbiU
- ***Mousetrap Cars: Construction tips*** Website
  https://www.docfizzix.com/topics/construction-tips/Mouse-Trap-Cars/

WHAT TO DO:

1. Review the Engineering Design Process again and explain that the group is now ready to start generating possible solutions. They will start out generating as many different ideas as possible before evaluating these and deciding which one they will try first. Emphasize again that teams are welcome to return to any of the previous steps to understand the problem more clearly or gather additional information.
2. Watch the videos called *d.school brainstorming rules* (2:31) and *how NOT to brainstorm* (1:17).
3. Now ask students to first spend a few moments completing **Section 6** in their workbooks where they create their own list of brainstorming 'do's and don'ts'. Have students share their ideas with the whole group while you compile a master list. Make sure you get at least the following onto the list:
   a. Value all ideas even the crazy ones
   b. Build off other ideas
   c. Defer judgement
   d. Aim for quantity over quality
   e. Listen to each other

TOP TIP

If teams have had experience with brainstorming from previous challenges, you can skip steps 2 and 3.

TOP TIP

If teams are unfamiliar with the **Decision Matrix** and how to use it, direct them to the section in their workbooks called **How to use the decision matrix.**

4. As teams start the design process, have them work through the notes and resources available in **Section 7** of their workbooks. This section will give them many helpful hints and tips.
5. Have teams brainstorm and generate different possible design ideas for their mousetrap vehicles.
6. As students think about their designs, have them consider the following questions:
   a. How can the energy stored in the spring be used to turn the vehicle's wheels?
   b. How can the energy stored in the spring be released in a slow and controlled manner?
   c. How can the friction experienced by the vehicle be reduced?
   d. How can enough traction between the wheels and the ground be created so that the wheels don't just spin without the vehicle moving forward?
   e. How can we ensure the vehicle travels in a straight line?
   f. What is the best lever length to use?
   g. How will the mass of the vehicle affect its performance?
   h. What is the best size of wheel to use?
   i. How will the mass of the wheels affect the vehicle's performance?
   j. Are you going to use a front or rear wheel drive design?
   k. What is the best material to use to attach your lever to your axle?
   l. What is the best diameter of axle to use?
7. Have teams express their ideas in words and sketches and generate multiple ideas (they can use **Section 8** in their workbooks to capture these).
8. Remind them that they are competing in two different races – an endurance race (the vehicle that travels the farthest) and a speed race (the vehicle that covers a set distance in the least time). Are they going to prioritize the needs of one race over the other or are they going to try and create a vehicle to take the overall title?
9. Have teams use the **Decision Matrix** tool in **Section 9** of their workbooks to compare and evaluate the different ideas to choose the best one(s). Remind teams that if this idea does not work out as expected, they can revisit their decision matrix to choose a different idea or come up with a totally new approach.
10. To conclude this stage of the design process, have each team produce a **design brief** which describes their chosen design by completing **Section 10** in their workbooks. The design brief includes:
    a. A design statement – a brief description of the chosen design solution.
    b. A set of detailed annotated sketches which describe the materials to be used, the important features of the design, how it will be constructed and an explanation of how it will work.
    c. A materials list.

Activity 5: Create a Prototype

INTRODUCTION:

Activities 5 – 7 represent a highly iterative cycle of repeated design, testing, and redesign. Creating a prototype can be intimidating for many students as they believe that it needs to be perfect. It is important, therefore, to emphasize that one of the most effective ways engineers have to learn what works and what does not is to fail and to do so quickly, cheaply, and repeatedly. In this process, it is equally important that engineers gather data upon which to make updates to their designs.

In this activity, teams will build their first prototype, which they will test in the next activity. Help them to understand that they can build prototypes that test only one or more features of their design. Help them also to understand that they should experiment with different materials and methods to find the most suitable.

Before starting this activity, you need to make sure that all the materials teams need to build their prototypes are available. Teams should have listed the majority of these in their materials list produced in the previous activity if you decided to allow teams to choose their own materials.

PROTOTYPE

A model of a possible solution used to test and refine various features.

OBJECTIVE:

Students will build an initial working prototype of their mousetrap vehicle.

EQUIPMENT AND MATERIALS:

- A presenter computer and projector (with sound for playing videos)
- Student workbooks
- Student computers or tablet/mobile devices with internet access
- Design equipment and materials

ONLINE RESOURCES:

- ***What is a Prototype?*** (4:11) Video
  https://www.youtube.com/watch?v=4XenqN5Ib9o
- ***Mouse Trap Cars: Construction Tips*** Website
  https://www.docfizzix.com/topics/construction-tips/Mouse-Trap-Cars/

WHAT TO DO:

1. Review the Engineering Design Process again and explain that teams are now ready to build their first **prototype**. Watch the video called *What is a Prototype?* (4:11) and then discuss the main features of a prototype. Explain that prototypes are used by engineers to test different ideas in the real world and to find out as quickly and cheaply as possible which ideas work best. Explain that prototypes can be used to test one or more features of a design.
2. Emphasize again that teams are welcome to return to any of the previous steps of the design process if they need to.
3. Have students split into their teams to build their prototype vehicles. As teams work, remind them to refer to the *Mouse Trap Cars: Construction Tips* website for all sorts of design and construction tips.

Activity 6: Test and Evaluate the Prototype

INTRODUCTION:

It can be difficult to clearly demarcate this step in the design process from the previous one because of the iterative nature of prototyping, testing, and redesign. The four key aspects that teams should focus on testing are:

- Does their vehicle travel in a straight line?
- Do their wheels spin without the vehicle moving?
- Does the mousetrap power the wheels for as long as possible?
- Where and how can friction be reduced?

OBJECTIVE:

Students will test their mousetrap vehicles and use the data gathered to generate improvements and optimizations for their design.

EQUIPMENT AND MATERIALS:

- A presenter computer and projector (with sound for playing videos)
- Student workbooks
- Student computers or tablet/mobile devices with internet access
- Design equipment and materials

ONLINE RESOURCES:

- ***Succeed by Failing*** (4:05) Video
  https://www.youtube.com/watch?v=TcUX6eNT2j4

WHAT TO DO:

1. Review the Engineering Design Process and explain that teams need to test their prototypes. Emphasize that this is just the first of many tests they will need to perform as they enter the iterative test and redesign part of the engineering design process.
2. Remind teams that failures are to be expected as this is what prototypes are for. It is very likely that their first prototype will fail in some way. Watch the video called *Succeed by Failing* (4:05) and discuss what the role of failure is in the design process. Discuss why it is important even if initial tests pass to keep testing and improving a design – a process called **optimization**. Refer to the examples of familiar products like smartphones, light bulbs, or cars. Even though the first models may have worked just fine, these products have been continuously improved. Why?
3. Discuss the kinds of tests that teams may want to perform by reviewing the success criteria for the challenge and reminding teams that their vehicles will compete in two different races:
   a. An **endurance** race to see which vehicle can cover the greatest distance on a single ‘charge’.
   b. A **speed** race to see which vehicle is fastest over a specific distance.
4. Explain that it is important that teams are structured in their testing approach. Therefore, encourage teams to test:
   a. **One part at a time** – rather than testing different wheels, body designs, or drive trains all at once, suggest that teams test each sub-system separately so that it is easier to discern the effects of different changes.

   b. **Different solutions to the same problem** – teams should test multiple different approaches to the same problem before deciding on the best approach. If they are looking at how to improve traction, they should test a range of different wheel designs before settling. Some ideas may surprise them.

5. Have students split into their teams but before they do any testing have them think about the following questions in **Section 11** of their workbooks:
   a. What aspect(s) of their prototype will they test?
   b. How will they test? What testing procedure will they follow?
   c. What are their criteria for success? How will they know if their design works or not, or which parts of it need to be refined and/or redesigned?
   d. What data will they collect? How will they collect this data?
   e. How will they analyze this data to draw accurate conclusions?
6. Have teams test their prototypes and collect and record their data. As they do, remind them that
   a. The engineering design process is **iterative** not linear. This means that it is about gradual testing, refinement, and improvement. Therefore, it is necessary to revisit earlier steps in the process.
   b. **Failure** is an essential part of the engineering design process. It is only through testing that we discover what works and how well it works. Never is a design perfect the first time.
7. Using **Section 12** of their workbooks, have teams start to describe the results of their tests.
   a. What worked and what failed?
   b. What were the problems encountered?
   c. What can be improved, changed, or modified?
8. Remind teams that they can use the decision matrix if they need to decide between different new or modified design options.
9. Inform teams that, based on the improvements or changes they would like to make, they need to either start collecting the materials they will need or update their materials list if they need you to obtain any of these materials.
10. Also remind teams that they need to present their test data as part of their public presentations. Therefore, they need to record things like the total distance travelled or the total time travelled by different designs.

TOP TIP

Modern smart phones have relatively good accelerometers in them (the devices which allow the phone to know what its orientation is). There are many free apps which teams can download that will allow them to measure and record the acceleration and speed of their vehicle as it moves. Suggest to teams that they take such recordings to compare with any theoretical calculations and to present these values in their final presentation.

Activity 7: Refine and/or Redesign the Solution

INTRODUCTION:

Based on the results of their tests, teams will need to refine and/or redesign parts of their solution or the entire solution. This is just the first of many possible turns of the iterative design-test-redesign cycle. Allow teams to move through this cycle as often and as quickly as they wish within the confines of the budget and time you have set for this challenge.

OBJECTIVE:

Students will iterate to improve the design of their mousetrap vehicles.

MATERIALS:

- A presenter computer and projector
- Student workbooks
- Student computers or tablet/mobile devices with internet access
- Design equipment and materials

ONLINE RESOURCES:

None

WHAT TO DO:

1. Have students split into their teams to make the necessary changes and refinements to their devices. For this design challenge you should expect teams to go through the design-test-redesign cycle about two to four times.
2. Have teams review **Section 13** of their workbooks for some additional handy troubleshooting hints.
3. Be aware of the following dynamics in some teams or individuals and intervene as required.
    a. **Aiming too high** – some teams or individuals may wish to aim for perfection. Remind teams of the constraints of time and budget within which they are working and that, often, engineering is about finding the solution that best balances the criteria and constraints rather than the very best solution. This is sometimes termed 'satisficing' – the solution that meets the specifications and goals in an acceptably efficient and functional manner.
    b. **Not aiming high enough** – some teams or individuals may become demotivated or inclined to accept their very first design even if it does not adequately meet the criteria. Explain that the engineering design process is all about incremental improvement. Work with these teams to help them see how they can improve their designs and encourage them to keep pressing into the design process.
4. As teams continue to test and refine their designs, have them start to work through the calculations in **Section 14** of their workbooks. They will need to present these calculations in their final presentation. See the *Section 14 Work Solutions* video in the Supporting Resources folder for worked solutions to each of the questions, noting that the recorded values used will be different from what each team uses.

!

FACILITATOR NOTE

For this design challenge you should expect that teams will need to go through the build, test, redesign cycle two to four times.

Activity 8: Present the Solution: Prepare

2 HOURS

INTRODUCTION:

The opportunity for teams to present and communicate their products and their process is important for three main reasons:

1. Knowing that the team will need to present to a public audience is a powerful motivator.
2. Learning to communicate complex ideas clearly and concisely to a diverse audience is an essential skill not just for engineers but for everyone.
3. The process of reflecting on and distilling what one has learned, discovered, and achieved into a clear narrative is a critical part of the learning process.

OBJECTIVE:

Students will prepare for the final presentation of their product and process to a public audience.

EQUIPMENT AND MATERIALS:

- A presenter computer and projector (with sound for playing videos)
- Flipchart paper and colored markers
- Student workbooks
- Student computers or tablet/mobile devices with internet access

ONLINE RESOURCES:

- ***Good Presentation VS Bad Presentation*** (5:12) Video
  https://www.youtube.com/watch?v=V8eLdbKXGzk
- ***TED's secret to great public speaking*** (7:56) Video
  https://www.youtube.com/watch?v=-FOCpMAww28
- ***How to avoid death By PowerPoint*** (20:31) Video
  https://www.youtube.com/watch?v=Iwpi1Lm6dFo
- ***17 Killer Presentations Tips for Students Who Want to Stand out*** Article
  https://www.powtoon.com/blog/17-killer-presentations-tips-students-stand/

WHAT TO DO:

1. Remind teams that they will present and demonstrate their mousetrap vehicles to a public audience. Watch the video called *Good Presentation VS Bad Presentation* (5:12) as a group for an illustration of some of the key differences between good and bad public presentations.
2. You can also watch the video called *TED's secret to great public speaking* (7:56) for a more in-depth look into how ideas are spread to others when we speak. Pay particular attention to Chris' four key tips.
3. In addition, you can also have the group review *How to avoid death By PowerPoint* (20:31) and the article *17 Killer Presentations Tips for Students Who Want to Stand out* if you like.
4. Remind teams that their presentation should include answers to the following questions:
   a. What problems related to friction did they encounter and how did they overcome these?
   b. What kind of wheels did they use? Why did they choose them?

FACILITATOR NOTE

A copy of the **final presentation** is a completion deliverable for this design challenge.

HOW TO GIVE A GREAT PRESENTATION

- Keep it simple
- Maintain eye contact
- Start strong
- Tell stories
- Use your voice
- Smile
- Practice

c. What was the total approximate elastic potential energy stored in their mousetrap?
d. What was the total mechanical advantage of their vehicle?
e. What was the acceleration of their vehicle while under power?
f. What was the maximum velocity achieved by their mousetrap vehicle?
g. How did the theoretical distance their vehicle might have covered compare to the actual distance it covered and what was responsible for this difference?
h. What was the force of friction acting in the opposite direction to the motion of their vehicle?
i. What was the overall efficiency of their vehicle in converting potential energy to kinetic energy? How might this be improved through additional optimization?

5. Have students divide into the teams and prepare their final presentations. They should have collected various pictures, video clips, and notes that they can use to create their presentation and even include in it.
6. Remind teams that they should aim to present for no more than **10 minutes** and that everyone in the team is expected to participate in the presentation.
7. Make sure that teams know when and where the presentations will take place.