The Tech
Museum of Innovation
201 S. Market St.
San Jose CA. 95113
1-408-294-8324
thetech.org

Go Rover Go!

The Tech Challenge 2017 Lesson 3:

Developed by The Tech Academies of Innovation

I. Lesson Overview

How can we use the concepts of potential and kinetic energy to power a rover on a distant planet?

Lesson Description: In this lesson students will learn and apply the concepts of potential and kinetic energy to design, build, test, and improve a system to power a model rover. By stretching, compressing, twisting or changing the position of various materials, students learn how to store energy that can be converted to kinetic energy.

Grade Levels: 4-8

Education Outcomes:

4^{th} – 5^{th} grade students will:

- Explain how a vehicle stores potential energy and how that energy is converted to kinetic energy to move the rover.
- Analyze data from testing to inform design decisions intended to improve the efficiency of a rover.
- Apply knowledge about potential and kinetic energy to design, build and improve the efficiency of a rover.
- Use evidence from testing and the concept of energy to support claims about how well a design meets the criteria and constraints of a design challenge.

6^{th} – 8^{th} Grade students will:

- Explain how the distance between parts of a system affects the amount of potential energy stored in that system.
- Analyze data from testing and knowledge about potential and kinetic energy to inform design decisions to improve the efficiency of a product.
- Use evidence from testing and science concepts to support claims about how well their design meets the criteria and constraints of the final design challenge.

201 S. Market St.
San Jose CA. 95113
1-408-294-8324
thetech.org

Education Standards

Met: (Note: bolded parts of the standards are fully met by this lesson)

Next Generation Science Standards (NGSS) Performance Expectations (PE):
4-PS3-4 **Apply scientific ideas to design, test, and refine a device that converts energy from one form to another.**

MS-PS3-2 Develop a model to describe that **when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system.**

NGSS Disciplinary Core Ideas (DCI):
MS-PS3.A: Definitions of Energy

- **A system of objects may also contain stored (potential) energy, depending on their relative positions.**

NGSS Science and Engineering Practices (SEP):
SEP #6

- [3-5th] **Use evidence (e.g., measurements, observations, patterns) to** construct or support an explanation or **design a solution to a problem**.
- [3-5th] **Apply scientific ideas to solve design problems**.
- [6-8th] **Apply scientific ideas or principles to design, construct, and/or test a design of an object, tool, process or system.**
- [6-8th] **Undertake a design project, engaging in the design cycle, to construct** and/or implement **a solution that meets specific design criteria and constraints**.

Addressed: (The following standards are practiced in this lesson but are not explicitly taught and assessed)

NGSS Disciplinary Core Ideas (DCI):
MS-PS3.C: Relationship between Energy and Forces

- When two objects interact, each one exerts a force on the other that can cause energy to be transferred to or from the object.

NGSS Science and Engineering Practices (SEP):
SEP #6:

- Apply scientific ideas or principles to design, construct, and/or test a design of an object, tool, process or system.
- Undertake a design project, engaging in the design cycle, to construct and/or implement a solution that meets specific design criteria and constraints.

NGSS Crosscutting Concepts (CCC):

The Tech
Museum of Innovation

201 S. Market St.
San Jose CA. 95113
1-408-294-8324
thetech.org

- Cause and effect - Events have causes, sometimes simple, sometimes multifaceted. Deciphering causal relationships, and the mechanisms by which they are mediated, is a major activity of science and engineering
- Systems and system models - A system is an organized group of related objects or components; models can be used for understanding and predicting the behavior of systems.

Common Core Standards:
CCSS.ELA-Literacy.W.6.1 - Write arguments to support claims with clear reasons and relevant evidence.

II. Advanced Prep & Set-Up for Lesson

Energized! Advanced Set-Up

Materials (per approximately 30 students)
- ~60 rubber bands mixed sizes
- ~32 pieces of white computer paper
- ~12 balloons (any size)
- ~40 paper clips
- ~32 wooden skewers
- ~ 25 straws
- ~ 25 springs
- ~ 32 3 oz. cups
- ~ 35 spoons
- ~20 small magnets
- Copies of *"Energized! Data Sheet"* (1 per student) *(see Appendix D: "Energized! Data Sheet")*

Data Collection and Notebooks

We recommend making additional copies of the data sheets for additional prototypes. Encourage teams to try at least 3 prototypes or 1 per student on their team.

Set-Up
1. Set up the classroom for students to work in teams of 4-5. Have a table where all materials are located. Organize the materials so that it is easy for students to see what is available and how much of each item there is.

2. Make a copy of the *"Energized! Data Sheet"* for each student *(see Appendix D: "Energized! Data Sheet")*.

3. Data collection: Below is an example of data that might be collected by students. While students are working with their teams, have them take data on all the different ways they are able to store energy in each item. This data will be important for developing student understanding of potential and kinetic energy (part C), as well as brainstorming solutions for the final design challenge (part D)

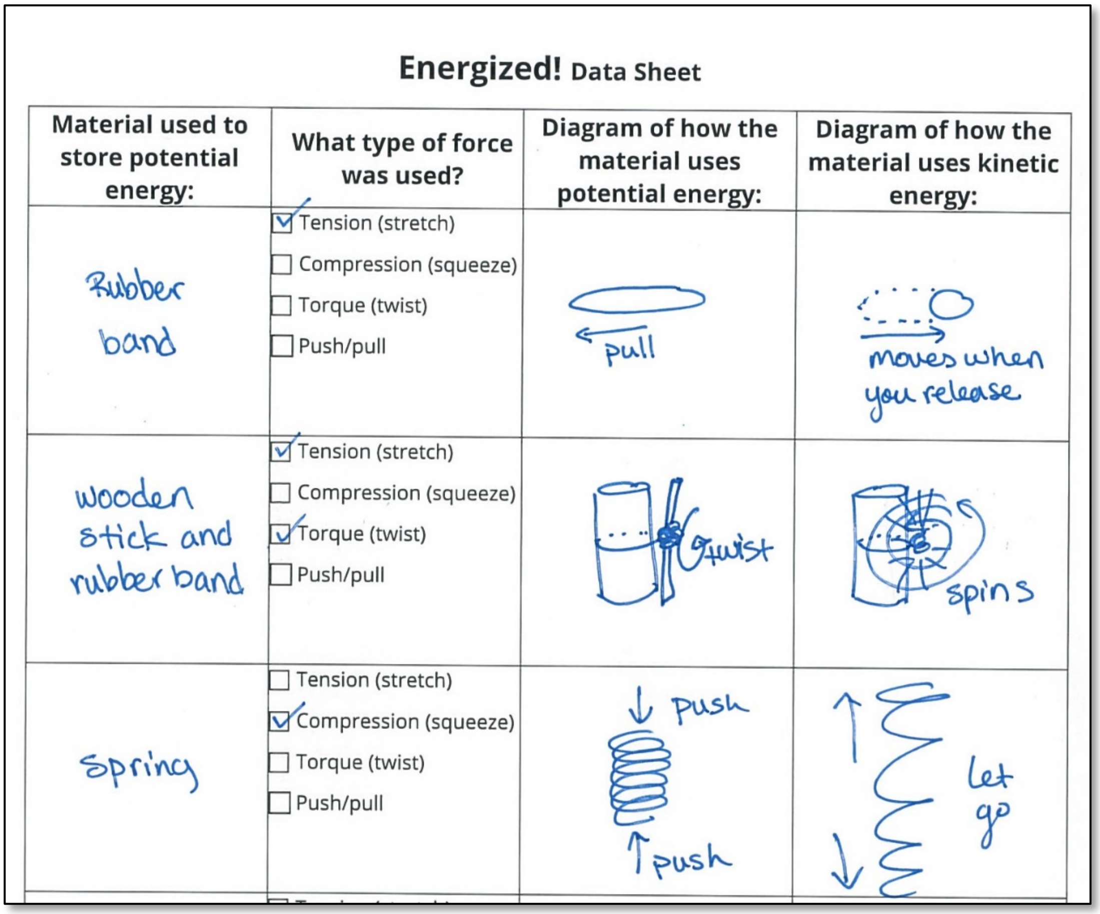
4. It may be helpful to display information for students on the design problem and key things to keep in mind while completing the design challenge. On a whiteboard or chart paper, display:
   - Goal: Create and test out materials in a variety of ways to produce potential energy from stretching, compression, twisting, and lifting to produce kinetic energy). Look for different types of ways potential energy is stored in different types of materials to convert into kinetic energy.
   - Think about: How will you record your data onto your data sheet? Are all materials the same when it comes to the amount of energy being stored? How about the amount of kinetic energy?

The Tech
Museum of Innovation

201 S. Market St.
San Jose CA. 95113
1-408-294-8324
thetech.org

Data Collection

Sample *"Energized! Data Sheet" (see Appendix D: "Energized! Data Sheet")*



Energized! Data Sheet

Material used to store potential energy:	What type of force was used?	Diagram of how the material uses potential energy:	Diagram of how the material uses kinetic energy:
Rubber band	☑ Tension (stretch) ☐ Compression (squeeze) ☐ Torque (twist) ☐ Push/pull	pull	moves when you release
wooden stick and rubber band	☑ Tension (stretch) ☐ Compression (squeeze) ☑ Torque (twist) ☐ Push/pull	twist	spins
spring	☐ Tension (stretch) ☑ Compression (squeeze) ☐ Torque (twist) ☐ Push/pull	push push	let go

Rover on a Roll! Advanced Set-Up

Materials (per approximately 30 students)

- ~40 rubber bands (mixed sizes)
- ~32 pieces of white computer paper
- ~12 balloons (any size)
- ~40 paper clips
- ~32 wooden skewers
- ~ 25 straws
- ~ 25 springs (mixed sizes)
- ~ 32 3 oz. cups
- ~ 35 spoons
- ~20 magnets
- 6-8 rolls of masking tape
- 8-10 rulers
- 8-10 scissors
- "Rover On a Roll" handout (1 per student) *(see Appendix D, "Rover on a Roll")*

201 S. Market St.
San Jose CA. 95113
1-408-294-8324
thetech.org

Set-Up

1. The set up should be similar to the *Energize!* Activity. Set up the classroom with separate areas for materials, building, and testing. Students should work in groups of 2-4.

2. Make a copy of the "Rover On a Roll" handout for each student *(see Appendix D, "Rover on a Roll").*

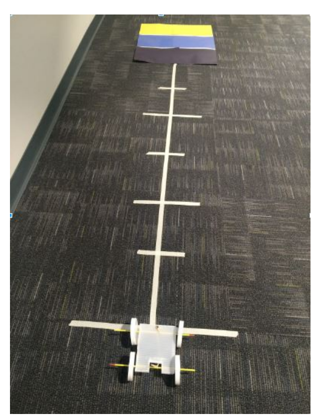
3. It may be helpful to display information for students on the design problem and key things to keep in mind while completing the design challenge. On a whiteboard or chart paper, display the Design Problem, Criteria, and Constraints for *Rover on a Roll*, for students to reference during build time (see Part D. Rover on a Roll).

4. Sort the materials into different bins and arrange them for easy student access. Establish expectations with students to ensure they only take what they need to get started. Remind them that they can return to exchange or get more materials as needed. Consider having one student from each group responsible for getting materials to ease traffic and limit wasted materials.

5. Students should work in groups of 2-4 students. Consider having scissors, tape, rulers and other such materials at each workspace to streamline building. You may want to move chairs out of the way to encourage movement and activity.

6. Set up a separate testing area where students can test their rovers. Mark a starting line on the floor with masking tape. Next place a target zone 6-8 feet or 2-3 meters from the starting line. Place incremental marks on the floor every 1 foot or 0.5 meter between the start and target zone. Encourages students to test early and often to promote use of the design process. Emphasize the importance of using data to help the group make decisions about how to improve their rover's design. Consider setting up 2 or more testing areas to minimize crowding, especially with larger classes.

7. Grades 4-5 may have a linear 3 (or more) colored target system. For example, If yellow, blue, and black colors are used as the target system, yellow can be least distance traveled, blue as the middle distance traveled, and black as the furthest distance traveled. Yellow can be seen as under shooting and black as overshooting. Use blue as the main target area.



8. Grades 6-8 will have a measured distance and a detailed target area). The main target will still be the blue area.

9. Below is an example of data that might be collected by students. Be sure that all groups have copies of the data collection to record their prototypes and iterations based on observations and data they collect. Decide if students will

201 S. Market St.
San Jose CA. 95113
1-408-294-8324
thetech.org

have one copy per team or if all students will have their own copies. This data will be important for completing the final assessment so remind students to be thorough in their data collection.

Data Collection
"Rover on a Roll!" handout *(see Appendix D, "Rover on a Roll")*

The Tech Museum of Innovation
201 S. Market St.
San Jose CA. 95113
1-408-294-8324
thetech.org

III. Go Rover Go! Lesson Guide

Guiding Question: How can we use the concepts of potential and kinetic energy to power a rover on a distant planet?

A. Introduction (15 minutes)

1. Introduce the topic of this lesson. Explain to students that in this lesson they will be working with a team to develop ways to make a rover that can roll on its own. Tell students that when rovers explore distant planets and asteroids they need to move on their own. No one is there to push them along. Rovers on Mars get their energy from the sun. They convert the solar energy to electrical energy that is then used to power motors that make the wheels spin and the rover roll.

> **Rovers:**
>
> If students built rovers in the previous lessons for The Tech Challenge 2017 (*Move It!* or *Traverse the Terrain*), consider using them for this lesson.

2. Explain to students that to explore planets that are too far from the sun to use solar energy, we need to explore other ways to store energy that can be used to make the rovers roll. That is what students will be doing in this lesson.

3. Lead a discussion with students on variety of ways energy is converted where something moves on its own and draws on students' prior knowledge.
   - *What are some real life situation where something moves on its own?* [Some examples include pull-back toy car, sling shot, rubber band, water rocket, and jack-in-the-box.]
   - *How do they move on their own?* [Some examples include wind it up, pull it back, stretch it, pump it up, etc.]
   - *Do they all move the same?* [No, different examples move in different ways.]
   - *Do they all use the same energy to move?* [No, different examples get their energy in different ways.]

> **Examples of things that move:**
>
> Consider bringing to class or finding images of various simple toys for discussion and exploration. Possible toys might include, sling shot, pull-back car, wind-up toys, toy airplane with propeller, water rocket, etc.

4. Discuss the definitions and differences between **potential energy** (stored energy) and **kinetic energy** (energy of motion) with students to prepare them to think like engineers.
   - **Potential energy** is the stored energy in an object due of its position or its configuration.
     - Examples of potential energy are oil sitting in a barrel, or a tightly coiled spring. This energy is referred to as potential energy, because once released, it has the potential to do a lot of work.
   - **Kinetic energy** is the energy which an object possesses because of its motion.
     - Moving water and wind are good examples of kinetic energy. Electricity is also kinetic energy because even though you can't see it happen, electricity involves electrons moving in conductors.
   - Energy can change from one form to another. A good example is a Roller Coaster. When it is on its way up, it is using kinetic energy since the energy is in motion. When it reaches the top it has potential (or stored) energy. When it goes down the hill it is using kinetic energy again.

5. Connect these definitions to the examples of things that move discussed earlier as a class. Help students make the distinction between when an object has potential energy and when it has kinetic energy. Use questions to guide students to this understanding. Possible questions:

201 S. Market St.
San Jose CA. 95113
1-408-294-8324
thetech.org

- *Does this object have high potential energy or low?* [Objects that have high potential energy are ones that move at high speeds when released. Objects that have low potential energy are ones that move slowly or over a very short distance when released.]
- *How could we give this object more potential energy?* [Ideas may include things like winding it up more, pull back farther on a rubber band, etc.]
- *How could we convert this potential energy into kinetic energy?* [The potential energy must be released.]

6. Connect this discussion to the larger ideas of the lesson. Tell students that as engineers, NASA has tasked them to provide a power source to their rovers in order to travel across a new dwarf planet in our solar system.

B. Energize! (20 minutes)

1. Introduce key concepts of this section: Students will build and refine a source of energy and record their findings on the *"Energized! Data Sheet"* provided *(see Appendix D: "Energized! Data Sheet")*. As an engineer, you have been tasked with the challenge of finding different ways to use kinetic and potential energy to move a ping pong ball. Explain to students that they are using ping pong balls instead of rovers at this point so they can focus on the different ways to store energy. They will be applying what they learn to rovers later in the lesson.

2. Introduce vocabulary terms to students. These are the different forces that students will be using during this design challenge to store potential energy in different materials. It is important to have a common vocabulary for students to communicate their ideas with others so be sure they are comfortable with the meaning and use of each term before moving on. Consider modelling and guided practice with each force using a material different from the ones they will be using in the challenge. Some possible materials include elastic exercise band, bungee cord, beach ball, foam block, sponge, slinky.
    - **Torqu**e – a force that causes something to rotate around an axis; a twisting force.
    - **Elastic force** – a force exerted by an object trying to return to its natural length.
    - **Tension** – a pulling force that is exerted by a string, cable, or chain on another object.
    - **Compression** – a force that is used to compress an object; a squeezing force.
    - **Attract/Repel**- when magnetic objects pull or push on each other without touching.

3. Introduce the specific design problem for this part to students:

    Materials:

    This activity should be used to generate more interest and ideas with the given materials; try not to limit the amount of each material a student may use (limit on materials = limited ideas/ creativity.)

    <u>Design Problem:</u>

    - You are working with NASA to come up with as many ways as possible to use materials available on space missions to create movement and force in case a disaster or accident puts the crew in an emergency situation. Your information will be taught to astronauts as part of their training preparing them for emergencies in space. Find as many ways as possible to store and convert energy to move the Ping-Pong ball, which represents any material they might have to move in an emergency. Using your materials, create, test, and record as many ways as you can to store and convert energy to move the ball.

The Tech
Museum of Innovation
201 S. Market St.
San Jose CA. 95113
1-408-294-8324
thetech.org

Criteria (Design Requirements)
- Use all materials at least once
- Use each material at least 2 different ways
- Find ways to create 4 types of potential energy: twisting, stretching, compressing, attraction/repulsion
- Collect data on all ways you find, including sketches of the designs
- Contribute to the group and be able to articulate your contribution

Constraints (Limitations)
- Budget: Use only the provided materials
- Schedule: Time limit of 9 minutes to test and record all data

Testing/ Data sheet-
- Students will test and record their findings in the data sheet provided by the facilitator
- Data sheet includes, but not limited to, materials used, source of potential energy, sketches of what potential energy/kinetic energy looks like.

4. Allow students a few minutes to glance over all materials to imagine any possible solutions. Then give each student one of each material that will function as an energy source (rubber band, magnet, balloon, paper). This time will be used to help the students familiarize themselves to the materials.

5. Share out results of the design challenge as a class.
   - Have students do a shout out or popcorn of their ideas for each material. Remind students that there are multiple forces (twist, compress, stretch, lift) that can be used to store energy in each item. If students don't share multiple ways to store energy in each item, give teams additional time to find more ways with specific materials.

6. Lead a class discussion about their results:
   - *What could you do to change and improve your design?* [Answers will vary, accept all answers]
   - *What kind of force (twist, stretch, compress, etc.) was easiest/most difficult to store energy in the rubber bands? Balloons? Magnets? Paper?* [Answers will vary. Students should back up their opinions with examples and descriptions from their data gathered during the challenge.]
   - *Did you find any ways to store energy that were similar to the real-life examples we talked about earlier? (Pull-back car, slingshot, etc.)* [Answers will vary, accept all answers]

Sharing out designs:

- Call out one material at a time and have students describe how they stored energy with that material. Then call out combinations of two materials and have students call out their energy source. Then call out combinations of three… etc.
- Typical student observations of materials' uses:
  - Rubber band – stretch, twist and stretch to make spin (torque)
  - Magnets – push/pull other magnets, pull a swinging object
  - Balloons – stretch (similar to a rubber band), push with wind power, push by lifting with breath inflating balloon

Recording student input:

Consider recording (on chart paper or projected from document camera) student responses as a reference for students and to model how to record data.

C. Content Learning (30 minutes)

1. Connect the *Energized!* design challenge to key vocabulary terms. Discuss the concept of potential energy using a focus question: "How could I show potential energy being converted to kinetic energy using balloons?"
    - Possible responses might include blowing it up and letting go, or stretching it and shooting it a distance like a rubber band. Use questioning to help students clarify and expand their ideas and encourage use of the vocabulary.
        - *What do you mean by that?*
        - *What kind of force does that idea use? (torque, lift, tension, compression)*
        - *What kind of energy would that be? (potential/kinetic)*

2. Review kinetic and potential energy.
    - When I stretch this balloon, what kind of energy does it have? How do you know? [Potential energy. When you do this you are storing energy in the object because it has the potential to move. When energy is stored this way it is called potential energy]
    - What about when I let it go? How do you know? [Kinetic energy. , the potential energy is converted into kinetic energy because the object is now in motion.]

3. Model how to explain the process of converting energy from potential to kinetic using cause and effect language.
    - *If I stretch the rubber band, then I am storing potential energy in it.*
    - *If I release the rubber band, then the potential energy is converted to kinetic energy as it flies away.*
    - Have students choose one of the ways they found to create force by storing and converting energy and explain the process using cause and effect language. They may do this with their team, on their own, written or orally. "If I _____ the _____, then…." "If I ______ the _______, then…."

4. Make a connection to rovers and begin to move towards adding independent motion to the rovers.
    - Blow up a balloon and ask students, *"If you connect the balloon to this rover like this (demonstrate with a rover and the balloon), which direction do you think the rover will move?"* [The rover will move in the opposite direction from the open end of the balloon.]
    - Allow students to discuss their ideas and how they might test them. Tell students that as they begin the next challenge it will be important to observe carefully and visualize what is happening with the energy in their rovers.

5. Discuss the connection between distance and the amount of potential energy in a system.
    - Introduce gravity as a form of potential energy. *One type of potential energy comes from the Earth's gravity. This is called gravitational potential energy (GPE). Gravitational potential energy is the energy stored in an object based on the height an object could potentially fall and the object's mass.*
        - Hold up an object (ball, rover, etc.).
        - Ask students: *What kind of energy does this object have?* [Potential]
        - *What will happen if I let go?* [It will fall to the ground.]
        - *Why?* [Gravity will pull it down.]
        - *Potential energy can come in many forms. You've explored* ***elastic potential energy*** *and you may have also explored* ***gravitational potential energy****. Can you give other examples from your Energized designs where you used gravitational potential energy to move your ping pong ball?*

201 S. Market St.
San Jose CA. 95113
1-408-294-8324
thetech.org

- Tell students that the object and the earth make up a system based on the force of gravity that attracts them to each other. As the distance between the two changes, the amount of potential energy changes.
- Place the object on a table or the floor and ask how much distance there is between them. Gradually lift the object and ask them what is happening to the amount of potential energy the object has. Explain that as the object gets farther from the earth it has the potential to fall farther, therefore its potential energy is increasing.
  - *What would you do if you wanted to increase the potential energy of this object?* [Raise the object higher above the ground]
  - *What if you wanted to decrease the potential energy?* [Lower the object so it is closer to the ground]
- Put two dots on an unused balloon. Have students note the distance between the dots.
  - *How much elastic potential energy is stored in the balloon the way it is right now?* [None]
- Inflate the balloon and look at the dots.
  - *What do you notice? What does this tell you about the amount of potential energy?* [The two dots spread apart. That tells you that the elastic potential energy of the balloon has increased.]
  - *What would happen to the distance between the dots if there was more/less elastic potential energy stored in the balloon?* [The dots would move farther apart if there was more elastic potential energy and closer together if there was less elastic potential energy.]

6. Have students practice describing how distance relates to potential energy using a different object: How does distance affect potential energy in other systems? Assign or allow students to choose another system from the *Energized*! activity and discuss how the distance between its parts affects the amount of potential energy it has. Remind students that not all systems will have more potential energy as the distance increases.
   - Possible discussion questions:
     - *What happens to the amount of potential energy as you decrease the distance between parts?* [decreases]
     - *What happens to the amount of potential energy as you increase the distance between parts?* [increases]
     - *What type of force do you apply to increase the amount of potential energy?* [elastic]

D. Rover on a Roll! (45-60 minutes)

1. Explain that students will be using what they know about energy to help NASA provide power to their exploration rover that will travel across the new dwarf planet found in our solar system. Combine an energy source to the rover and use it to make the rover roll.

2. One way to emphasize the real-world problem of exploring dwarf planets is to discuss newly discovered dwarf planets in the news. There have been several discovered within our solar system within the last few years, and one that was discovered at the time of this lesson writing is described in this New York Times article on recent dwarf planet discoveries. Some of these bodies could have water, precious metals or other valuable resources. A rover could travel across the surface of one of these dwarf planets to collect data and samples that could help scientists study it.

3. Introduce the key concept of this section and how it connects to what students have previously done. Student will be combining their previous knowledge and concepts learned from Section B to apply an energy source to a pre-existing rover.

Rovers:

- A previously made rover may be made by students in *Move It!* Or *Traverse the Terrain*. If no rover has been made, consider making enough rovers for each group. An example of how to build a rover may be found in this WikiHow article on building toy cars with every day materials.
- Consider making each rover as similar in size, shape, materials used to create an equal basis for this section

- *As a team of engineers, your task is to design and refine a way to include a source of energy into the rover so that it can move without being pushed or pulled.*

4. Randomly assign a force to each team. There may be some groups who have the same force. Explain that the group must find a way to use this force to store potential energy in their rover. This is one of the design criteria. It is intended to promote a wider variety of design solutions.
   - Torque (twist)
   - Tension (stretch)
   - Compression (squeeze)
   - Repel/attract (push/pull)

> **Assigning forces:**
>
> - When assigning a force for each team to use in the design challenge, you may want to write each force on a slip of paper and put them in a container. Make sure that all forces are represented at least once and that the number of slips matches the number of teams. Invite a member of each group to pull out a slip, without looking.
> - You could also allow a short "trade time" for groups to trade slips with other teams, if both groups agree to trade.

5. Go over all parts of the design challenge with the class:

   Design Problem:
   - Use your prior knowledge of energy to help NASA provide power to their exploration rover that will travel across the new dwarf planet found in our solar system. Combine an energy source to the rover and use it to make the rover roll.

   Criteria (design requirements)
   - Rover must be able to be re-energize/reused at least 5 times
   - Rover must reach the target area 3 out of 5 times.
   - Rover must store energy using your group's force
   - Rover must move without being touched by a person
   - All group members must contribute and be able to describe their contribution

   Constraints (limitations)
   - Budget: Use only the provided materials
   - Schedule: Time limit of 30 minutes

   Testing/ Data sheet-
   - Students will test and record their findings in the data sheet provided
   - Data collection on "Rover on a Roll!" handout includes, but not limited to, materials used, source of potential energy, sketches of what potential energy/kinetic energy looks like *(see Appendix D, "Rover on a Roll")*.

6. Connect what students have learned to the lesson's guiding question. Explain to students that they will use what they have learned about potential and kinetic energy to create designs to meet NASA's design challenge.
   - As a way to begin the design process, students will work with their group to brainstorm ways to use what they have learned about energy to help guide their designs for the upcoming design challenge.

> **Brainstorming:**
>
> - If you or your students are new to brainstorming, it is a good idea to do the first several brainstorms as a whole-class activity so you can model and teach appropriate and productive behaviors. If brainstorming is done well, the group will have a much higher likelihood of success with the design.
> - Consider using rules, such as those developed by Stanford University's Institute of Design to guide students' brainstorming session:
>   - Suspend Judgement
>   - Go for quantity
>   - Be concise!
>   - Capture all ideas
>   - Go for wild ideas
>   - Build on ideas of others
>   - Be visual, sketch
>   - Focus on the topic
>   - All ideas are valid

- Explain that brainstorming is a great way to gather ideas before you start working, and lead them in a brainstorm about different ways they could incorporate their knowledge about potential and kinetic energy.
- Be sure to help students keep an open mind as they brainstorm. Possible questions to guide the brainstorming session include:
  - *Which types of forces and materials do you think might work to store potential energy in the rover?*
  - *What toys or other real-life systems could we use as inspiration?*
  - *Which parts of the rover could the force be applied to? (axle, wheel, chassis)*
  - *How could you convert potential energy to make the rover axle spin?*
  - *How could you convert potential energy to push or pull the rover chassis forward?*

7. Go over the "Rover on a Roll" data sheet *(see Appendix D, "Rover on a Roll")* with the students and have them fill in the data sheet as they test their rover. Use questions to facilitate imagination and creativity:
   - *How would you define success in this activity?*
   - *What about this design makes it successful?*
   - *Which criteria/constraints does your design meet?*
   - *How could you improve your design to meet more criteria?*
   - *Looking at your data, in what area could your rover improve?*

Early finishers:

If a team is finishing the challenge quickly, challenge the group to find the furthest distance their rover can achieve or to use an additional type of force to power their rover in two ways.

8. While students are engaged in the design process with their groups, circulate, observe, and provide feedback for students in the form of encouragement and questions that push their thinking (see questions above)

9. When the activity is finished, lead students in a share out and a discussion about their designs and process. Ensure that every group demonstrates their design and shares their process and thinking. Facilitate questions to help with the discussions.
   - *What could you do to change and improve your design?*
   - *What part of your rover would you describe as successful? How do you know?*
   - *What would you do differently if we had the chance to do this activity again?*
   - *What part of the other groups would you have liked to add to your rover?*
   - *What type of force would you have liked to use instead of your assigned force? Why?*

E. Evaluation (40 minutes)

1. Explain that engineers and scientists use email as a fast and effective way to communicate with their peers. Scientists who live in different parts of the world often work together to make discoveries they couldn't make on their own. Email is an important way for them to communicate ideas, data, questions and feedback. Tell students that they will be sharing how their best design uses potential energy to move the rover, through a short design proposal in the form of an email.

Writing emails:

If some students don't have a working prototype, or feel their design isn't optimal suggest they write their email based on promising aspects of their design. Students may also write about lessons they learned about failures so they don't get repeated and NASA can learn from their experiences.

201 S. Market St.
San Jose CA. 95113
1-408-294-8324
thetech.org

2. As a class, brainstorm pieces of information that might be helpful to share with engineers to explain how their rover stores and uses energy, as well as how well their design meets the criteria and constraints of the challenge.

3. Share with students the template they will use to guide their writing *(see Appendix D, "Template for Draft of Email to NASA")* and make connections to the list students brainstormed. Explain any information they left out. Also explain the format of the email as this may be new to many of them.

4. Share the rubric with students *(see Appendix D, "Student Rubric")*. Focus their attention on the "meeting standard" column and explain that is the target that all students should strive to achieve.

5. Remind students about the importance of evidence in making an argument. Explain that data from the testing of their rovers will be a convincing form of evidence to support the design decisions they made during the design challenge and in their email about their design.

6. Students should have all relevant resources with them as they complete this email (like a real engineer would). All data sheets from this lesson, the email template, rubric, any notes they took during the unit.

Drafts:

Consider having the students submit a draft that you use the rubric to provide feedback then have students revise and resubmit a final version. This is also a time to teach other useful email skills like adding an attachment (photo of the rover). Other useful skills you may integrate include collecting and analyzing data with excel or google sheets.

7. Circulate to give encouragement and feedback as students are working on their email.

The Tech
Museum of Innovation
201 S. Market St.
San Jose CA. 95113
1-408-294-8324
thetech.org

IV. Appendices

A. Vocabulary

The following is the start of a suggested list of words to discuss as you read and discuss with students.

term	**student-friendly definition**
attract	when magnetic objects pull on each other without touching
compression	a force that is used to compress an object; a squeezing force
constraint	the limitations of a design problem which typically include budget and schedule limitations but may also include other limitations such as maximum size restrictions
criteria	the requirements or desired features of a design problem often describing the purpose and standards that a system or device must meet
design problem	The identified challenge, goals, or needs that a design addresses. What you are trying to solve.
design process	a series of steps that engineers use to guide them as they solve problems. The process is nonlinear but cyclical, meaning that engineers repeat the steps as many times as needed, making improvements along the way of imagining, creating, reflecting, testing and iterating. These are steps used to come up with solutions: [design process graphic goes here]
elastic force	a force exerted by an object trying to return to its natural length
engineer	a person who designs and builds innovative solutions (machines, systems, or structures) to solve a problem or meet a need
engineering	the process that engineers go through to create, design, test, and build a solution
failure point	a place where the design or system failed
force	Force is a push or a pull on an object resulting from interaction with another object.
friction	the resistance that one surface or object encounters when moving over another.
function	the action or purpose of an object including how it moves or interacts with other objects
gravity	a force which tries to pull two objects toward each other. Earth's gravity is what keeps you on the ground and what causes objects to fall.
iteration	when you try different solutions (create, test, reflect, imagine) over and over

201 S. Market St.
San Jose CA. 95113
1-408-294-8324
thetech.org

kinetic energy	the energy which an object possesses because of its motion
load	another word for force, or what the structure has to hold up to; in a machine doing work, like simple machines, a load is the weight or mass being supported and/or moved
optimal design	the design or device that best meets the criteria and constraints
potential energy	the stored energy in an object due of its position or its configuration
prototype	the models that you build to test before you get to your final solution
repel	when magnetic objects push against each other without touching
structure	the material or arrangement of parts in an object to make up the whole
tension	a pulling force that is exerted by a string, cable, or chain on another object; a stretching force
torque	a force that causes something to rotate around an axis; a twisting force
trade-off	a situation in which you must choose between or balance two things that are opposite or cannot be had at the same time
work	using a force to move an object a distance (when both the force and the motion of the object are in the same direction.)

B. Resources and Background Information

Resources:

- PBS Build Rubber Band Car - Gives the instructor a way to build a rover (if not previously built). Also gives the instructor an idea of how to use a rubber band as a source of energy (Elastic energy/ stretching energy) <http://pbskids.org/designsquad/build/rubber-band-car/>

- Kinetic Energy - Gives an understanding of potential and kinetic energy and gives examples of such. Also, gives example of other type of energy such as electrical and mechanical. https://www.enwin.com/kids/electricity/types_of_energy.cfm

- Potential and Kinetic Energy for Kids - This video explains the concept of potential and kinetic energy. The video also offers the formula for potential and kinetic energy. https://www.youtube.com/watch?v=IqV5L66EP2E

- Energy Conversion - A fun demonstration that shows the conversion of energy from one object to another. May be used as a hook to get students excited about the challenge. https://youtu.be/_occxMbMzHQ?t=173

Background Information:

Simple Machines:

Explain to students that as mechanical engineers, they must use their scientific eyes to carefully observe **simple machines.** Class will come up with an observation list. This will enable students to start thinking about how they notice simple machinery at work.

- *We noticed rover(s) crossing the terrain. Rovers are designed to cross terrains that can be very challenging. Based on your observations, what are some characteristics of a rover? What does it look like? How do these machines move?*
- Students should note that rovers have x number of wheels, x type of shape, etc. Answers may vary, but students should notice that there are 4 wheels for stability and that each pair of wheels is connected by an axle.
- The class will be focusing on a specific aspect of the function of the rover: the rolling. *What makes the rover roll? How do these wheels actually move?*

Review simple machines: **wheel and axle**

- Organize students into groups of 3-4. Hand students black box. Inside the black box, place a small toy or device that requires the use of a wheel and axle. Students will play with these items, noting the function and structure of the wheel and axle.
- *Now, as engineers, we are going to explore simple machines. Let us focus on a simple machine called wheel and axle. In your boxes, you have an item. Observe your [toy]. How does it move? What allows it to roll? What makes it work? Take 3 minutes to observe and write down your observations.*
- Project a visual of a wheel and axle. Allow 2-3 students to share their observations out-loud addressing the previous questions:

- *How does it move? What allows it to roll? What makes it work?* [Students should notice that the wheel is attached to a "rod" or "stick" that spins freely allowing the wheel to turn easily.]
- Explain the logistics of the wheel and axle. The wheel and axle machine works when a circular object--called a wheel--and a shaft--known as an axle--are attached. The wheel and axle work by reducing the effect of **friction** on an object.
  - *We call the "rod" or "stick" an "**axle**." Instead of sliding across the ground, the wheel turns, so there is less resistance or "**friction**" from the ground allowing it to move more easily.*
  - Model this by holding up one of the toys and asking students how the toy's movement would differ if it did not have wheels. Student answers should explain the aforementioned logistics.

Creating Criteria and Constraints as a class

[6-8th] As middle school students develop their skills in defining the problem, guide them in a group decision-making process of the criteria and constraints for the design problem.

- Ask students to think about the design problem with their teams*. How will they know if a design is successful? Specifically students should decide:*
  - *How will we know where each obstacle is on the challenge terrain?*
  - *What kind of constraints need to be in place (radio contact) in order for a successful navigation of the terrain?*
- After teams have discussed in small groups, have the class come together and lead a discussion to come to consensus on the criteria and constraints for this design problem.
- Students should develop a drawing of what they want their grid/terrain to look like before creating the full size terrain.

The Engineering Design Process:

Introduce the engineering design process graphic with students to show how engineers engage in fun, creative, problem-solving that is core to their work.

- Explain to students that as engineers go about solving problems and coming up with creative and innovative solutions to challenges, they follow the **design process.**
  - **Design Process**: a series of steps that engineers use to guide them as they solve problems. The process is non-linear but cyclical, meaning that engineers can follow the steps in no particular order, repeat the steps as many times as needed, and make improvements along the way of imagining, creating, reflecting, testing and iterating.
- We represent this process with a graphic that shows the main steps someone goes through as they solve a problem.

The Tech Museum of Innovation
201 S. Market St.
San Jose CA. 95113
1-408-294-8324
thetech.org

    - Define your problem: What is the problem you are trying to solve? What are the **criteria** (design requirements that will determine the success of your solution)? What are the **constraints** (real-life limitations like budget and schedule) that you have to work within?
    - Test/reflect – imagine – create: This is the main part of the process that is cyclical. This is where engineers go through multiple designs as they have ideas, try something out, test it, have new ideas, and incorporate it all into more building and testing. This process can go through many rounds as an engineer gets more information from each test and design that is tried.
    - Share your solution: Engineering is about teamwork, and engineers frequently learn from each other as they solve problems. It's important for students to communicate and share throughout the process so that just like real engineers, they can learn from each other and improve their solutions. It's particularly important to culminate a project with a formal sharing of solutions and perhaps even a showcase or other authentic way to share lessons learned with the broader community (e.g. community members, family members, principal, younger students etc.)
- When you see the design process in action, you'll notice that it's rarely the smooth succession of steps that the diagram implies. The steps often overlap and blur, and their order is sometimes reversed—it's a creative, fluid way of working that has to be adapted to each individual situation.
- As you guide students through the design process, you'll want to be flexible and receptive to the different approaches your students may try.
- Ask students to notice where they are in the design process and even to trace their path through the steps, so they can see how messy it can be.

Failure

One important aspect about engineering that is vital to how engineers solve problems is the importance of failure to learn and improve solutions.

- As engineers work on creating solutions and improvements, it is important to remember that failure is not only part of the process, it is necessary in order to improve and find success.
- Every time an engineer fails to solve a problem completely, s/he learns a new piece of information about how the design functions and how to make it better.
- When engineers find a part of the design that doesn't work, it is called a **failure point**.
    - A **failure point** is a design element that can cause an unsuccessful result. This is the point in a system that if it fails, the whole system fails.
- It is important to celebrate the failures that students may experience during the design process. Instead of "Oh no, that doesn't work!" try
    - *Now you know what happens when you try that! You have more information!*
    - *What did you learn from that?*
    - *What will you try next to improve your design?*
- Failure is an important part of the design process and should be celebrated as a positive way to learn. It is important to remind students that there is no single "right" answer in engineering; one problem can have many solutions.

201 S. Market St.
San Jose CA. 95113
1-408-294-8324
thetech.org

C. References

- "Brainstorming with Rules." *Brainstorming with Rules*. 2016 Stanford University Institute of Design, 12 Oct. 2009. Web. 28 July 2016. http://dschool.stanford.edu/blog/2009/10/12/rules-for-brainstorming/
- Build Rubber Band Car." *PBS KIDS*. PBS, 2016. Web. 28 July 2016. http://pbskids.org/designsquad/build/rubber-band-car/
- Chang, Kenneth. "Astronomers Discover New Likely Dwarf Planet, the Latest ..." *The New York Times*. N.p., 13 July 2016. Web. 2 Oct. 2016. http://www.nytimes.com/2016/07/14/science/astronomers-discover-new-likely-dwarf-planet.html
- "Investigating Kinetic and Potential Energy." *PBS LearningMedia*. PBS LearningMedia, n.d. Web. 28 July 2016. http://ca.pbslearningmedia.org/resource/hew06.sci.phys.maf.lpenergy/investigating-kinetic-and-potential-energy/
- "Kinetic Energy." *EnWin Kids Zone:*. Edwin Utilities, 2007. Web. 28 July 2016. https://www.enwin.com/kids/electricity/types_of_energy.cfm
- Kulakov, Taras. "5 Cool Science Experiments." *YouTube*. CrazyRussianHacker, 16 July 2016. Web. 28 July 2016.https://youtu.be/_occxMbMzHQ?t=173
- "Merriam-Webster." *Dictionary and Thesaurus | Merriam-Webster*. Merriam-Webster, 2015. Web. 28 July 2016.
- "Physics for Kids." *Energy*. Technological Solutions, Inc., n.d. Web. 27 July 2016. http://www.ducksters.com/science/energy.php
- Smartlearningforall. "Potential and Kinetic Energy for Kids." *YouTube*. YouTube, 24 Mar. 2015. Web. 28 July 2016. https://www.youtube.com/watch?v=IqV5L66EP2E
- Wargan, Michael. "Make a Toy Car." *WikiHow*. N.p., n.d. Web. 2 Oct. 2016. http://www.wikihow.com/Make-a-Toy-Car

The Tech
Museum of Innovation

201 S. Market St.
San Jose CA. 95113
1-408-294-8324
thetech.org

D. Lesson Handouts

Name: ______________________

Date: __________ Class: ______________

Energized! Data Sheet

Material used to store potential energy:	What type of force was used?	Diagram of how the material uses potential energy:	Diagram of how the material uses kinetic energy:
	☐ Tension (stretch) ☐ Compression (squeeze) ☐ Torque (twist) ☐ Push/pull		
	☐ Tension (stretch) ☐ Compression (squeeze) ☐ Torque (twist) ☐ Push/pull		
	☐ Tension (stretch) ☐ Compression (squeeze) ☐ Torque (twist) ☐ Push/pull		
	☐ Tension (stretch) ☐ Compression (squeeze) ☐ Torque (twist) ☐ Push/pull		
	☐ Tension (stretch) ☐ Compression (squeeze) ☐ Torque (twist) ☐ Push/pull		

Name: ______________________

Date: __________ Class: ______________

Rover on a Roll!

4 – 5th Grade

Prototype 1:

Sketch of prototype	For each launch, record the **color** target the rover stopped in:: 1: __________ 2: __________ 3: __________ 4: __________ 5: __________
How does this design store potential energy?	
How could you maximize the stored potential energy?	
How could you make the rover more energy efficient?	
What changes will you make to the rover to improve the next prototype?	

Name: ______________________________

Date: __________ Class: ______________

Prototype 2:

Sketch of prototype	For each launch, record the **color** target the rover stopped in:: 1: ___________ 2: ___________ 3: ___________ 4: ___________ 5: ___________
How does this design store potential energy?	
How could you maximize the stored potential energy?	
How could you make the rover more energy efficient?	
What changes will you make to the rover to improve the next prototype?	

Name: ______________________________

Date: __________ Class: ______________

Prototype 3:

Sketch of prototype	For each launch, record the **color** target the rover stopped in:: 1: __________ 2: __________ 3: __________ 4: __________ 5: __________
How does this design store potential energy?	
How could you maximize the stored potential energy?	
How could you make the rover more energy efficient?	
What changes will you make to the rover to improve the next prototype?	

Name: ______________________________

Date: __________ Class: ______________

Prototype 4:

Sketch of prototype	For each launch, record the **color** target the rover stopped in:: 1: __________ 2: __________ 3: __________ 4: __________ 5: __________
How does this design store potential energy?	
How could you maximize the stored potential energy?	
How could you make the rover more energy efficient?	
What changes will you make to the rover to improve the next prototype?	

Name: ______________________

Date: __________ Class: ______________

Rover on a Roll!

6 – 8th Grade

Prototype 1:

Sketch of prototype	For each launch, record the **distance** the rover stopped from the target: 1: __________ 2: __________ 3: __________ 4: __________ 5: __________
How does this design store potential energy?	
How could you maximize the stored potential energy?	
How could you make the rover more energy efficient?	
What changes will you make to the rover to improve the next prototype?	

Name: ______________________________

Date: __________ Class: ______________

Prototype 2:

Sketch of prototype	For each launch, record the **distance** the rover stopped from the target: 1: __________ 2: __________ 3: __________ 4: __________ 5: __________
How does this design store potential energy?	
How could you maximize the stored potential energy?	
How could you make the rover more energy efficient?	
What changes will you make to the rover to improve the next prototype?	

Name: ______________________________

Date: __________ Class: ______________

Prototype 3:

Sketch of prototype	For each launch, record the **distance** the rover stopped from the target: 1: __________ 2: __________ 3: __________ 4: __________ 5: __________
How does this design store potential energy?	
How could you maximize the stored potential energy?	
How could you make the rover more energy efficient?	
What changes will you make to the rover to improve the next prototype?	

Name: ______________________________

Date: __________ Class: ______________

Prototype 4:

Sketch of prototype	For each launch, record the **distance** the rover stopped from the target: 1: __________ 2: __________ 3: __________ 4: __________ 5: __________
How does this design store potential energy?	
How could you maximize the stored potential energy?	
How could you make the rover more energy efficient?	
What changes will you make to the rover to improve the next prototype?	

Name: ______________________________

Date: __________ Class: ______________

Template for Draft of Email to NASA

4 – 5th Grade

To: ____

Cc (your partners): ____________________________________

From: ____

Subject (what this email is about): ___________________________

____

Attachment(s): Images of your rover Low potential energy (before you add PE), High potential energy (after you add potential energy but before you let it go)

Optimal design #______ (from data collected *Rover on a Roll!*)

Materials:

Explanation of how our rover converts potential energy to kinetic energy (refer to your images)

Our rover gets its potential energy from…
The more you _____ (twist, pull, push) the _____ more potential energy is stored.
So, the rover moves when you… because…

____

____

____

____

____

____

____

____

Name: ___________________________

Date: __________ Class: ______________

Explanation of how well the design meets each of the criteria and constraints.

The criteria and constraints we met or exceeded are... we did this by...
The criteria and constraints we didn't meet are... because...
Our data supports this design because...

Sincerely,

Name: ______________________________

Date: __________ Class: ______________

Template for Draft of email to NASA

6 – 8th Grade

To: ____

Cc (your partners): ______________________________________

From: ____

Subject (what this email is about): ___________________________

____

Attachment(s): Images of your rover Low potential energy, High potential energy

Optimal design #______ (from data collected *Rover on a Roll!*)

Materials:

Explanation of how our rover converts potential energy to kinetic energy (refer to your images)

The rover will have low potential energy if..
To add more potential energy to the system you have to…
As the distance between… increases/decreases… the amount of potential energy…
So, the rover moves because…

____

____

____

____

____

____

____

Name: ______________________

Date: __________ Class: ______________

Explanation of how well the design meets each of the criteria and constraints.

The criteria and constraints we met or exceeded are... we did this by...
The criteria and constraints we didn't meet are... because...
Our data supports this design because...

Sincerely,

____

Name: ______________________________

Date: ____________ Class: ______________

Reflecting on the Design Challenge

1. Describe how your design meets the design challenge: ______________________________

2. What was the most difficult part of designing your solution? ______________________________

3. What was your favorite part of designing your solution? ______________________________

4. Explain 2 things that you learned about potential and kinetic energy during this process:
    a. ______________________________
    b. ______________________________

Name: ______________________________

Date: __________ Class: ______________

5. If you had another chance to iterate your design, what would you want to do next to improve on your design? ____

____

____

____

Collaboration:

Score your own work with your team and other students throughout the design challenges. Be sure to give reasons to justify your score!

4	I was frequently and actively engaged in sharing, listening and trying ideas from my partners.
3	I was usually engaged in sharing ideas, listening to, and trying ideas from my partners.
2	I was sometimes listening and sharing, and tried to use some ideas from my partners or I took over and did most of the work which didn't allow others to participate.
1	I worked mostly by myself, did not listen or share or use ideas from my partners
My reasons for giving myself this score:	

____

____

____

____

____

Name: ______________________________

Date: __________ Class: ______________

ric – 4-5th Grade

	Below Standard	Approaching Standard	Meeting Standard	Above Stan
nce *):* **s to** **nd** **e** that y from nother**.**	*Areas that individual students may need one-on-one support with*: ● Understanding how potential energy affects kinetic energy and rover performance. ● Understanding of how to effect changes in potential energy of an object or system. ● Appropriate use of target vocabulary.	● Description of how the amount of potential energy in the rover affects the performance of the rover. ● May not be accurately applied to how the rover works. ● Uses some target vocabulary appropriately but could improve in consistency of use, accuracy and variety of words used.	● Clear and accurate description of how the amount of potential energy in the rover affects the performance of the rover (distance, speed, etc.) ● Uses most key vocabulary accurately. ● Key Vocabulary: energy, kinetic energy, potential energy, distance, force, compression, torque, tension	*Areas where students r* ● Exceptional detail i description of ener in rover. ● Fluent use of targe and professional w *Ideas for next steps for* ● Description of how of potential energy changes as the dis between its parts c
gineering *structing* *nd* *ions* **tific** **ve** **blems.** **ce (e.g.,** **ents,** **ns,** **o** . or **lution** **m.**	*Areas that individual students may need one-on-one support with*: ● Explaining how the rover uses potential and kinetic energy to move. ● Explaining how energy can be stored using different materials and the forces of lifting, twisting, compressing and stretching. ● Analyzing data to identify ways to improve the rover design.	● Applies the concepts of potential and kinetic energy to partially explain how the rover stores and uses energy to move. ● Explanation is partially incorrect or lacks clarity. ● Uses 1 additional piece of evidence to support design decisions made in improving the rover. ● Evidence could come from any of these: data sheets, observations of other groups' designs, and comparisons between iterations.	● Applies the concepts of potential and kinetic energy to accurately to clearly explain how the rover stores and uses energy to move. ● Uses target vocabulary accurately and consistently. ● Uses 2 additional pieces of evidence to clearly support design decisions made in improving the rover. ● Evidence could come from any of these: data sheets, observations of other groups' designs, and comparisons between iterations.	*Areas where students r* ● Thoroughness and explanation. ● Use of target vocal well as other scien vocabulary. ● Use of professiona style. *Ideas for next steps for* ● Research potential energy. Apply findi improve the rover.

Name: ______________________________

Date: __________ Class: ______________

ric – 6-8th Grade

	Below Standard	Approaching Standard	Meeting Standard	Above Standa
nce Expectation (PE): lop a model to **hen the of objects a distance rent amounts of gy are stored in** *y Core Ideas (DCI):* nitions of Energy **f objects may also ored (potential) pending on their sitions.**	*Areas that individual students may need one-on-one support with*: • Understanding how distance of parts in a system relates to the amount of PE stored in the system. • Appropriate use of target vocabulary.	• Description of how the amount of potential energy in the rover changes as the distance between its parts changes. • May not be accurately applied to how the rover works. • Uses some target vocabulary appropriately but could improve in consistency of use, accuracy and variety of words used.	• Clear and accurate description of how the amount of potential energy in the rover changes as the distance between its parts changes. • Uses most key vocabulary accurately. • Key Vocabulary: energy, kinetic energy, potential energy, distance, force, compression, torque, tension	*Areas where students may* • Exceptional detail in de energy changes in rove • Fluent use of target vo professional writing sty *Ideas for next steps for gro* • Description of how bal and KE changes as rov across terrain. • Explain how the rovers different energy syster criteria and constraints store PE and convert it
ineering Practice 6: planations and ons **a design project, n the design cycle, ct** and/or **a solution that cific design criteria aints.**	*Areas that individual students may need one-on-one support with*: • Connecting evidence from data, design decisions, etc. to specific criteria and constraints of the challenge.	• Uses 1-2 pieces of evidence to describe how well they rover meets the specific criteria and constraints of the challenge. • Evidence could come from any of these: design test results, data analysis, specific comparisons between iterations, or science concepts around energy.	• Uses 3 pieces of evidence to describe how well they rover meets the specific criteria and constraints of the challenge. • Evidence could come from any of these: design test results, data analysis, specific comparisons between iterations, or science concepts around energy.	*Areas where students may* • Uses more than 3 piec evidence. • Uses a wide variety of sources. • Explanation is very clea convincing. *Ideas for next steps for gro* • Optimize your rover to greatest distance from amount of PE. • Propose changes in ma construction to the rov to scale it up to a large