

Energy Madness

Engineer a Rube Goldberg Device to Solve a Problem

The Tech Challenge 2017 Lesson 4: Engineering

Developed by The Tech Academies of Innovation

Lesson Overview and Standards

Advanced Prep and Set-Up for Lesson

Lesson Guide

- A. Introduction
- B. First Design Challenge
- C. Content Learning
- D. Final Design Challenge
- E. Evaluation

Appendices

- A. Vocabulary
- B. Resources
- C. Background Information
- D. References
- E. Lesson Handouts

I. Lesson Overview

How can we design a machine that will deliver a remote control to an immobile friend?

Lesson Description:

Students will apply knowledge of energy transfer by working in teams to design and build a Rube Goldberg machine to move an object from one place to another.

Grade Level: 4-8

Education Outcomes:

Students will:

- Use their knowledge of energy transfer to complete a design challenge with given criteria and constraints.
- Compare and evaluate solutions based on how well they meet the criteria and constraints.
- Iterate design solutions based on their observations of failure points and combine the best characteristics from multiple machines into a new solution to better meet the criteria for success.
- Describe how elements of the design process were used to achieve an optimal design solution.

Education Standards:

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

NGSS Disciplinary Core Ideas (DCI):

3-5-ETS1-2 **Generate and compare multiple possible solutions to a problem based on how well** each is likely to **meet the criteria and constraints of the problem.**

MS-ETS1-2 **Evaluate** competing **design solutions** using a systematic process to **determine how well they meet the criteria and constraints of the problem.**

NGSS Science and Engineering Practices (SEP):

Constructing Explanations and Designing Solutions:

[4-5th Grade] **Generate and compare multiple solutions to a problem based on how well they meet the criteria and constraints of the design solution.**[6-8th Grade] **Optimize performance of a design by prioritizing criteria, making tradeoffs, testing, revising, and re-testing.**

NGSS Crosscutting Concepts (CCC):

Energy and Matter: Flows, Cycles, and Conservation:

[4-5th Grade] **Energy can be transferred** in various ways and **between objects.**

[6-8th Grade] **The transfer of energy** can be tracked **as energy flows through a designed** or natural **system.**

II. Advanced Prep & Set-Up for Lesson

Standard Setup for Design Challenge Learning:

1. Set up the classroom so that students can work in groups of 3-4 students at 4-8 stations.
2. Place the materials in an area that is accessible by the students. Organize the materials so that it is easy for students to see what is available and how much of each item there is. Depending on the size of the class, it may be important to limit the traffic going up to the materials table.

Advance Set-Up

Materials (per approximately 30 students)

Educators should make available a variety of materials to students for their machine. Since designing a Rube Goldberg machine can be very open-ended, the particular materials you use can also be fairly open-ended. It's important to have materials enough for 30 students. Here are some examples of the types of materials to make available:

- Empty boxes
- Small containers
- Empty plastic jars
- Paper towel or toilet paper rolls
- Scrap fabric
- Paper (various types of thickness)
- Paper clips



- Binder clips
- Various types of tape
- Foam tubes
- Foam shapes
- Rubber bands (various sizes)
- Legos
- Jenga blocks
- Art supplies
- Dominoes
- String
- Marbles or small balls
- Cardboard
- Small rolling cars
- Small toys
- Tinker toys
- Foam tubing
- PVC pipes/connectors

Set-Up

1. Designate tables for easy access to materials and construction of machines.
2. Place small materials in separate containers or bags.
3. Assign groups of 3-4 students. Optional: assign each member a role (see Appendix C, Group Roles).
4. Provide basic supplies such as scissors and tape.

Data Collection

1. Students will be making observations about their design's performance throughout the build process and during testing. These observations will be recorded in tables printed on the handouts. For Example:

Criteria and constraints this solution DOES meet:	Criteria and constraints this solution DOES NOT meet:
<i>Rolling ball falls 2 inches onto the spoon. Energy from the ball falling moves into the spoon-end, pushing it down and lifts up the spoon handle moving energy into the block.</i>	<i>Justin's "remote" only moved 1 inch.</i>

III. Energy Madness Lesson Guide

A. Introduction (30-45 Minutes)

1. Explain to students that they are going to solve an energy problem as engineers (See Appendix C, Engineering Design Process).
 - *Who is an engineer? What does an engineer do?* (Possible answers include: someone who solves a problem; someone who designs buildings or bridges, etc.)
 - *Whenever you work to create a solution to a problem, you are an engineer!*
 - *When have we been engineers in the classroom?* (Possible answers include: when we solve problems like in Project Cornerstone or in Tech Challenge Club; when we work in teams on a project to create a solution, etc.)
 - *Tell me about a time when you had to solve a problem or fix something that was broken?* (Possible answers include: fixing a bike, making a present, etc.)
2. Introduce Rube Goldberg machines.
 - Read and explore more about Rube Goldberg machines. Some options include:
 - [4-5th] "What is a Rube Goldberg Machine"
(<https://wonderopolis.org/wonder/what-is-a-rube-goldberg-machine>)
 - [4-5th] "Rube Works: The Official Rube Goldberg Invention Game"
(<https://www.rubegoldberg.com/education/rube-works-game/>)
 - [6-8th] "Beyond a Man's Machines: Exploring an Inventor's Cartoons in 'The Art of Rube Goldberg'" Article and Video <http://www.nytimes.com/2013/12/10/science/exploring-an-inventors-cartoons-in-the-art-of-rube-goldberg.html>)
 - [6-8th] Rube Goldberg website with videos, gallery, contests, and more
(<https://www.rubegoldberg.com/>)
 - Possible facilitative questions to discuss Rube Goldberg machines include:
 - *What is the point or purpose of a Rube Goldberg machine?* (Possible answers include: to entertain, to challenge yourself to build a complicated machine.)
 - *What does a Rube Goldberg machine do?* (Possible answer: accomplishes a simple task in the most complicated way possible.)
 - *What are some of the pieces, or components, that you saw in the machines?* (Possible answers include: a wind-up toy, ping pong ball, shoe, etc.)
 - *How does the movement of one object initiate the movement of another? Give specific examples.* (Possible answer: a marble rolls into another marble and that marble knocks over a domino.)
 - *Who can build a Rube Goldberg machine?* (Possible answers include: anyone or everyone.)
3. Introduce the engineering design challenge big picture.

Close your eyes and imagine this: your friend, Justin Case, has had a rough week! He was on a hiking trip when he tripped and fell down into a ravine, into a patch of poison oak, and broke his leg. Can you imagine your friend's disappointment at being stuck elevating his leg and itching everywhere? His doctor told him that he needs to rest and do his best not to scratch his skin. Justin is pretty upset (and itchy).



All he wants to do is sit and watch TV. Lucky for Justin, you are an amazing inventor! As his friend, you decide to build him a ridiculous machine to cheer him up that will also deliver the TV remote control directly to his hand. Can you build a Rube Goldberg machine that will bring the TV remote control to him from where it sits on the shelf next to his chair? His favorite television show begins in 15 minutes!

B. Energy Madness (45 Minutes)

1. Introduce the Energy Madness Engineering Design Challenge.

Design Problem:

Design a ridiculous Rube Goldberg machine to delight Justin and deliver the TV remote control to him in time before his show begins.

Criteria (Design Requirements/Desired Features):

- The machine must include at least 4 different objects.
- The machine must have 3 different places where the movement of one object starts the movement of another.
- Justin's remote control must move from a starting point and end at least 6 inches away.

Constraints:

- The machine may only be touched once in order to initiate the machine.
- Budget: Any materials provided on the materials table are allowed to be used for this challenge.
- Schedule: Teams have 15 minutes to complete the initial design because that is when Justin's favorite show starts.

Testing:

- Test the machine frequently while building to confirm that all components are functioning as planned.

2. Lead the students through the brainstorming process about how to use the materials provided for the engineering design challenge.
 - Distribute one Materials Brainstorming Form to each team. (See Appendix E, Materials Brainstorming Form).
 - Hold up a rubber band
 - *What could this do in a Rube Goldberg machine?*
 - Model recording ideas on the worksheet.
 - Give student teams 10 minutes to walk to the materials table and write down 5 materials on the table, then return to their desks to discuss how those 5 objects can be used in a Rube Goldberg machine.
 - If time remains, students may return to the table to select 5 other materials.
 - Discuss the materials as a class and how they might be used in a Rube Goldberg machine.



3. Give teams 15 minutes to design, build, and test their first prototype.
 - Ask facilitative questions to encourage student learning and problem-solving.
 - *Explain your group's prototype idea.*
 - *What parts of your prototype meet the engineering design challenge criteria and constraints?*
 - *How could you use that material in a different way?*
 - *Have you tested the design?*
 - *What materials do you think will work best?*
 - *Where are you having problems in your design?*

4. Have teams share out their first prototypes.
 - Give each team 2 minutes to set up their Rube Goldberg machine.
 - Have teams gather near the machine to be demonstrated.
 - Educator Note: Due to the nature of Rube Goldberg machines there may be a need for extra time to reset the machines. Consider setting a time limit for each group's test based on classroom needs.
 - Ask teams to:
 - Explain why they chose these specific materials.
 - Identify any failure points. (See Appendix C, Addressing Failure Points.)
 - Debrief the demonstrations as a class, after all the presentations are complete.
 - [4-5th] *How did these machines address the criteria and constraints of the engineering design challenge?*
 - *Which machine(s) met all of the criteria and constraints?*
 - [6-8th] *Which machine(s) best addressed the criteria and constraints?*

5. Have students draw a diagram of their team's first prototype. (See Appendix E, Prototype Diagram Handout.)
 - Direct students to fill out only the front side of this handout that says "Prototype Diagram Handout" at the top. They will fill out the back at the end of Section C of this lesson.
 - Encourage students to title and label their diagrams.
 - Optional: Have students add measurements to their diagrams.
 - For more information on teaching scientific illustrations, see the Appendix. (See Appendix C, Creating Labelled Diagrams.)



C. Content Learning (45 Minutes)

1. Connect the Engineering Design Challenge: Save The Hiker (See [TTC 2018 Engineering Lesson, "Save the Hiker"](#)) to the Engineering Design Challenge
 - *In the science engineering design challenge we worked with energy transferring from one type to another.*
 - *Does anyone remember the two main types of energy we discussed? Hint: One type of energy is stored and the other is the energy of movement. Does anyone remember what they are called? (Answers: Potential energy and kinetic energy.)*
 - *In this lesson, we are going to further explore how energy is transferred from one type to another and from one object to another. Our goal is to create complex and fun Rube Goldberg machines to demonstrate what we know about how energy is transferred between objects in different ways.*
2. Review types of energy and energy transfer.
 - *What is energy transfer? (Possible answers include: when energy changes form e.g. potential to kinetic, or when energy transfers from one object to another e.g. when sound from a speaker makes a table shake.)*
 - [4-5th] Show "Energy & Energy Transformations: Wile E Coyote & Roadrunner" (https://www.youtube.com/watch?v=i6e-KrNCe_E)
 - [6-8th] Show "Types of Energy in Cartoon" (<https://www.youtube.com/watch?v=hxK1Tq3rkDw>)
 - Have students clap every time an energy transfer takes place.
 - Pause the video during the first few energy transfers to discuss how the students know an energy transfer took place.
 - Optional: [6-8th] Read about different forms of energy (<http://burnanenergyjournal.com/forms-of-energy-motion-heat-light-sound-2/>)
 - Lead a discussion on energy transfer in the video.
 - *What types of energy were shown in the video?*
 - *What kind of energy transfers were shown?*
 - *Where are energy transfers occurring?*
 - *Can you think of a real-life examples of energy transfer?*
 - Show second Wile E Coyote Energy Video (https://www.youtube.com/watch?v=x9hejMbz_kk)
 - Have students demonstrate their understanding by answering the questions in the video.
3. Discuss the different forms of potential and kinetic energy shown in the videos.
 - Discuss gravitational and elastic forms of potential energy.
 - *Gravitational potential energy is the potential energy created by increasing the height of an object in relationship to the ground.*
 - *How could we use gravitational energy in a Rube Goldberg machine? (Possible answers include: adding height into our machine or a drop.)*
 - *Elastic potential energy is the potential energy created by deforming an elastic object like a rubber band or a bouncy ball.*
 - *How could we use elastic energy in a Rube Goldberg machine? (Possible answer: adding a spring to pull back and snap something like a marble into motion.)*



- Discuss motion and sound forms of kinetic energy.
 - *Motion kinetic energy is a moving object, like throwing a ball.*
 - *How did we use motion energy in our first Rube Goldberg machines?*
 - *Sound kinetic energy is when sound waves are made by a vibrating object.*
 - *How can sound be used in a Rube Goldberg machine? (Possible answer: adding a speaker to vibrate the table.)*

- 4. Connect Rube Goldberg machines with the concept of energy transfer.
 - *We will watch a video of a Rube Goldberg machine. Pay careful attention to how the different objects are used together to transfer energy. Are there similar things we can do in our designs using the materials we have available?*
 - Show at least one video of a Rube Goldberg machine. A few options include:
 - “ULTIMATE Rube Goldberg machine” (<https://www.youtube.com/watch?v=QmOxqhEuBUM>)
 - “OK Go – This Too Shall Pass – Rube Goldberg Machine – Official Video” (<https://youtu.be/qybUFnY7Y8w>)
 - “Breakfast Machine (Rube Goldberg) Jiwi’s Machines” (<https://www.youtube.com/watch?v=2K7ntQyglWg>)
 - After watching the videos have students discuss in pairs or groups the types of energy transfer they observed.
 - Lead a whole class discussion about energy transfer and the Rube Goldberg video(s).
 - *What kinds of energy transfers took place?*
 - *What are some of the unexpected energy transfers that you observed?*
 - *What kinds of changes could the inventor of this machine make to add additional examples of energy transfer? To take away examples of energy transfer?*
 - *Could we replicate any of the energy transfers with our materials?*

- 5. Discuss design choices when creating Rube Goldberg machines.
 - *Creating a Rube Goldberg machine is not easy; it is a balance between using materials in the right order with the right types of energy transfer to create a successful and delightful result. What are some considerations your group made when you designed your first Rube Goldberg machine? (Possible student answer: we used ___ object, but it didn’t work so we pulled it out and switched _____ for _____, etc.)*
 - As engineers there are words to describe the choices we make to improve our designs. We are going to discuss three of these words: trade-off, optimization, and failure point.
 - [6-8] *Trade-offs are compromises in design; often you have to give up something in one area to gain something in another area. It could be buying a cheaper material that doesn’t perform as well to stay within budget or using a material because it looks cool and accepting that it might slow down the machine. Turn to your group and discuss if your team made any trade-offs in your first design.*
 - Have students share examples of trade-offs they made in the first engineering design challenge.
 - *Optimization is the process of iterating, refining and making trade-offs until we find the solution that best meets the criteria and constraints. While there is no perfect solution, engineers work to find the optimal solution. Cars are sometimes designed to be optimized for gas mileage meaning*



that the car can go as far as possible on a tank of gas but the trade-off might be to give up fast acceleration. What were areas in your design where you tried to optimize your design for a particular criterion?

- Have students share examples of optimization from their first engineering design challenge. (Educator Note: Though the purpose of a Rube Goldberg Machine is to be deliberately complex, students can still optimize elements of their design. For example, a falling object's energy can be more efficiently transferred into another object's motion to keep the machine working rather than be absorbed into the surface it lands on.)
 - *A failure point is a part of a machine that, if it fails, it stops the entire machine.*
 - Ask students questions to begin conversation around the concept of failure points:
 - *Where are the places in your machine that did not operate on your first trials?*
 - *What did your team do to improve in the design at (failure point)?*
6. Have students demonstrate their understanding of the energy and engineering concepts by adding to their initial prototype diagram.
- Have students mark and label energy transfer points on their diagram and indicate if each energy transfer included: gravitational, elastic, motion, or sound.
 - Have students label any failure points in their diagram.
 - Have students fill out the back portion of their diagram paper with answers to how their team used trade-offs and optimization in their design process.

D. Iterating Design Solutions (85 Minutes)

1. Introduce the second engineering design challenge:

Design Problem:

Justin was delighted by your first Rube Goldberg machine. This time he is adding extra criteria to make it even more challenging for you and delightful for him to watch.

Criteria (Design Requirements/Desired Features):

- Machine must include a drop of at least 2 inches.
- Machine must include at least 4 different energy transfers.
- The Rube Goldberg machine process should take less than 1 minute.
- Justin's remote control must move from a starting point and end at least 8 inches away.
- [6-8th] Additional student developed criteria that is agreed upon by the class.

Constraints:

- Machine may only be touched once to initiate the machine.
- No electricity is allowed anywhere in the Rube Goldberg Machine.
- Budget: Any materials provided on the materials table are allowed to be used for this challenge.
- Schedule: Teams have 40 minutes to complete their second design.
- [6-8th] Student developed constraints that are agreed upon by the class.



Testing:

- Test the machine frequently while building to confirm that all components are functioning as planned.
 - When demonstrating the machine, students are allowed 3 tries with a reset time of 30 seconds (or less, depending on the time needs of the classroom).
 - Team share-outs will include discussion of the following:
 - Trade-offs and optimization efforts
 - Analysis of any failure points
 - [4-5] Explain how energy is transferred from one object to another in at least one place within the machine.
 - [6-8] Explain how energy is transferred through the Rube Goldberg machine.
2. Give students 40 minutes to redesign their Rube Goldberg machine for this challenge.
- Ask students facilitative questions while they build to help them iterate their designs. Some questions that you may want to ask include:
 - *I see that you did _____ which caused _____ and it looks really cool. What could you change to help _____ meet the criteria?*
 - *Which of the criteria and constraints does your machine meet for this design challenge?*
 - *What are you doing to optimize this machine?*
 - *What trade-offs are you making?*
 - *What effect would it have on your machine if you swapped _____ and _____?*
 - *What is working differently in this iteration of your prototype?*
 - *What's another way you could use _____ energy in your Rube Goldberg machine?*
3. Have teams share out their second prototypes.
- Give each team 2 minutes to set up their Rube Goldberg machine.
 - Have teams gather near the machine to be demonstrated.
 - Give each team up to 3 times to demonstrate their machine with reset times of no more than 30 seconds (or less depending on the needs of your classroom).
 - Ask teams to:
 - Explain why they chose these specific materials.
 - Identify trade-offs and optimization efforts.
 - Analyze any failure points.
 - [4-5] Explain how energy is transferred from one object to another in at least one place within the machine.
 - [6-8] Explain how energy is transferred throughout the Rube Goldberg machine.



4. Debrief the demonstrations as a class, at the end of all of the presentations.
 - *How did your understanding of energy transfer affect your design?*
 - *What types of trade-offs did your team consider?*
 - *Where was energy put into the system? How was it transferred through the machine?*
 - *[4-5th] How did these machines address the criteria and constraints of the engineering design challenge?*
 - *Which machine(s) met all of the criteria and constraints?*
 - *[6-8th] Which machine(s) addressed the criteria and constraints in the most optimized way? Why?*
5. Have students draw a diagram of their team's second prototype on their **second copy** of this handout. (See Appendix E, Prototype Diagram Handout)
 - Encourage students to title and label their diagram, with horizontal printed labels, including:
 - Materials used
 - Failure points
 - Optional: Measurements
 - Answer the questions on the second side regarding:
 - Energy transfer points
 - Optimization
 - Trade-offs

E. Evaluation (70 Minutes)

Educator Note: For this evaluation, it would be ideal to expand the audience for students so they can practice demonstrating their knowledge in front of larger audiences. Some possible options include:

- Open up the final evaluation to another classroom, especially of younger students so the students can practice teaching what they have learned to others.
 - Have students make videos of their machines. Students can present their machine in action and talk about their process to share on the school website for friends or family that cannot normally come to events during the school day.
 - Have students set up their machines in a school public space and invite multiple classes to come and observe their work.
 - Invite family and community members to the classroom.
1. Introduce the final design challenge with the students (Appendix E, Final Design Challenge Museum Exhibition Submission Checklist)

Justin saw a commercial on television advertising that the local innovation museum is asking for ideas for a new Rube Goldberg machine they are designing in honor of their upcoming anniversary. The theme of the new exhibit will be "Getting Better All the Time" and the designs need to show off how innovators use iteration to build on existing ideas. The museum is planning to incorporate the most innovative parts from multiple submissions into the final machine. Justin thinks your machine has what it takes to impress the museum officials.

Design Problem:

How can you refine your machine to delight and inspire the community?



Criteria (Design Requirements/Desired Features):

- Machine must include a drop of at least 2 inches.
- Machine must include at least 4 different energy transfers.
- Machine must include at least one optimization explained by the presenter.
- A target object (formerly Justin's remote control) must move from a starting point and end at least 8 inches away horizontally.
- Presentation of the machine must showcase how energy transfer works and incorporate engineering concepts including: optimization, failure points, and iteration.
- [6-8] Create a high-quality diagram that shows how energy is transferred through your Rube Goldberg Machine.
- [6-8] Other student-developed criteria that is agreed upon by the class.

Constraints:

- Machine may only be touched once to initiate the machine.
- No electricity is allowed anywhere in the Rube Goldberg Machine.
- The Rube Goldberg machine process should take less than 1 minute.
- Budget: Any materials provided on the materials table are allowed to be used for this challenge.
- Schedule: Teams have 40 minutes to complete their second design.
- [6-8th] Other student-developed constraints that are agreed upon by the class.

Testing:

- Test the machine frequently while building to confirm that all components are functioning as planned.
 - When demonstrating the machine, students are allowed 3 tries with a reset time of 30 seconds.
 - Team share-outs will include discussion of the following:
 - Trade-offs and optimization efforts
 - Analysis of any failure points
 - [4-5] How energy is transferred from one object to another in at least one location within the machine.
 - [6-8] How energy is transferred through the Rube Goldberg machine from beginning to end.
2. Review the rubric with students, so students have a clear understanding of how their machine will be assessed. (See Appendix C, "Evaluating Student Learning using a Rubric")
- Hand out the rubric (See Appendix E, "Rubric").
 - Students' assessment will include participation in making a high-quality Rube Goldberg machine and completing the final reflection to demonstrate their understanding.
 - Show students the Final Design Checklist (See Appendix E, Final Design Checklist)
 - Show students the Final Reflection so they can ask any questions about the assessment (See Appendix E, Individual Final Reflection)
 - [6-8] Show students the Final Design Diagram where they will create a high-quality diagram that explains how energy is transferred through their Rube Goldberg Machine. (See Appendix E, Final Design Diagram)




3. Give students materials and 30 minutes to iterate and optimize Rube Goldberg machine.
 - Fix any failure points.
 - Create decorations and designs for the Rube Goldberg Machine
4. Pair teams up. While one team is demonstrating, the other team will mark the checklist. This will create accountability and have teams look critically at their design and at least one other team's design.
 - Discuss with the class the roles and responsibilities of pair teams.
 - *Pair teams are critical friends who want to hold their pair team accountable for their design during the demonstrations. However, we want to look for every team's successes, so if something is a borderline point always give the points. If there are any questions or tie-breaker decisions that is up to the educator.*
 - *Pair teams give checks based on their observations of the three demonstrations. They will not award points based on anything that happened during testing or while they were not observing.*
 - *Keep an eye out for parts of the team's Rube Goldberg machine that addresses the criteria and constraints really well and is an inspiring design.*
 - Optional: paired teams record video for each other.
 - Remind the class that the checklist is for fun, to see what can be done with Rube Goldberg Machines with these materials in class. Encourage students to take risks and try creative ideas; the focus should be on their ability to discuss the science and engineering involved in designing and redesigning the machine.
5. Have students demonstrate and explain their machines. This presentation will be different depending on the audience and method of demonstration selected by the educator.
 - Remind pair teams to be critical friends. This can include:
 - *If a team is borderline for a checkmark, give them the benefit of the doubt.*
 - *Ask questions to give teams an opportunity to answer all the important questions.*
6. Celebrate success.
 - Address any concerns brought up by teams or pair teams.
 - Review the team checklists.
 - Lead a classroom discussion.
 - *Which solutions best met the criteria and constraints of the design challenge?*
 - *What energy transfer was the most interesting to you?*
 - *Which parts of different teams' Rube Goldberg machines would you like to see incorporated into the final museum display?*
7. Have students complete the Individual Final Reflection and [6-8] Final Design Diagram. This will serve as the Final Assessment for this lesson (See Appendix E, Individual Final Reflection and Final Design Diagram). The Individual Final Reflection will include the following components:
 - Explanation of various iterations of design, including failure points.
 - Explanation of how final design solution is optimal, and how it meets the criteria and constraints.
 - Explanation of how various design ideas (from their team or another team) were integrated into the final design.

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
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 machine 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: <div style="text-align: right;">  </div>
Elastic Energy	Potential energy created by deforming an elastic object like a rubber band or a bouncy ball.
Energy Transfer	The conversion of one form of energy into another, or the movement of energy from one place to another.
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.
Function	The action or purpose of an object including how it moves or interacts with other objects.
Gravitational Energy	Potential energy created by increasing height.
Iteration	When you try different solutions (create, test, reflect, imagine) over and over.
Kinetic Energy	Energy that is in motion. Examples: wind, moving water, a ball rolling down a hill, even electricity (although you can't see it, electricity involves electrons moving in conductors).



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.
Motion Energy	A moving object like throwing a ball.
Optimal design	The design or machine that best meets the criteria and constraints.
Optimization	The process of iterating, refining and making trade-offs until a solution is found that best meets the criteria within given constraints.
Potential Energy	The stored energy an object has because of its position or state. Examples: a bicycle on top of a hill, a book held over your head, and a stretched spring all have potential energy.
Prototype	The model(s) that you build to test before you get to your final solution.
Scientific Illustration	A visual representation or picture of a scientific concept or process, with different parts labeled, focused on accuracy and usefulness; blueprint.
Sound Energy	Sound waves are made when something vibrates.
Structure	The material or arrangement of parts of an object to make up the whole.
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.



B. Resources

- "75 Rube Goldberg Ideas & Inventions." *YouTube*, DoodleChaos, 14 Apr. 2012. Accessed 20 Sept. 2017. www.youtube.com/watch?v=6FzUx2EFk8s
- "Design Challenge Learning Lesson Plans." *The Tech*, The Tech Museum of Innovation, 23 June 2017. Accessed 20 Sept. 2017. www.thetech.org/education/forteachers/resources/lessonplans
- Jenkins, Nicholas. "The Engineering Process: Crash Course Kids #12.2." *YouTube*, Crash Course Kids, 29 May 2015. Accessed 20 Sept. 2017. www.youtube.com/watch?v=fxJWin195kU
- "NASA's BEST Students: An Educator's Guide to the Engineering Design Process Grades 3-5." NASA. Accessed 20 Sept. 2017. https://www.nasa.gov/pdf/630753main_NASAsBESTActivityGuide3-5.pdf
- "Small Rube Goldberg Machines." *YouTube*, BigGameTommy, 26 Oct. 2014. Accessed 20 Sept. 2017. www.youtube.com/watch?v=863z_eHGJw
- "The Engineering Design Process." *Science Buddies*. Accessed 20 Sept. 2017. www.sciencebuddies.org/science-fair-projects/engineering-design-process/engineering-design-process-steps#theengineeringdesignprocess
- "What Is the Engineering Design Process?" *PBS LearningMedia*, PBS and WGBH. Accessed 20 Sept. 2017. www.pbslearningmedia.org/resource/phy03.sci.engin.design.desprocess/what-is-the-engineering-design-process/#.WcLKYciGM2y



C. Background Information

Addressing Failure Points

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, they learn 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.

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.
 - *Define your problems: 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.

Evaluating Student Learning using a Rubric

Review the rubric with students at the introduction of the project so they know what their learning goals are. It is important to allow students to begin with the end in mind, just as teachers backwards plan, using standards and assessments to inform units, topics, and day-to-day activities.

The rubric in the lesson guide is designed to evaluate student mastery of the “met” standards using the categories *Below Standard*, *Approaching Standard*, *Meeting Standard*, and *Above Standard*. This allows teachers to give individual feedback particularly for the students who are *Below Standard* or *Above Standard* in particular areas.

- In the Below and Above Standards sections of the rubric, the idea is that no student should be receiving these scores without personalized attention from the teacher – either as remediation or as extension to reach students where they are.
- With that in mind, the descriptions and observations in these two sections are simply examples of what you might see for students performing at that level. The comments and notes in these sections should be tailored to the specific student and should accompany individualized support and conversations.
- To learn more about Understanding by Design and rubrics, see [ASCD's Understanding by Design](#).

Group Roles

Using group roles in teamwork is a way to increase engagement and participation in the content and process of work. There are many roles and tasks to give team members to encourage positive participation. Here are a few sources for group work roles.

- Cooperative Group Role Cards
http://www.readwritethink.org/files/resources/lesson_images/lesson277/cooperative.pdf
- Cooperative Learning: How to Assign Meaningful Tasks to Group Members
www.dailyteachingtools.com/cooperative-learning-tasks.html#5

Creating Labelled Diagrams

Creating clearly labeled and drawn illustrations can aid a scientist, engineer, or cartoonist in remembering iterations of design and explaining their design process. Encourage students to draw their illustrations in pencil and then add color to them. Labeling is a key part of scientific illustrations. Students should title their illustrations and use horizontal, printed labels to explain the key components of their design. For more information on creating labelled diagrams consider reviewing one of these sources:

- How to do a Scientific Drawing www.youtube.com/watch?v=-TogFh8Ap30
- Rules for Scientific Drawings www.youtube.com/watch?v=HElwooECI2Y
- Rube Goldberg's "Send Late Stayer Home" www.rubegoldberg.com/artwork/send-late-stayer-home/?c=45



D. References

- "Cooperative Group Role Cards." Read Write Think, IRA/NCTE, 2004. Accessed 17 Sept. 2017. http://www.readwritethink.org/files/resources/lesson_images/lesson277/cooperative.pdf
- "Cooperative Learning: How to Assign Meaningful Tasks to Group Members." Daily Teaching Tools. Accessed 18 Sept. 2017. www.dailyteachingtools.com/cooperative-learning-tasks.html#5
- Deb, Anrica. "Forms of Energy: Motion, Heat, Light, Sound." BURN An Energy Journal, 29 Nov. 2015. Accessed 17 Sept. 2017. www.burnanenergyjournal.com/forms-of-energy-motion-heat-light-sound-2/
- "Energy & Energy Transformations: Wile E Coyote & Roadrunner." YouTube, MMG970, 10 Jan. 2012. Accessed 17 Sept. 2017. www.youtube.com/watch?v=i6e-KrNCe_E
- Goldberg, Rube. "Send Late Stayer Home." Rube Goldberg. Accessed 19 Sept. 2017. www.rubegoldberg.com/artwork/send-late-stayer-home/?c=45
- Hersher, Joseph. "Breakfast Machine (Rube Goldberg) | Jiwi's Machines." YouTube, Joseph's Machines, 17 Mar. 2016. Accessed 19 Sept. 2017. www.youtube.com/watch?v=2K7ntQyglWg
- "How to do a Scientific Drawing." YouTube, TheREALadawg, 2 June 2016. Accessed 19 Sept. 2017. www.youtube.com/watch?v=-TogFh8Ap30
- Jaramillo, Eduardo and Zuluaga, Pablo. "Types of Energy in Cartoon." YouTube, ejaramillo99, 18 Mar. 2014. Accessed 17 Sept. 2017. www.youtube.com/watch?v=hxK1Tq3rkDw
- Jennings, Dana. "Beyond a Man's Machines." The New York Times, The New York Times, 9 Dec. 2013. Accessed 17 Sept. 2017. www.nytimes.com/2013/12/10/science/exploring-an-inventors-cartoons-in-the-art-of-rube-goldberg.html
- "OK Go - This Too Shall Pass - Rube Goldberg Machine - Official Video." YouTube, OK Go, 1 Mar. 2010. Accessed 19 Sept. 2017. www.youtube.com/watch?v=qybUFnY7Y8w&feature=youtu.be
- "Rube Goldberg – Home of the Official Rube Goldberg Machine Contests." Rube Goldberg. Accessed 17 Sept. 2017. www.rubegoldberg.com/
- "Rube Works Game – Rube Goldberg." Rube Goldberg. Accessed 17 Sept. 2017. www.rubegoldberg.com/education/rube-works-game/
- Scholle, Jeanne. "Rules for Scientific drawings." YouTube, 9 July 2014. Accessed 19 Sept. 2017. www.youtube.com/watch?v=HElwooECI2Y



- "ULTIMATE Rube Goldberg machine." YouTube, YouTube, 20 June 2012. Accessed 17 Sept. 2017. www.youtube.com/watch?v=QmOxqhEuBUM " Understanding By Design® Framework - Videos, Articles, Resources, Experts ." *Ascd.org*. N. p., 2017. Web. 18 Oct. 2017. <http://www.ascd.org/research-a-topic/understanding-by-design-resources.aspx>
- "What Is a Rube Goldberg Machine?" Wonderopolis, National Center for Families Learning. Accessed 17 Sept. 2017. www.wonderopolis.org/wonder/what-is-a-rube-goldberg-machine
- "Wile E Coyote Energy." YouTube, Angie Payne, 13 Nov. 2015. Accessed 17 Sept. 2017. www.youtube.com/watch?v=x9hejMbz_kk



E. Lesson Handouts

Handout Title	Page
Engineering Design Process	18
Materials Brainstorming Form	19
Prototype Diagram Handout	20-21
Final Design Checklist [4-5 th Grade]	22
Final Design Checklist [6-8 th Grade]	23
Individual Final Reflection	24-25
Final Design Diagram	26
Rubric [4-5 th Grade]	27
Rubric [6-8 th Grade]	28



Engineering Design Process and Innovator Mindsets





Materials Brainstorming Form

In order to create a Rube Goldberg machine it is valuable to consider how materials can be used. In your group record different materials and use pictures and/or words to describe how these materials can be used.

MATERIAL	DESCRIPTION (words or pictures)
<i>Example:</i> Rubber band	Stretch it out and release it to snap a different object.



Name: _____

Date: _____ Class: _____

Prototype Diagram Handout

Draw a diagram of your machine.

- A. Include a title.
- B. Label materials by writing in print horizontally across the diagram.
- C. Label any failure points.

Date:	Title:	Name:
Criteria and constraints this solution DOES meet:	Criteria and constraints this solution DOES NOT meet:	

To improve on our prototype, some improvements we can make are:



A. Number **at least 3 energy transfer points** on your diagram and explain how energy is being transferred in the space provided.

- 1. _____

- 2. _____

- 3. _____

- 4. _____

B. What decisions did your team make that **optimized** part of your Rube Goldberg machine?

C. What **trade-offs** did your team make in this prototype? What other trade-offs did you consider?

Final Design Challenge [4-5th Grade]: Museum Exhibit Submission Checklist

Team Name:

Pair Team Name:

Justin saw a commercial on television advertising that the local innovation museum is asking for ideas for a new Rube Goldberg machine they are designing in honor of their upcoming anniversary. The theme of the new exhibit will be “Getting Better All the Time” and the designs need to show off how innovators use iteration to build on existing ideas. The museum is planning to incorporate the most innovative parts from multiple submissions into the final machine. Justin thinks your machine has what it takes to impress the museum officials. How can you refine your machine to delight and inspire the community?

Reason	Machine Features	Checkmark	Notes
Criteria	Successful drop of 2 inches		
Criteria	4 successful energy transfers		
Criteria	1 optimization (explained by presenters)		
Criteria	Target object travels 8 inches horizontally		
Criteria	Presenters explain at least 3 points of energy transfer within their machine		
Criteria	Presenters addresses failure points and ideas for iteration OR If there are no failure points, students discuss how they solved for a past failure point		
Constraints	Machine only touched once to initiate process		
Constraints	No electricity use		
Constraints	Entire machine process lasts 1 minute or less		

Final Design Challenge [6-8th Grade]: Museum Exhibit Checklist

Team Name:

Pair Team Name:

Justin saw a commercial on television advertising that the local innovation museum is asking for ideas for a new Rube Goldberg machine they are designing in honor of their upcoming anniversary. The theme of the new exhibit will be “Getting Better All the Time” and the designs need to show off how innovators use iteration to build on existing ideas. The museum is planning to incorporate the most innovative parts from multiple submissions into the final machine. Justin thinks your machine has what it takes to impress the museum officials. How can you refine your machine to delight and inspire the community?

Reason	Machine Features	Checkmark	Notes
Criteria	Successful drop of 2 inches		
Criteria	4 successful energy transfers		
Criteria	1 optimization (explained by presenters)		
Criteria	Target object travels 8 inches horizontally		
Criteria	Presenters explain how energy is transferred through their machine from beginning to end		
Criteria	Presenters addresses failure points and ideas for iteration OR if there are no failure points, students discuss how they solved for a past failure point		
Constraints	Machine only touched once to initiate process		
Constraints	No electricity use		
Constraints	Entire machine process lasts 1 minute or less		
Class Defined Criteria/Constraints			
Class Defined Criteria/Constraints			
Class Defined Criteria/Constraints			



Individual Final Reflection

Name: _____

Date: _____

1. Describe **at least 2** of the designs your team tried. Include any **failure points** you observed in each design.

2. Describe how each design **met or did not meet** the criteria and constraints.

Criteria/Constraints	Design #1	Design #2
Energy transfer		
Vertical drop		
Horizontal move		
Only one touch in beginning		
Used only given materials		
Built within time limit		



Name: _____

Date: _____ Class: _____

3. How did your final design improve on previous iterations?

4. What successful aspects of previous designs (from either your team's or another team's) were included in the final design?

5. If you had another chance to iterate your design, what would you want to do next to improve on your design? **Make sure to explain reasons why you would make the change on your design.**

6. Why is your final design the optimal design of all of your prototypes?



Name: _____

Date: _____ Class: _____

7. Explain at least **3 ways you used energy transfer** during this design challenge.
(Use the terms **kinetic and potential** in your explanation)



Final Design Diagram

Draw a diagram of your machine.

- A. Include a title.
- B. Label materials by writing in print horizontally across the diagram.
- C. Indicate how energy flows from object to object through the machine. Explain in words below.

Date:	Title:	Name:
Grid area for drawing		

Energy is transferred from one object to another in a Rube Goldberg machine. Our machine begins to work when:

Engineering Lesson: Energy Madness 4-5th Grade

Standard and Topic	Below Standard	Approaching Standard	Meeting Standard	Above Standard
<p>3-5-ETS1-2 Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.</p> <p>SEP 6 (ES) Constructing Explanations and Designing Solutions Generate and compare multiple solutions to a problem based on how well they meet the criteria and constraints of the design problem.</p>	<p><i>Areas that individual students may need one-on-one support with:</i></p> <p>In the Final Reflection</p> <ul style="list-style-type: none"> Applying criteria and constraints as an evaluation technique. Comparing ideas. <p><i>Areas that individual students may need one-on-one support with:</i></p> <p>In the Prototype Diagrams</p> <ul style="list-style-type: none"> Reviewing criteria and constraints definition. Reviewing design problems. 	<p>In the Final Reflection</p> <ul style="list-style-type: none"> Student generates a solution, but does not accurately assess it against the criteria and constraints of the problem. Student identifies similarities and differences with one other team's design or with one previous prototype. <p>In the Prototype Diagrams</p> <ul style="list-style-type: none"> Student creates 1 Prototype Diagram or 2 partially complete Prototype Diagrams. Student identifies only 1 way that their machine meets and/or does not meet criteria and constraints. 	<p>In the Final Reflection</p> <ul style="list-style-type: none"> Student generates a solution and accurately assesses it against the criteria and constraints of the problem. Student compares at least 2 solutions on how the design meets each of the criteria and constraints. <p>In the Prototype Diagrams</p> <ul style="list-style-type: none"> Student creates 2 complete Prototype Diagrams. Student identifies multiple ways that their machine meets and/or does not meet criteria and constraints. 	<p><i>Areas where students may exceed:</i></p> <ul style="list-style-type: none"> Compares solutions of 3 or more designs. <p><i>Ideas for next steps for growth:</i></p> <ul style="list-style-type: none"> Develop additional solutions to design problem. Develop new criteria and constraints for additional solutions. <p><i>Areas where students may exceed:</i></p> <ul style="list-style-type: none"> Student creates 3 or more iterations with complete Prototype Diagrams. <p><i>Ideas for next steps for growth:</i></p> <ul style="list-style-type: none"> Student identifies additional, more rigorous criteria to measure machine against.
<p>CCC 5 (ES) Energy and Matter: Flows, Cycles, and Conservation Energy can be transferred in various ways and between objects.</p>	<p><i>Areas that individual students may need one-on-one support with:</i></p> <ul style="list-style-type: none"> Reviewing content regarding how energy is transferred. Reviewing documentation protocols. 	<p>In Final Reflection</p> <ul style="list-style-type: none"> Student identifies 3 energy transfers, but only explains 1. Student explains 3 energy transfers, but does not identify where they took place in the Rube Goldberg machine. 	<p>In Final Reflection</p> <ul style="list-style-type: none"> Student identifies and explains at least 3 energy transfers accurately. 	<p><i>Areas where students may exceed:</i></p> <ul style="list-style-type: none"> Student identifies and explains 4 or more energy transfers. <p><i>Ideas for next steps for growth:</i></p> <ul style="list-style-type: none"> Explore more examples of different types of potential and kinetic energy



Engineering Lesson: Energy Madness 6-8th Grade

Standard and Topic	Below Standard	Approaching Standard	Meeting Standard	Above Standard
<p>(MS-ETS1-2) Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.</p>	<p><i>Areas that individual students may need one-on-one support with:</i> In the Final Reflection</p> <ul style="list-style-type: none"> Applying criteria and constraints as an evaluation techniques. Comparing ideas. 	<p>In the Final Reflection</p> <ul style="list-style-type: none"> Student uses criteria and constraints to evaluate 1 design solution. Student identifies failure points and optimization OR trade-offs when evaluating design choices. 	<p>In the Final Reflection</p> <ul style="list-style-type: none"> Student uses criteria and constraints to evaluate 2 or more design solutions. Student addresses failure points, optimization, and trade-offs when evaluating design choices. 	<p><i>Areas where students may exceed:</i></p> <ul style="list-style-type: none"> Evaluations go into more detail on specific points and make connections between multiple designs. Students use criteria and constraints to evaluate 3 or more design solutions. <p><i>Ideas for next steps for growth:</i></p> <ul style="list-style-type: none"> Students collect and display information using a variety of methods (charts, written, graphs, use of technology).
<p>SEP 6 (MS) Constructing Explanations and Designing Solutions Optimize performance of a design by prioritizing criteria, making tradeoffs, testing, revising, and re-testing.</p>	<p><i>Areas that individual students may need one-on-one support with:</i></p> <ul style="list-style-type: none"> Optimizing a design. Using criteria and constraints as evaluation tools. Making observations during testing. 	<ul style="list-style-type: none"> Student can explain what optimization or trade-offs are, but cannot apply the concepts to their design. Student includes some of the class developed design criteria. When reflecting, student suggests revisions without giving observations to support them. 	<ul style="list-style-type: none"> Student applies the concepts optimization and trade-offs to their design within their reflection. Student addresses all design criteria and considers tradeoffs to increase success of the machine. When reflecting, student suggests revisions based on observations during testing. 	<p><i>Areas where students may exceed:</i></p> <ul style="list-style-type: none"> Student optimizes design by using fewer materials through iteration and by making tradeoffs. <p><i>Ideas for next steps for growth:</i></p> <ul style="list-style-type: none"> Students defines more rigorous criteria to apply to their design.



Standard and Topic	Below Standard	Approaching Standard	Meeting Standard	Above Standard
<p><u>CCC 5 (MS) Energy and Matter: Flows, Cycles, and Conservation</u> The transfer of energy can be tracked as energy flows through a designed or natural system.</p>	<p><i>Areas that individual students may need one-on-one support with:</i></p> <ul style="list-style-type: none"> • Reviewing types of energy transfer. • Reviewing types of energy. <ul style="list-style-type: none"> • Reviewing documentation of ideas in written and visual formats. 	<ul style="list-style-type: none"> • Student team creates a design diagram that shows energy transferring through the Rube Goldberg machine. • Student addresses energy flow through the Rube Goldberg machine in a Prototype Diagram or the Final Reflection. • Student uses the terms: kinetic or potential energy with some accuracy or can accurately identify when potential and kinetic energy occur during performance with prompting. 	<ul style="list-style-type: none"> • Student team creates a design diagram showing the transfer of energy through the entire Rube Goldberg machine. • Student addresses how energy flows through Rube Goldberg machines in their Prototype Diagrams and Final Reflection. • Student uses the terms kinetic and potential energy accurately in their final reflection. 	<p><i>Areas where students may exceed:</i></p> <ul style="list-style-type: none"> • Student uses terms: elastic, gravitational, sound, and motion in their written work. <p><i>Ideas for next steps for growth:</i></p> <ul style="list-style-type: none"> • Learn and document about how energy flows through a system found in the real-world.