Everyday Encounters with Science

Smooth Travels

Program Type: Classroom Program	**Audience Type:** Grades 3–8

Description: Students design an accessible path that will allow for the slowest, safest route possible down a mountain.

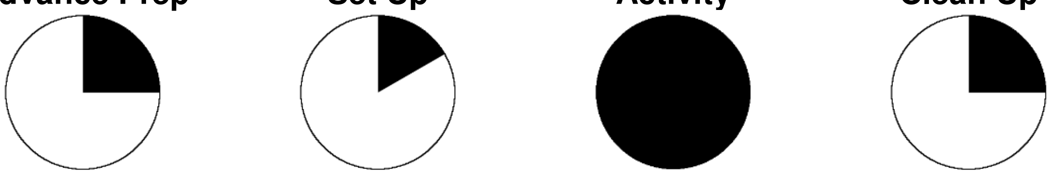
LEARNING OBJECTIVES

For Next Generation Science Standards alignment, see end of outline.

- Students will design a ramp to decrease the speed of a rolling object
- Students will test and improve their design route to achieve the slowest speed possible

TIME REQUIRED

Advance Prep	Set Up	Activity	Clean Up



15 minutes	10 minutes	60 minutes	15 minutes

SITE REQUIREMENTS

- Standard size classroom
- Tables or grouped desks with chairs for each student, or a large floor space with room for all students to sit and work in groups of 3–4

PROGRAM FORMAT

Segment	Format	Time
Introduction	Large group discussion	10 min
Design, Test, Improve	Group activity	45 min
Wrap-Up	Large group discussion	5 min

SUPPLIES

Supplies	Amount	Notes
Choose a base: pegboard, foam board, or cardboard 24”x18” or larger	1/group	Pegboard can be found at hardware stores and cut to size **See “Note on Supplies” below*
Materials to secure ramp to about a 60^o angle from the table or floor (see diagram in “Set Up”)		Wooden blocks and/or books can be used to prop up pegboard
String	8 ft./group	For prototyping paths
Scissors	1/group	
Container	1/group	For holding building supplies
Small bouncy ball	1/group	
Small paper viewpoint signs	1/group	*(Optional)* See *Advance Prep* and *Appendix*
Photos of switchbacks		Photos in *Background Information* section
Stopwatch	1/group	*(Optional)* For Extension activity
Blank paper or notebook	1/group	*(Optional)* For Extension activity. To record times for different iterations
Ping pong balls	1/group	*(Optional)* For Extension activity
Marbles	1/group	*(Optional)* For Extension activity
Golf balls	1/group	*(Optional)* For Extension activity

Note on Supplies: The supplies for the base are flexible. If the activity will be done often with multiple groups, using pegboard as a base is recommended. If this activity is used less frequently, cardboard or foam board is cheaper. If using pegboard, you will find large 4’x8’ sheets at your local hardware store. Often, store employees are able to cut it on-site. To make things easy, cut the sheet once the long way, to make two long strips, each 24” wide. Then cut each strip into five pieces approximately 19” wide, for a total of 10 pieces. **You can reuse the same pieces of pegboard for Energetic Ocean, another engineering activity in the Designing Our World curriculum.**

Suggested Building Materials:
Common classroom supplies and recyclables can be used as building materials in this activity. Listed below are a few suggestions.

- Golf tees
- Wooden craft sticks
- Rubber bands
- Brads
- Rulers
- Binder clips
- K'NEX®
- Toilet paper/paper towel rolls
- Pipe cleaners
- Pencils (to poke holes)
- Twist ties
- Straws
- String or yarn
- Toothpicks
- Cardstock
- Craft foam

ADVANCE PREPARATION

- Collect all materials
- Cut pipe cleaners in half
- Cut string or yarn into 8-ft. lengths for each group
- *(Optional)* Print and cut out "Viewpoint" signs (see Appendix).

SET UP

- Assemble an assortment of ramp-building supplies in a container for each group.
- Set a ramp base at an angle of about 45-60° at each table. The exact angle is not important, but all ramps should be at the same angle. See Figure 1.
- *(Optional)* Attach one "Viewpoint" sign to the top corner of each ramp, using tape, a binder clip, or similar.

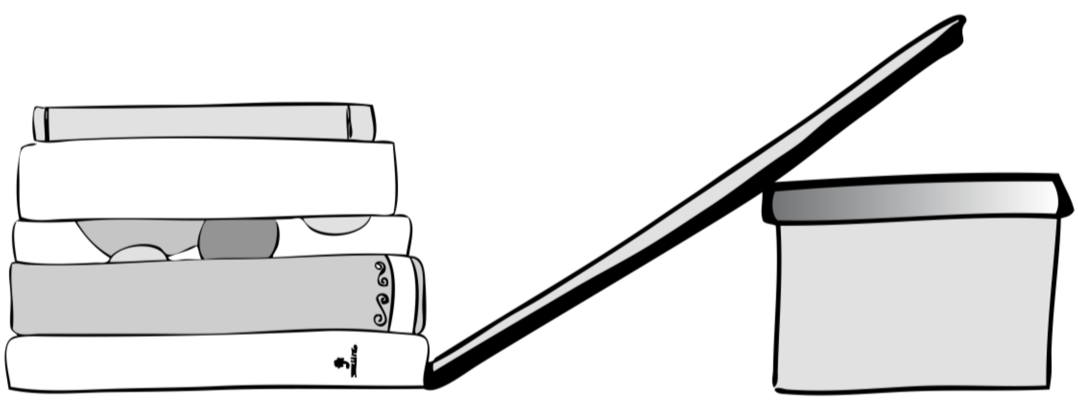


Figure 1: Ramp setup, propped up by common household items.

INTRODUCTION

10 minutes

Let students speculate before offering answers to any questions. The answers given are provided primarily for the instructor's benefit.

Ask the students the following questions in **bold**.
Suggested script is shaded. Possible answers are shown in *italics*.

Imagine a time that you went up or down a steep hill or mountain. Maybe you were riding your bike, hiking, or in a car. What did you notice about these roads or paths?

Allow students to tell some short stories about their experiences. The goal is to determine the types of roads and/or paths that engineers design to traverse steep slopes. The back and forth zigzag pattern is known as a switchback.

Why do you think steep paths are designed differently than straight, flat paths?

Facilitate a short discussion about some of the benefits of zigzags, switchbacks, or long, windy paths for going down steep inclines. The primary goal of these designs is to decrease the amount of slope, which makes climbing easier, prevents users from going too fast downwards, and prevents erosion. See the *Background Information* section in this outline for more detailed information.

Today, our engineering firm has been asked to design a safe path that people in wheelchairs can use to get to a viewpoint that only hikers can access. How would we do that? What characteristics will this path need to have?

Have students "pair-share" ideas for a minute. They may suggest lowering the inclined plane to decrease the slope. Tell them this change is not an option because it would mean tearing down the whole mountain.

GROUP ACTIVITY

Design, Test, Improve

45 minutes

Split students into groups of 3–5 and pass out the 8-ft. lengths of string or yarn to each group.

Our first step is planning! Now is the time for your group to start talking about what your ramp will look like. Use the string to plan a path down the mountain. Using more string to get from the top to the bottom means you are creating a longer path, which will be less steep for people in wheelchairs. Try out a few different paths with your group.

Give groups 3–5 minutes to experiment with the string. Encourage students to try different paths and encourage switchbacks. For groups that are struggling, suggest specific points of entry and exit on opposite sides of the base.

Pass out the building materials to each group.

Start talking with your team and come up with a plan for your wheelchair ramp to get up and down the mountain. When you've come to an agreement on the design plan, you can start building. Remember to test early and test often! The ball must roll all the way to the bottom in order for your path to work- it can't get stuck!

See Figure 2 for a visual illustration of what a ramp might look like.

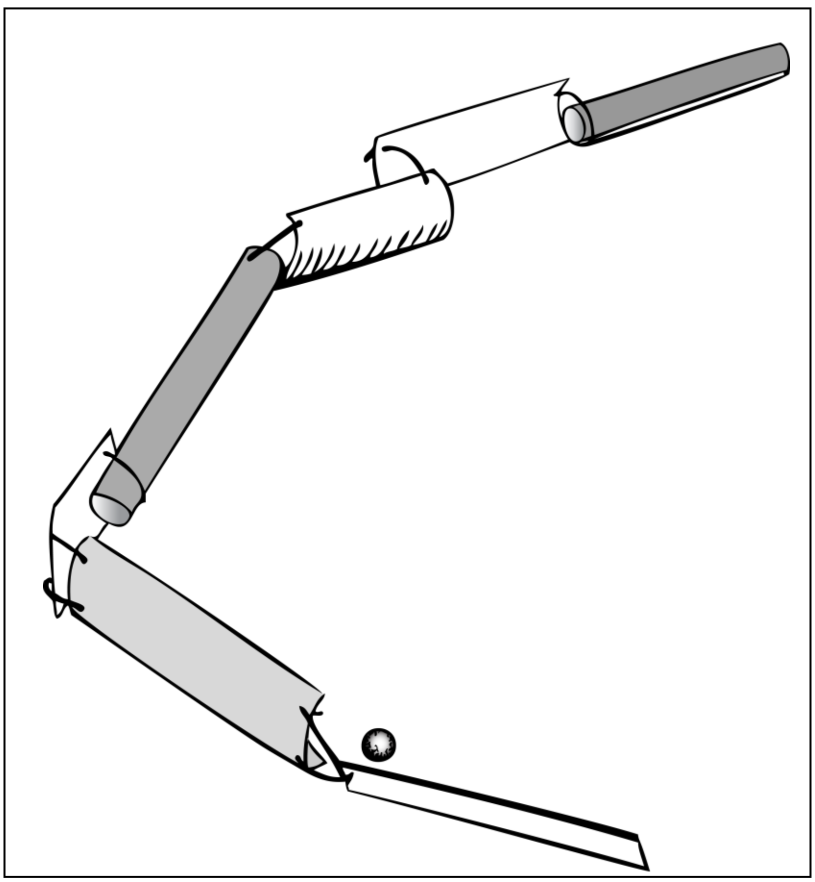


Figure 2: An example ramp.

After about 10 minutes, when groups have made ramps that are at least halfway complete, do a "hands-off" trial run (students can't interfere with ball) with a facilitator.

You may wish to use a stopwatch to time the ball as it rolls down their path. Have students test their prototype ramps. Be consistent with the number of trials each team gets, how and where they release the ball, and when you start and stop the stopwatch.

Have all groups watch as each test occurs. Encourage struggling groups to look for ideas on how to improve their design.

If time allows, have all students watch each group's trial runs in order to get additional ideas for their own designs. Encourage the group to discuss what they need to improve or change as they continue building. Students should aim to have many rounds of iteration, including several "hands-off" trials.

Younger or inexperienced students may need some hints on how to use the building materials to create pathways. Encourage them to think about the wheelchair-accessible ramps they have seen in malls, parks, and restaurants, to look at other groups, and to remember the path they planned with string.

WRAP-UP

5 minutes

Ask for student observations. There is no correct answer. Let students guide the discussion and present their hypotheses before discussing explanations.

Tell us about your design.
Be ready to dig deeper by asking specific questions about the number of switchbacks they created or how they decided on a specific design. Now is also a good time to talk about how the students used the materials.

What would you have done if you had more time to work on your path?
Answers will vary from adding more paths to fixing parts that didn't work during testing. Groups testing later in the order may reference other teams' designs. Use this opportunity to talk about how engineers share their designs.

What made your designs more or less successful?
Answers will vary depending on your class' designs.

CLEAN UP

- Ask the groups to disassemble their design, return all usable materials to their containers, and recycle or throw away any trash

OPTIONAL EXTENSIONS

- **Measurement**
  Was the group with the longest time really the group that had the slowest ball? Maybe, but not necessarily. We did not measure the speed of the ball—just how long it could stay on the pegboard. To see which group actually had the slowest average velocity for their ball, have students measure the length of the path the ball followed on its way down the slope using strings and rulers. Divide the distance by the amount of time to determine the average velocity of their ball.

  Speed (velocity) = distance ÷ time

  For added challenge, convert to meters per second, feet per minute, miles per hour, or any other unit.

- **Multi-use**
  Add the criteria that several different types of balls must be able to travel down their designed path. Balls of the same size will be easy; balls of different sizes will be more challenging. Try adding a marble, a golf ball, or a ping-pong ball. These balls may represent different types of wheelchairs.

- **Math Extension**
  Use the pegboard to simulate a coordinate graph and have students create a map of their pathway. They can determine the slope of each pathway on the board as well. Advanced students can determine what the slope is when the board is then placed at an angle. Make a graph of the teams' times versus the length of their paths.

BACKGROUND INFORMATION

Often, engineers work to make things faster. However, there are also times when they wish to design a system that makes things move more slowly or more easily. One such situation is when designing roads to ascend and descend a steep slope. Too steep, and the road will be exhaustingly slow on the way up—and dangerously fast on the way down!

People who design roadways are typically known as civil engineers. Nearly all roadways have some degree of slope, and engineers must pay careful attention to make sure it's safe to go up and down. By creating switchback patterns, engineers decrease the slope of a roadway, making it easier to climb and safer to descend. However, civil engineers must balance cost and safety, designing their paths to be effective with the least amount of resources. Users will complain if roadways are too long and winding, slowing them down far more than necessary.

Engineers keep the same principles in mind when designing paths for wheelchair users. Buildings, parks, and other public spaces often use ramps with switchbacks to make paths and entryways accessible to all users.

Figure 3: A wheelchair-accessible trail allows all visitors to safely explore Mammoth Caves National Park in Kentucky. (Image: National Park Service).

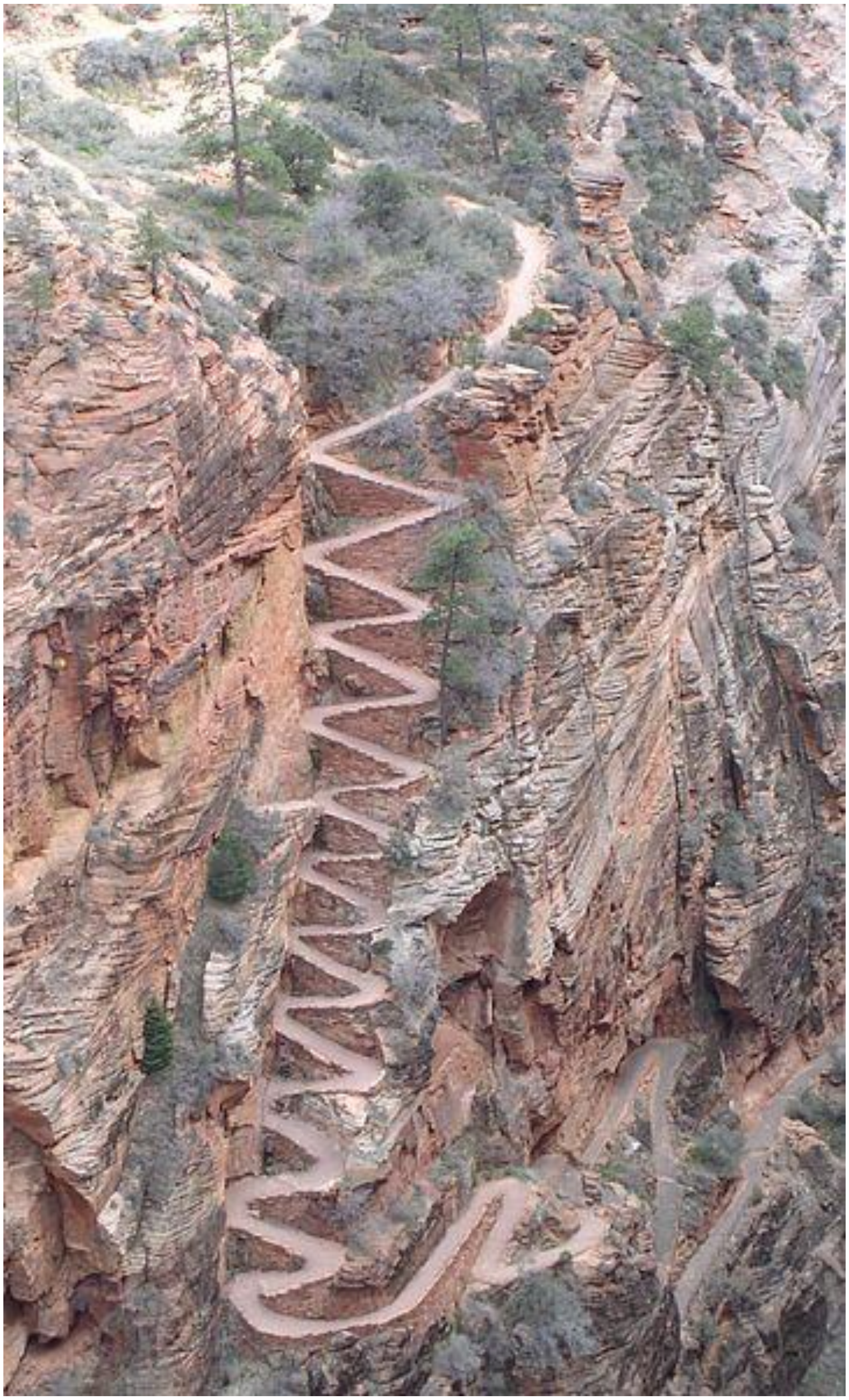


Figure 4: An impressive series of switchbacks allows hikers to safely ascend and descend a steep rock face on the West Rim Trail in Zion National Park. (Image: National Park Service).

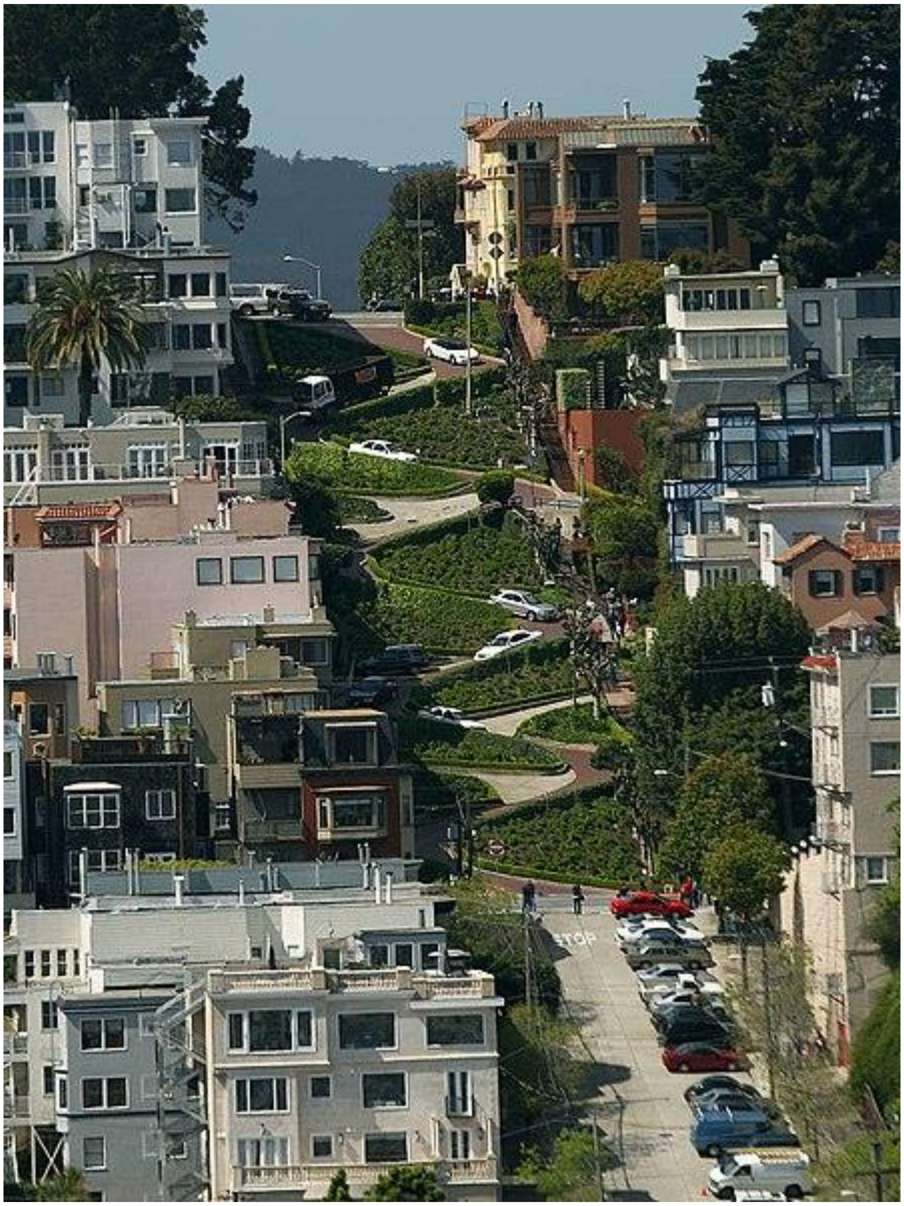


Figure 5: Lombard Street in San Francisco utilizes sharp switchbacks to make a steep hill accessible to cars. (Photo: Wikimedia Commons).

GLOSSARY

Slope	A measurement of change in height divided by distance traveled.
Switchback	A method of switching direction at certain intervals when climbing a slope to make ascension and descension safer and easier.

NEXT GENERATION SCIENCE STANDARDS

	Practices
✓	Asking questions and defining problems
✓	Developing and using models
✓	Planning and carrying out investigations
	Analyzing and interpreting data
	Using mathematics and computational thinking
✓	Constructing explanations and designing solutions
	Engaging in argument from evidence
✓	Obtaining, evaluating, and communicating information

	Crosscutting Concepts
✓	Patterns
✓	Cause and effect
	Scale, proportion, and quantity
	Systems and system models
✓	Energy and matter
	Structure and function
	Stability and change

	Disciplinary Core Idea	**3**	**4**	**5**	**MS**
	Physical Science				
PS1	Matter and Its Interaction	n/a	n/a		✓
PS2	Motion and Stability: Forces and Interactions	✓	n/a	✓	✓
PS3	Energy	n/a	✓		✓
PS4	Waves and Their Applications in Technologies for Information Transfer	n/a		n/a	
	Life Science				
LS1	From molecules to organisms: Structures and processes				
LS2	Ecosystems: Interactions, Energy, and Dynamics		n/a		
LS3	Heredity: Inheritance and Variation of Traits		n/a	n/a	
LS4	Biological Evolution: Unity and Diversity		n/a	n/a	

Earth & Space Science					
ESS1	Earth's Place in the Universe	n/a			
ESS2	Earth's Systems				
ESS3	Earth and Human Activity				
Engineering, Technology, and Applications of Science					
ETS1	Engineering Design	✓	✓	✓	✓

DCI Grade Band Endpoints
3-5 ETS1.A: Defining and Delimiting Engineering Problems
- Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria). Different proposals for solutions can be compared on the basis of how well each one meets the specified criteria for success or how well each takes the constraints into account. (By the end of Grade 5)

3-5 ETS1.B: Developing Possible Solutions
- Research on a problem should be carried out before beginning to design a solution. Testing a solution involves investigating how well it performs under a range of likely conditions. (By the end of Grade 5)
- At whatever stage, communicating with peers about proposed solutions is an important part of the design process, and shared ideas can lead to improved designs. (By the end of Grade 5)
- Tests are often designed to identify failure points or difficulties, which suggest the elements of the design that need to be improved. (By the end of Grade 5)

3-5 ETS1.C: Optimizing the Design Solution
- Different solutions need to be tested in order to determine which of them best solves the problem, given the criteria and the constraints. (By the end of Grade 5)

MS ETS1.A: Defining and Delimiting Engineering Problems
- The more precisely a design task’s criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions. (By the end of Grade 8)

MS ETS1.B: Developing Possible Solutions
- A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. (By the end of Grade 8)
- There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (By the end of Grade 8)
- Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. (By the end of Grade 8)
- Models of all kinds are important for testing solutions. (By the end of Grade 8)

MS ETS1.C: Optimizing the Design Solution

- Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design. (By the end of Grade 8)
- The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution. (By the end of Grade 8)

3-5 PS2.A: Forces and Motion

- Each force acts on one particular object and has both strength and a direction. An object at rest typically has multiple forces acting on it, but they add to give zero net force on the object. Forces that do not sum to zero can cause changes in the object's speed or direction of motion. (By the end of Grade 8)
- The patterns of an object's motion in various situations can be observed and measured; when that past motion exhibits a regular pattern, future motion can be predicted from it. (Boundary: Technical terms, such as magnitude, velocity, momentum, and vector quantity, are not introduced at this level, but the concept that some quantities need both size and direction to be described is developed.) (By the end of Grade 5)

MS PS2.A: Forces and Motion

- The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion. (By the end of Grade 8)

Performance Expectation

3-5-ETS1-1	Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
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.
3-5-ETS1-3	Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.
MS-ETS1-1	Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
MS-ETS1-2	Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
MS-ETS1-3	Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that

	can be combined into a new solution to better meet the criteria for success.
MS-ETS1-4	Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.
3-PS2-1	Plan and conduct an investigation to provide evidence of the effects of balanced and unbalanced forces on the motion of an object.
3-PS2-2	Make observations and/or measurements of an object's motion to provide evidence that a pattern can be used to predict future motion.
4-PS3-1	Use evidence to construct an explanation relating the speed of an object to the energy of that object.
MS-PS2-2	Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.
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.

Smooth Travels
Appendix


VIEWPOINT

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FACILITATION GUIDE

Smooth Travels

Description: Students design an accessible path that will allow for the slowest, safest route possible down a mountain.

Promoting collaboration and organization

- During the introductory discussion, have students “pair-share” with a neighbor before the large group discussion. Doing so will ensure that all students share their ideas in some way.
- Allow each team member to use the long string to show his or her proposed plan for the path down the mountain.
- You may choose to create a “budget” for materials and give teams an allowance. This will teach students about planning wisely and reducing waste of materials.
- Consider assigning roles for collaborative groups. Possible roles can include group leader, recorder, materials manager, timekeeper, and ambassador.

Encouraging iteration

- Remind students that the “wheelchair” must go down at a slow and safe speed. Is there anything they can do to slow the ball down even more? How can you make your path even longer?
- Iteration means taking things apart sometimes! It’s okay to alter parts of your ramp if your group has a better idea.
- Remind students about the purpose of this challenge: “Is your path safe and smooth for the person in the wheelchair? How can you make it more comfortable?”
- Test early and often! Encourage groups to test every few minutes to make sure their path is working.

Helping those who are stuck

- Show pictures of switchback roads and ask students about what they notice.
- Encourage students to visit each group and see if they can gather more ideas for building ramps.
- Do a test run with the group and discuss each point where the ball falls or gets stuck. Ask specific questions to work toward a solution:
  - What could you do to widen this ramp so the ball won’t fall?
  - Are there other building materials that may work better/be stronger?
  - Where does the ball lose control? How can you reinforce the ramp here?

Real-world applications

- On real wheelchair ramps, engineers have to make the ramp no more than a five-degree incline so that it’s safe for people in wheelchairs to go up and down. That means for every twelve inches of length the ramp can only go up one inch.
- In 2017, the project “Pompeii for All: Accessibility Paths Overcoming Architectural Barriers” was launched. This path made Pompeii, a unique World Heritage site, accessible to all visitors, and is considered to be the longest barrier-free accessible path in Italy.