Lesson Activity

Title	**Design a Roller Coaster (2 sessions, 60-80 minutes)**
ID Number	MS-S-C2
Sequence and Duration	Session 1: Background and Planning • Lead In: 30-40 minutes • Activity: 20-30 minutes Session 2: Building and Testing • Activity: 40-45 minutes • Closure: 20-30 minutes
Age Level	Middle School
Essential Question	**What affect do Newton's Laws and the Law of Conservation of Energy have on the motion of roller coasters?**
Learning Objectives	• TSW use the Law of Conservation of Energy to explain the layout of a roller coaster. • TSW explain how a roller coaster works in terms of physics concepts. • TSW design and build a roller coaster that fits within the given specifications. • TSW identify and explain the features of their roller coaster and describe how it works.
Other Objectives	• TSW develop a working plan with their group to develop a cooperative environment. • TSW communicate with their group by contributing their vocal input. • TSW write down the procedure they used to design their project.
Key Terms	• Gravity • Potential energy • Kinetic energy • Law of Conservation of Energy • Newton's 1st Law • Newton's 2nd Law • Acceleration • Velocity • Inertia • Centripetal force • Thrill elements
Materials Needed	For Group: • Box of assorted materials for building, such as: popsicle sticks, pipe cleaner, oak tag, paper towel rolls, empty 2-liter bottles, plastic tubes, scissors, glue, tape • Roller coaster kit (optional; can check out from EAO) Per Student: • Handout: MESA Notebook Per Team: • Handout: Design a Roller Coaster Competition • Handout: "Roller Coaster Run" MESA Day Event Specifications • Drawing paper • Colored pencils • Meter stick • Stopwatch • Marble

Session 1	Background and Planning
Lead In	1. Ask students about their experiences with roller coasters. How many of them have ever ridden one? Who loves roller coasters; who hates them? Why? What is it about roller coasters that makes them fun/scary? Allow time for students to relate their experiences and discuss roller coaster elements they have seen or heard about that they find especially exciting or frightening. 2. Ask students if they know what makes a roller coaster work. Guide students to an understanding that roller coasters are powered by *gravity*. Make sure students have a solid understanding of gravity: the force of attraction between two masses; on Earth, the force that pulls objects toward the center of the Earth. Write this term on the board and have students write it and define it in their MESA Notebooks. 3. Ask students if they can think about what all roller coasters have in common at the beginning of the ride. [They are pulled up to the top of a big hill to start the ride; this hill is the biggest hill on the track.] Why do all roller coasters start this way? What does this do? [Going to the top of the hill provides the roller coaster with enough *potential energy* to complete the rest of the track.] Ask students if they've ever learned about potential energy before, and if they can think of any examples (batteries store energy; energy is stored in springs when you compress them; energy is stored in a bow's string when you pull it back, etc.). When an object has potential energy, it has the *potential* to do something. In the case of something at the top of a hill, it has the potential to come down the hill. The higher up it is, the more potential energy it has. Have students think about whether they'd rather drop a penny into their hand from two feet up, or from 200 feet up! The penny at the greater height would have more potential energy, so it could *potentially* hurt you when it hit your hand. Have students write and define the term in their MESA Notebooks. Example definition: stored energy. In the case of roller coasters, they have the potential to fall toward the ground when they are at the top of the hill. How much potential energy the roller coaster has depends on how high it is lifted at the beginning of the ride. 4. Ask students what happens once the coaster is let go at the top of the hill [it rolls faster and faster down the hill]. When the roller coaster starts moving, the potential energy is converted into *kinetic energy*, the energy associated with motion. Have students write this term in their Notebooks and define it in their own words. Ask students to give example of objects that have kinetic energy (e.g. a moving car, a running person, a river, the wind, a watch hand, etc.). What would they expect has more kinetic energy, something moving fast or something moving slow? (something moving fast) The faster something is moving, the more kinetic energy it has. Also, the more massive something is, the more kinetic energy it has. Which would case more damage, a mouse running into a wall or a car running into a wall? The car is more massive so would cause more damage, even if it and the mouse were moving at the same speed. 5. Ask, "Why do they call them 'roller coasters'? What does it mean to *coast*?" Guide students to an understanding that all the energy for the ride comes from the potential energy of being at the top of the first hill, and that the coaster uses this energy to coast along the rest of the track. [Note: There are some roller coasters that use other sources of power at certain points of the ride, but true roller coasters simply coast the whole way.] 6. Ask if anyone has heard of the Law of Conservation of Energy [energy cannot be created or destroyed; it can only be transformed (changed from one type to another) or transferred (exchanged between objects)]. Have students discuss this concept until they can define it in their own words in their MESA Notebooks. Ask, "How does the Law of Conservation of Energy apply to roller

coasters?" [The roller coaster's potential energy from being at the top of the first hill is transformed into kinetic energy as it falls down the hill; the energy is often transformed multiple times as the roller coaster goes over additional hills and loops.]

7. Ask, "Why does the first hill have to be the tallest? Why can't there be any taller hills later?" [There isn't sufficient energy in the system for the coaster to climb a taller hill.] "Why can't there be any hills just as tall as the first one later in the ride?" [Even though the coaster begins with enough energy to climb a hill equally tall as the first one, the system constantly loses energy to *friction*. Friction of the wheels on the tracks, as well as friction from air resistance, causes some energy to be converted to heat, which then escapes. Make sure students understand that the energy is lost to the *system*, not the Universe! Energy is still being conserved.] Make sure students can define friction, and write this in their Notebooks. Example definition: the force of rubbing between two objects that works against motion.
8. Ask students to think about what they've learned about objects in motion (Newton's Laws from previous lesson on Newton scooters). Have students discuss Newton's Laws of motion as they relate to roller coasters. Newton's 2nd Law states that force equals mass times acceleration, or acceleration equals force over mass. Make sure that students are able to explain this in their own words: the greater the force on the object, the more it will accelerate; the more massive the object, the smaller the change in acceleration for a given force. Ask, "What does it mean to *accelerate*?" [to experience a change in velocity] "What is *velocity* (or speed)?" [how fast an object is going] "What are some ways that velocity can change?" [it can increase (go faster), decrease (go slower, or *decelerate*), or change direction] Have students write these terms in their Notebooks.
9. Have students talk about what it *feels* like to accelerate. Tell students that they've all experienced the different types of acceleration when they've ridden in a car. What happens to your body when the car speeds up? [your body goes backward] When the car slows down? [your body goes forward] When the car changes direction, like going around a turn? [your body moves in the opposite direction] What makes your body do these things when the car accelerates? [your inertia] Make sure students write *inertia* in their Notebooks and can describe it in their own words: a tendency to keep doing what you're doing, or a tendency to continue moving at a constant velocity (even if that velocity is zero). Remind students that this is Newton's 1st Law.
10. Explain that it is inertia that keeps people from falling out of the roller coaster when it goes through a loop. Your body wants to keep moving in a straight line, regardless of what the roller coaster is doing. When you get to the top of the loop, both you and the roller coaster want to keep going in a straight line headed away from the track, but the track pushes against the roller coaster to keep it in the loop, and the roller coaster pushes against you! This push is toward the center of the loop, and is called the *centripetal force*. The centripetal force is what keeps objects moving in a circle instead of continuing off on a straight line. Students can play with centripetal force by swinging objects *carefully* around their heads on a piece of string, or you can demonstrate this motion for the class. What is providing the centripetal force? [the string and your hand] Ask students to predict what will happen if you let go of the string – will the object keep moving in a circle? (It is a common misconception among students that it will.) Demonstrate that the object does indeed continue moving in a straight line when the centripetal force toward the center of the circle is no longer acting on it. Have students write *centripetal force* in their Notebooks and ensure that they understand it by describing it in their own words.

	11. Loops and other parts of the roller coaster ride that are especially exciting are called *thrill elements*, and they include hills (where the roller coaster slows down going up and speeds up coming down), turns (where the roller coaster changes direction), and loops (where it changes in speed and direction!). Have students think about thrill elements they've experienced or seen on roller coasters, and what makes them thrilling. They will find that many of these thrill elements are thrilling because they involve acceleration. The feeling of your body's inertia reacting to the acceleration of the roller coaster cart is what makes roller coasters so exciting (and scary!).
Activity	1. Tell students that their mission is to design a roller coaster for a marble "rider" that satisfies the specs on the handout they will receive. Their roller coasters must have at least two thrill elements and must safely deliver the marble to the end of the track after a ride of 10-25 seconds. 2. Hand out the Design a Roller Coaster instructions and the drawing paper and colored pencils. Tell them they have the rest of the session to come up with their design and to try out different things using the materials available in class. The marble will be provided and the classroom materials will be available, but they must bring any other objects they might need from home to build their final roller coaster designs. [Note: Strips of oak tag work well as a cheap material for prototyping designs.] 3. Write the following questions on the board: What thrill elements will your coaster have? How will you control the length of the marble's ride? How can you minimize friction so the marble has enough energy to finish the ride? How will you make sure the marble completes the ride safely? How will you get your marble to a complete stop at the end? 4. Monitor and check student progress. Before students begin building, make sure their concept drawing addresses competition rules and specifications. Make sure their materials are reasonable things they can easily get from home or the classroom. 5. Have students identify on their drawings where the roller coaster will experience maximum potential energy (at the top of the first hill) and where it will experience maximum kinetic energy (at the bottom of the first hill). Have them identify where the coaster experiences a centripetal force, and the direction of that force (centripetal force comes into play whenever the roller coaster travels on a curve, and the force points toward what would be the center if the curve were a complete circle). 6. During the last 5 minutes of project time, tell teams to assign materials. Who is going to bring materials for the next meeting? (You may want to follow up this meeting with an email to all MESA students reminding them to bring their materials for the next meeting.)
Session 2	**Building and Testing**
Activity	1. Have students get with their teams and get out their designs and the materials they brought from home. Tell teams that they can use the classroom supplies as well. 2. Give them 5 minutes to gather their supplies and to go through your supplies. 3. After 5 minutes, ask teams if they need to modify their drawings based on their supplies. If they do, they may do so now. Pass out colored pencils to the teams that need to modify their design. 4. Tell teams they have 25-40 minutes to build their roller coasters. Advise them to work together in their teams and to ask for help if they need it or if they have questions. 5. Monitor student progress and check to make sure their construction follows their design concept and the competition specs closely. 6. When teams begin to wrap up their construction, encourage them to test their designs and make modifications as necessary.

	7. When time is up, have students clean their areas and bring their roller coasters to a common area.
Closure	1. When all students have had a chance to finish building and testing their designs, allow each team an opportunity to demonstrate their coaster and explain their design for the whole class. Have the rest of the class point out ways each team satisfied the specs and how the team's creativity came through. 2. Review the ways the physics concepts discussed the previous week affected the roller coasters. Revisit the questions on the board from last week and ask the students to talk about how they answered those questions with their designs. 3. Make sure students can apply the concepts they've copied into their MESA Notebooks to their experience with their roller coasters. 4. Tell students they have the remainder of the time to complete the MESA Notebook. They may work with their team. Write the following 'conclusion' questions on the board and tell them to answer them using what they have learned from the activity: • *How do Newton's laws of motion affect the motion of roller coasters?* • *How does the Law of Conservation of Energy apply to roller coaster design?* • *How does friction affect roller coasters? How can friction be reduced?* • *If you could do this activity again, what changes would you make to your roller coaster to make it better?* 5. Monitor their progress. 6. Students may complete their MESA Notebook at home. 7. Optional extension: Explain that for the MESA Day competition, the roller coaster will need to have a theme. What themes could work for a roller coaster design?
Informal Assessment	13. Monitor students as they progress through the project. 14. Monitor students to check for understanding periodically. 15. Informal Oral Presentation of team design and roller coaster.
Formal Assessment	• Completed roller coaster design. • Completed roller coaster. • Completed MESA Notebook.
Trouble Shooting	• Use visuals and manipulatives to demonstrate concepts in Session 1 as much as possible. You can use a toy car track or model roller coaster to point out concepts such as potential energy, kinetic energy, acceleration, and friction. You can also fashion your own roller coaster design, but be wary of the possibility that students might mimic your design rather than come up with an original design and construction technique. • Consider having students build roller coaster prototypes with cheaper materials, such as strips of oak tag, to test out their ideas about how the marble will move, prior to building with more expensive or harder to come by materials. • Encourage students to be creative in their design and choice of materials. Each roller coaster should be unique!

SEI Strategies Used

Preparation	Scaffolding	Grouping Options
☐ Adaptation of Content	☐ Modeling	☒ Whole class
☒ Links to Background	☐ Guided practice	☒ Small groups
☒ Links to Past Learning	☒ Independent practice	☐ Partners
☒ Strategies incorporated	☒ Comprehensible input	☐ Independent

Integration of Processes	Application	Assessment
☐ Reading	☒ Hands-on	☐ Individual
☒ Writing	☒ Meaningful	☒ Group
☒ Speaking	☒ Linked to objectives	☒ Written
☒ Listening	☒ Promotes engagement	☒ Oral

Arizona Math Standards Addressed	(none)
Arizona Science Standards Addressed	• S5C2: TSW understand the relationship between force and motion by explaining how Newton's laws apply to objects in motion. • S5C3: TSW understand that energy can be stored and transferred.

Team Members:____

Design a Roller Coaster Competition

Goal:

Your mission is to design a roller coaster that satisfies the specifications below. In teams of three or four, you will first draw your design on paper. If you are not sure if something will work, try it out with materials like paper, cardstock and masking tape. Once you have a final design, have your advisor approve it and you can start building with materials of your choosing. Choose your materials wisely, and BE CREATIVE!

Roller Coaster Specifications:

- Fit within a 70x70x70 cm^3 space and weigh no more than 10 kg
- Have at least 2 thrill elements
- Keep contact with the marble at all times
- Consist of a ride of 10 – 25 seconds, more points for longer rides without going over
- Get the marble to a complete stop at the end

Treat the marble like a car full of people – make sure it reaches the end of the track safely! Don't allow the marble to do anything that roller coaster designers wouldn't allow with people: no flying through the air, crashing, etc.

Team Materials:

Design Drawing

- Drawing paper
- Colored Pencils

Roller Coaster

- One marble (provided by advisor)
- Meter stick
- Stopwatch
- Any other materials decided upon by each team

Instructions:

Day 1:

1. Design your roller coaster with your team.
2. Draw your design on the drawing paper provided by your advisor. Use colored pencils.
3. Your drawing must show what types of materials are being used in your design.
4. Identify on your drawing the place where the roller coaster will experience the maximum potential energy.
5. Identify on your drawing the place where the roller coaster will experience the maximum kinetic energy.
6. Identify on your drawing any place where the roller coaster experiences a centripetal force, and draw an arrow indicating the direction of that force.
7. If there are any components you want to test out before you prepare your final design, take some time to use the materials set out by your instructor to construct a model to test.
8. Have your advisor approve your design before you build your final design.
9. Be creative!

Day 2:

a. Check to make sure your team has all the materials needed for your roller coaster. If not, you need to modify your drawing.
b. Build your roller coaster with your team.
c. Test your roller coaster with any remaining time.