Lesson Plan: Roller Coaster Physics - The Thrill of STEM

Materials Needed:

- Cardboard tubes (from paper towels or wrapping paper), cut in half lengthwise to make tracks
- A few marbles
- Masking tape or painter's tape
- Scissors
- A collection of sturdy household objects to act as supports (e.g., books, boxes, cans)
- A large, flat surface to build on (e.g., a table, the floor against a wall)
- A stopwatch (a phone app works perfectly)
- A flexible measuring tape or ruler
- A notebook and pen/pencil for observations and calculations
- A device to watch a short online video

Lesson Details

Subject: STEM (Science, Technology, Engineering, Math)

Grade Level: 10th Grade (approx. 16 years old)

Time Allotment: 90 minutes

1. Learning Objectives

By the end of this lesson, the student will be able to:

- **Explain** the relationship between potential and kinetic energy in the context of a roller coaster.
- **Apply** the principles of gravity, inertia, and friction to design a functional model.
- **Design and construct** a marble roller coaster with at least one hill and one loop that successfully transports a marble from start to finish.
- **Analyze and evaluate** their coaster's performance, identifying areas for improvement based on scientific principles.

2. Alignment with Standards (Example)

This lesson aligns with Next Generation Science Standards (NGSS), including:

- **HS-PS3-1:** Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known. (Focus on the conceptual model of energy transformation).
- **HS-PS2-1:** Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration. (Focus on the concepts of inertia and forces like gravity and friction).

3. Instructional Sequence & Strategies

Part 1: The Hook - What's the Secret? (10 minutes)

1. **Ask an engaging question:** "What forces make a roller coaster thrillingly fast but also keep you safely in your seat, even upside down?"
2. **Watch a video:** Find a short (2-3 minute) point-of-view (POV) video of a famous roller coaster (e.g., Fury 325, Kingda Ka). This creates immediate engagement and a real-world connection.
3. **Initial thoughts:** Briefly discuss initial reactions. What was the fastest part? What was the scariest part? How do you think it works without an engine on the train itself?

Part 2: The Science Behind the Speed - Core Concepts (15 minutes)

Introduce the key physics principles using simple analogies and quick demonstrations.

- **Potential Energy (PE) & Kinetic Energy (KE):**
  - **Explanation:** "Potential energy is stored energy, like the energy a coaster car has at the top of the first big hill. Kinetic energy is the energy of motion, which takes over as the car plummets down."
  - **Mini-Demo:** Hold a marble at shoulder height (high PE). Drop it (PE converts to KE). Ask: "Where would a real coaster need the most potential energy?" (At the very beginning/highest point).
- **Gravity:**
  - **Explanation:** "Gravity is the engine. The initial lift hill stores potential energy, and gravity does all the work from there, pulling the car down and creating speed."
- **Inertia:**
  - **Explanation:** "Inertia is an object's resistance to changing its state of motion. It's the force that pushes you back into your seat when the coaster accelerates and the reason you don't fall out during a loop."
  - **Mini-Demo:** Place a marble on a book. Move the book forward slowly; the marble stays. Now, jerk the book forward quickly; the marble stays behind. This demonstrates inertia.
- **Friction:**
  - **Explanation:** "Friction is the force that resists motion when surfaces rub together. It's the 'energy thief' that slows the coaster down. Engineers must account for it so the coaster has enough energy to finish the track."

Part 3: The Engineering Challenge - Design & Build (45 minutes)

1. **The Mission:** "Your challenge is to become a roller coaster engineer. Using the materials provided, you will design and build a roller coaster for this marble."
2. **The Rules:**
   - The coaster must have a starting point and an ending point.
   - It must include at least **one hill** (that is NOT the first drop) and **one loop or tight curve**.
   - The marble must travel the entire length of the track without falling off.
   - The first hill must be the highest point on your coaster. Why? (To ensure maximum potential energy).
3. **Build Time:** Allow the student to experiment freely. This phase is about problem-solving, testing, and redesigning. Encourage them to "fail forward" – when the marble falls off, it's not a mistake, it's data for improvement.

Part 4: Testing, Analysis, & Reflection (20 minutes)

1. **Data Collection:** Once a working model is complete, run 3-5 "official" tests.
    - Use the measuring tape to find the total length of the track.
    - Use the stopwatch to time how long it takes the marble to complete the course.
    - In the notebook, record the times and calculate the average time and average speed (Speed = Distance / Time).
2. **Guided Analysis Questions:**
    - "Where did you have to make the most changes? Why do you think that spot was so tricky?" (e.g., "The loop was hard because the marble didn't have enough kinetic energy to make it all the way around.")
    - "What role did inertia play in your tight curve? How did you design the curve to keep the marble on the track?" (e.g., "I had to bank the turn.")
    - "If you wanted to make your coaster faster, what is one specific change you would make and why?" (e.g., "Make the first hill steeper to generate more KE.")
    - "If you wanted to make it safer, what would you change?" (e.g., "Add higher walls on the turns.")
3. **Wrap-up:** Connect the model back to real roller coasters. Discuss how real engineers use computer-aided design (CAD) and advanced materials to solve these same problems on a massive scale, but the core principles of physics remain exactly the same.

5. Differentiation and Inclusivity

- **For Support:** If the student struggles with the open-ended design, provide a visual "starter idea," like a simple diagram of a first hill and a loop. Work together on the first component (the main drop) to build confidence.
- **For an Advanced Challenge:**
    - **The "Safety" Challenge:** Add a "passenger" (e.g., a tiny ball of clay) to the marble with tape. The goal is to complete the track without the passenger falling off.
    - **The "Maximum Thrill" Challenge:** Design a coaster that has two loops or a corkscrew element.
    - **The "Efficiency" Challenge:** Try to build the *slowest* possible coaster that still successfully finishes the track, forcing a deep understanding of how to manage and conserve energy.

6. Assessment Methods

- **Formative (During the lesson):** Observe the student's design process and listen to their self-talk as they problem-solve. Ask targeted questions during the build (e.g., "What do you predict will happen if you make that turn sharper?").
- **Summative (End of lesson):**
    1. The final, functional roller coaster model serves as a performance-based assessment of the engineering objective.
    2. The student's verbal or written answers to the "Analysis & Reflection" questions serve as an assessment of their understanding of the core science concepts.