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**Guidebook for Railway-themed K-12 STEM Outreach Activities**

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## Introduction

Welcome to the *Guidebook for Railway-themed K-12 STEM Outreach Activities*! Inside, you will find descriptions of educational activities designed to introduce students to the railroad transportation mode through the lens of STEM (Science, Technology, Engineering, and Mathematics) concepts.

Railroads have been a critical part of the global economy since the 1830s. Today, railroads haul more ton-miles of intercity freight (one ton of freight moved one mile) than any other mode of transportation in the United States. While the railroad industry is the leader in long-haul freight transportation, recruiting students to leadership roles in the industry is challenging. With many railroad employees approaching retirement age, the need to raise student awareness of railway industry career opportunities has never been greater.

The activities in this guidebook cover a wide variety of railroad topics. The activities are intended to be hands-on to provide students with knowledge through experiential learning that also increases their awareness of railway transportation technology. Although the following chapters provide a step-by-step guide to each activity, we encourage you to experiment with modifications to each activity and to create your own activities on other facets of the railroad industry and STEM topics.

We hope you find the activities in this guidebook to be informative and entertaining!

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## Train Rolling Resistance

*Trains rely on the low friction between a steel wheel and steel rail to provide efficient transportation. This activity examines the forces resisting the movement of a train and compares them to that of a truck.*

**Number of Participants:** 1-4

**Recommended Age:** 8+

**Setup Time:** 15 minutes

**Activity Time:** 15-30 minutes

### **STEM Concepts:**

- *Science: rolling resistance is a function of material properties and weight*
- *Technology: railroads can efficiently haul large amounts of freight over long distances partly due to low rolling resistance per ton of freight transported*
- *Engineering: railroad transportation engineers must estimate the rolling resistance and corresponding pulling force required to move a train at a constant speed in order to determine the maximum size and weight of train that can be moved by a particular locomotive*
- *Mathematics: rolling resistance force per ton is the force required to move the vehicle divided by the weight of the vehicle; graphs can reveal trends and relationships in observed data*

### **Key Learning Points**

1. **Trains must overcome resistance to begin moving.**
2. **Drawbar pull is the force being exerted by the locomotive(s) on the train and train resistance is the total resistance of all the cars and locomotives in the train.**
3. **As train weight increases, its total resistance force also increases.**
4. **Rubber tires have more resistance than steel wheels, partially explaining why trains provide more efficient long-distance freight transportation than trucks.**

### **Background**

Newton's first law of motion states that an object will remain at rest or in uniform motion unless acted upon by an external force. In a railroad setting, the locomotives on a train provide that "external force" that propels the train into motion. However, the train is also subject to external forces such as friction on the train wheels and axles, wind resistance, and gravity (if the train is on a slope), all of which resist the movement of the train. Of those factors, friction on the train wheels, axles and bearings has been the subject of much investigation. Lower friction means that a vehicle will have less rolling resistance to motion and consume less fuel and energy when transporting freight or passengers. Reduced energy and fuel consumption improves transportation efficiency by saving money and, by producing fewer greenhouse gas and other emissions, is better for the environment.

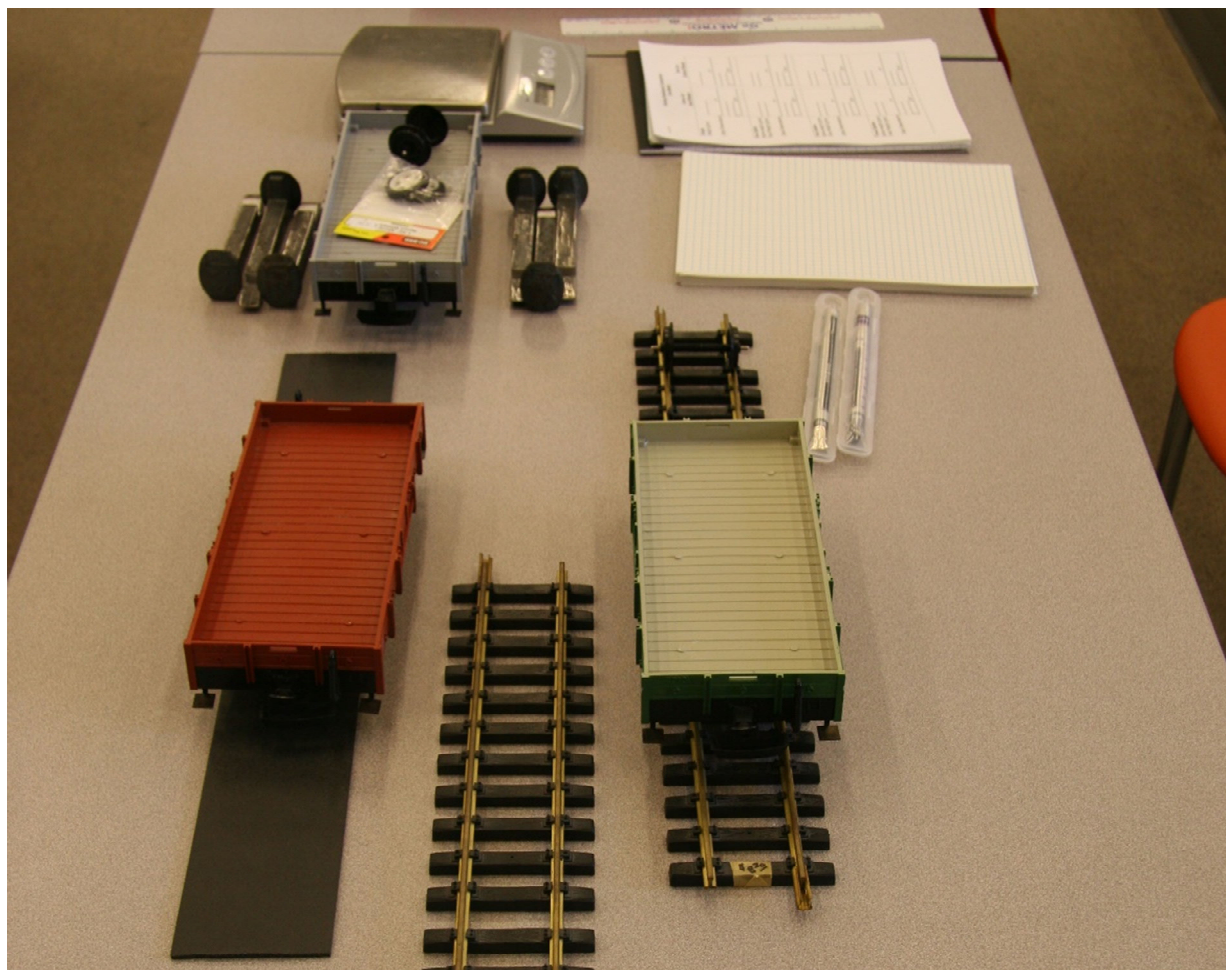
The steel railroad wheel on a steel railroad rail provides a stiff, low-friction interface between trains and the track structure. In comparison, rubber truck tires and asphalt pavements deform to produce a higher friction interface. Because of this difference, railroads have a lower rolling resistance per unit weight (ton) compared to highway trucks, buses and automobiles, as demonstrated by this activity.

## Materials List and Setup

### *Materials:*

This activity will require two model railcars capable of being loaded with additional weight, such as a flatcar, gondola or open hopper. One of the railcars should be kept in its standard configuration with metal railroad wheels while the other railcar is modified to be equipped with rubber tires in place of its metal wheels. Axles with the appropriate rubber-tire wheel spacing can be assembled from radio-control (RC) car parts appropriate for the particular railcar models, axle lengths and wheel sizes. Alternatively, to avoid modifying the railcars, one of the two railcars can be pulled on a rubber foam pad to represent the deformation of roadway pavement under highway trucks. Stiffer pads tend to yield better results.

- Two G scale gondola cars (one will suffice if using the rubber foam pad)
- Rubber-tire wheelsets for one railcar (or rubber foam pad)
- G scale track sections (a total of 2 to 4 feet of track length)
- Spring scale (500g/5 N range)
- Digital kitchen scale to weigh the railcars and verify weights
- Weights to load the railcars

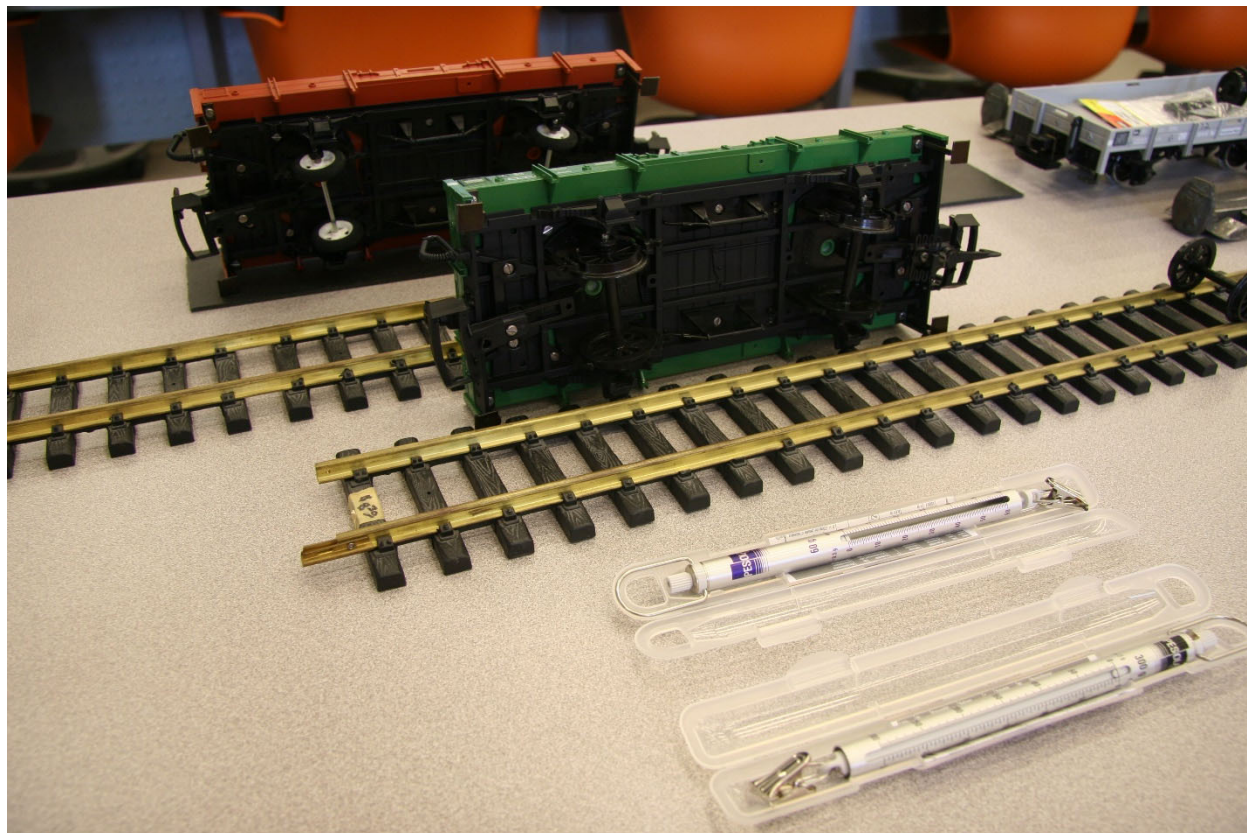


**Figure 1: Some of the materials required for this activity.**



### Script

1. Set up one of the two freight cars with rubber tires instead of metal wheels if not using a rubber foam pad (Figure 2). This car will represent a rubber-tired truck driving on an asphalt road.



**Figure 2: Railcars with metal wheels (front) and rubber tires (back).**

2. Using a digital kitchen scale, measure the empty weight of each railcar and record it on the activity worksheet.
3. Place the rubber-tired car on the table surface or rubber foam pad (the “road”) and clip the spring scale to one end of the car. Use the spring scale to pull the car across the table or along the “road” at a constant speed and measure the force required. The participant may need to use both hands to support the spring scale and ensure it is measuring in a direct line of force parallel to the track centerline and tops of the rails (Figure 3). It may take a slightly larger force to start the car moving than required to move it at a constant speed. It may take a few tries to determine the proper pulling force to keep the car moving smoothly at a constant speed. Record the constant speed force on the worksheet as the “roadway” rolling resistance force.
4. Repeat Step 3 by loading the car with one or two weights. We tested the cars empty, loaded with one railroad spike, and loaded with two railroad spikes (each spike is about 12 oz.). Be sure to record both the total weight of the car (empty weight plus load) and the pulling (rolling resistance force) read from the spring scale on the worksheet for each combination!



**Figure 3: Testing a car with metal wheels on a section of G-scale track.**

5. Place the metal-wheeled railcar on the G scale track section and repeat Steps 3 and 4 to determine the “railroad” rolling resistance force with the same three weight conditions (empty, one weight, and two weights). Record both the total weight of the railcar (empty weight plus load as appropriate) and the pulling (rolling resistance force) read from the spring scale on the worksheet for each combination.
6. Plot the observed values of weight and rolling resistance force for each railcar on the same set of axes (weight on the horizontal axis and rolling resistance on the vertical axis). The resulting data points and trend lines will show the relationship between total railcar weight, rolling resistance force, and the effect of wheel material (or highway and rail transportation mode) on the rolling resistance relationship.

The experimental results should show that the “railroad” condition with metal wheels on track have less friction than the “highway” condition with rubber-tire wheels or a car on the foam rubber pad. This same relationship is observed in full-scale real-world transportation systems. Trucks must overcome more friction than trains and therefore burn more fuel by ton-mile. On average, a truck requires three times more fuel to haul a ton of freight one mile compared to a train. Stated differently, for the same amount of fuel, a train can transport a ton of freight approximately three times farther than a truck!

### Questions to Stimulate Student Thought

1. Which transportation mode (truck or railroad) has lower resistance per ton? How do you know?
2. Which transportation mode would be better for moving a large amount of freight over long distances? Why?
3. Which is more expensive to construct, road or railroad? How does this relate to resistance per ton? (Does higher expense mean lower resistance per ton?)

### Adjusting for Time and Participant Age

1. For older participants, try performing three measurements of each distinct railcar loading condition and then taking the average of those values for your final observed value. Explain that this averaging process more closely reflects the scientific process than only testing once.
2. For younger participants, or to shorten the activity, use Excel or other spreadsheet programs to plot the observed values quickly and show that the “railroad” railcar with metal wheels has a lower resistance than the “highway” car, and the overall trend as the total weight increases.
3. For a more comprehensive experiment that investigates other factors affecting train and railcar resistance to motion, experiment with one or both of the following:
  - a. Elevate one end of the track section to create an incline or track “gradient”. Test different amounts of incline and plot its relationship to the amount of force required to move the railcar at constant speed. This force relationship, known as “grade resistance” is explained by the classic physics and trigonometry of a block on an inclined plane.
  - b. Instead of a straight track section, measure the force required to move the railcar at constant speed around a curved section of track. If possible, investigate track sections with a different curve radii to compare sharp and broad curves. The resisting force, known as “curve resistance” should be larger for sharper curves (of a smaller radius).

## Train Resistance

Empty Cars:

	Rubber Tires (or Foam Pad)	Metal Wheels on Track
Car Weight		
Force Measurement 1		
Force Measurement 2		
Force Measurement 3		
Average Force		

One Weight:

	Rubber Tires (or Foam Pad)	Metal Wheels on Track
Car Weight		
Force Measurement 1		
Force Measurement 2		
Force Measurement 3		
Average Force		

Two Weights:

	Rubber Tires (or Foam Pad)	Metal Wheels on Track
Car Weight		
Force Measurement 1		
Force Measurement 2		
Force Measurement 3		
Average Force		



**Additional Weight Point:**

	Rubber Tires (or Foam Pad)	Metal Wheels on Track
Car Weight		
Force Measurement 1		
Force Measurement 2		
Force Measurement 3		
Average Force		

**Additional Weight Point:**

	Rubber Tires (or Foam Pad)	Metal Wheels on Track
Car Weight		
Force Measurement 1		
Force Measurement 2		
Force Measurement 3		
Average Force		