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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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Wheel-Rail Dynamics: How Railcars Travel Around Curves

The wheels are one of the most important parts of a railcar. This activity examines how the shape of railroad wheels is designed to minimize wear and steer the railcar on straight and curved track.

Number of Participants: 2+ **Recommended Age:** 6+

Setup Time: 45 minutes **Activity Time:** 10-15 minutes

STEM Concepts:

- *Science: A stable equilibrium is self-correcting while an unstable equilibrium is hard to maintain.*
- *Technology: Negotiating a curve with a fixed-axle railroad wheelset is a technical challenge.*
- *Engineering: The taper of a conical railroad wheel is designed for steering and stability at speed.*
- *Mathematics: The circumference or distance around a curve is related to its diameter or radius.*

Key Learning Points

1. **Railroad wheelsets use a fixed axle and are designed to steer around a curve. This is done by using a conical section for the wheel.**
2. **Use of a conical wheel section results in the wheelset hunting (a side to side motion) as it travels down straight track. This phenomenon is called Klingel motion.**
3. **A wheelset with conical wheels results in a stable equilibrium that helps keep the wheels on the track. However, other potential wheel designs could result in an unstable equilibrium that will pull the wheels off the track.**

Background

Unlike highway vehicles, railway locomotives do not have a steering wheel that allows the train crew to actively control the direction of the train. Instead, the track serves as a fixed guideway that dictates the path a train will follow. The flanged railroad wheel is a critical part of a railroad locomotive or railcar. Not only do railroad wheels support the weight of the railcar and allow it to roll and along the track, they also help steer the railcar through the various geometric features of the track. It is commonly thought that the flange on the railroad wheel always contacts the rail on curves and forces the train to follow a curved path. However, such an arrangement would generate a large amount of friction and noise on curves and increase wear on both the wheels and the rails.

Instead of relying on the flange, the shape of the wheel tread (the portion that rolls on the top of the rail) is carefully designed to allow railcars to negotiate curved and straight sections of track. Railroad wheelsets use a fixed axle to prevent the wheels from rotating at different rates or directions and subsequently causing a derailment on straight (tangent) track. On curves, the wheelset must be able to adjust its position so each wheel progresses through the curve at the same speed. A conical tapered wheel design allows the wheelset to shift in curves such that the difference in rolling radius between the two wheels can "match" the difference in length between the inside and outside rails on a curve. This activity examines different wheel designs and demonstrates the benefits of the conical design.

This activity is composed three parts:

- Background activity on rolling radius and curvature
- Main wheel-rail dynamics activity
- Behavior of additional wheelset shapes (see Adjusting for Time and Participant Age)

Materials List and Setup

Materials:

The background activity requires two "wheel set models" (one cylindrical and one conical) that can be constructed from several different materials:

- Two sheets of paper and tape
    - One sheet rolled and taped to form a cylinder
    - One sheet rolled and taped to form a cone
- Drinking glasses or cups
    - One with straight sides so the top and bottom have equal radius
    - One with tapered sides such that the top is larger than the bottom
- Circular cardboard cutout wheels pressed on to a pencil axle
    - One axle with two wheels of equal radius
    - One axle with two wheels of different size radius
- Tinker toys with wooden wheels and axles
    - One wheelset with two wheels of equal radius
    - One axle with two wheels of different radius

The main wheel-rail dynamics activity can be constructed in several ways:

- PVC pipe and/or wooden dowels and popsicle stick track with plastic cups as wheelsets
- G scale model railroad track with machined wheelsets (see worksheet for possible shapes)
- O scale model railroad track with icing tip wheelsets held together with modeling clay (see worksheet for possible shapes to make with pairs of icing tips)

For main the wheel-rail dynamics activity setup using PVC pipe and plastic cups described in detail on the following pages, the following materials are required:

- 8-12 feet of ½" diameter PVC pipe and/or wooden dowels to serve as rails
- Popsicle sticks (to serve as crossties)
- Glue to fasten pipe/dowel rails to popsicle stick crossties (a hot glue gun works well)
- 4 x Tapered plastic cups (taped end-to-end in normal and inverted configurations)
- Cardboard paper towel roll (optional)

The extended activity with additional wheelset shapes is best conducted with the G scale model railroad track and machined metal wheelsets or the O scale model railroad track and icing tip wheelsets.

Script for Background Activity:

1. Gather the required materials and assemble two railroad wheelset models, one cylindrical and one tapered.

2. Place the two wheelsets on a table or level surface and ask the students what is different about the two wheelsets. They should be able to identify that one is "cylindrical" or has wheels of equal size, while the other is "tapered/conical" or has wheels of different sizes.

3. Ask the students to predict what will happen when each of the two wheelsets is rolled forward across the table.

4. Roll the cylindrical or equal-sized wheelset forward. It should travel in a straight line.

5. Roll the tapered/conical or unequal-sized wheelset forward. It should travel in a curved path, turning in the direction of the smaller wheel or small end of the taper/cone (Figure 1).

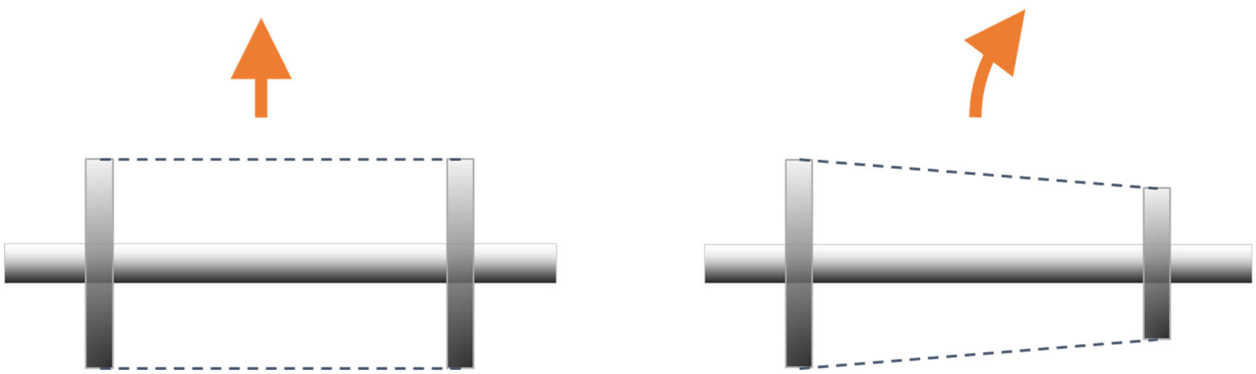

Figure 1: Straight direction of travel for cylinder or wheelset with equal-size wheels and curved direction of travel for taper/cone or wheelset with unequal-size wheels.

6. Ask the students to explain why the tapered/conical or unequal-sized wheelset travels in a curved path.
   a. With or without prompting, they may recognize that the wheels or ends of the taper/cone have different radius or diameter.
   b. Because of the difference in diameter, the circumference or distance around the wheels or opposite ends of the taper/cone will also be different. The circumference corresponds to the distance the wheel/end will travel forward when rotated once.
   c. Since the wheelset model has a fixed axle, for each rotation, the larger wheel/end must travel a longer distance than the smaller wheel/end while still moving together. This difference in rolling distance creates a curved path.

7. Ask the students to imagine or draw a circle of railroad track with a pair of rails.

8. Ask the students if each rail, referred to as the inner rail and the outer rail, comprising the circle of track is of equal length.
    a. They should come to the conclusion that the outer rail makes a larger circle than the inner rail, and hence the outer rail must be longer than the inner rail.
9. Explain to the students that because the outer rail is longer than the inner rail, if a railroad wheelset were to roll around the circle, the outer wheel must travel a longer distance then the inner wheel (Figure 2).

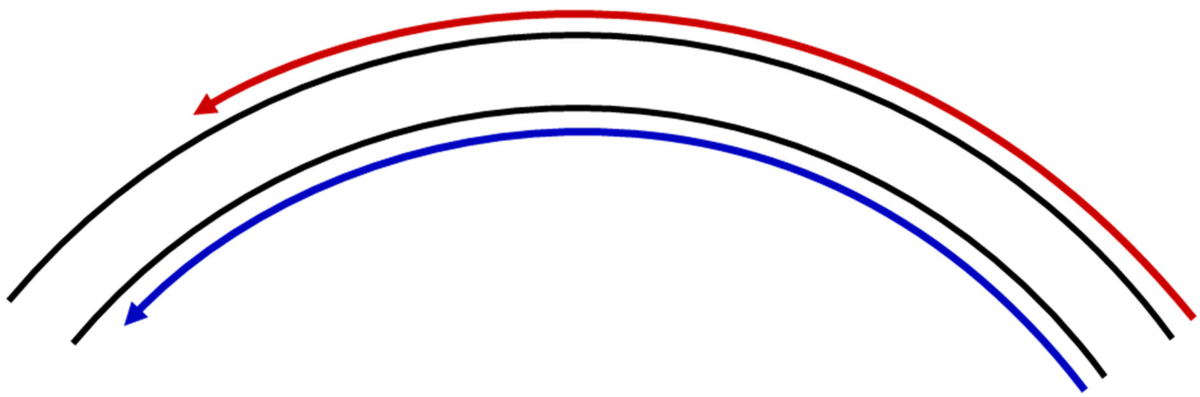

Figure 2: Difference in length between the inner and outer rail of curved track.

10. Ask the students how this relates to the first experiment with the cylindrical/equal-sized wheelset and tapered/conical/unequal-sized wheelset.
    a. They may suggest that a tapered/conical/unequal-sized wheelset would be able to roll around the circle of track.

11. Ask the students how such a tapered/conical wheelset would roll on straight track or a track with a different curvature.
    a. With or without prompting, the students should conclude that a different shape might be needed for different curves and straight sections of track.
    b. For example, a larger difference in wheel size is needed to travel around a sharper curve while a smaller difference in wheel sizes is required to travel in a broader gentle curve.

12. Explain that if the two wheels could change their diameters, the wheelset could adapt to travel on different curves in either the left or right-hand direction or, when the wheels are equal in size, travel straight.

13. Using the tapered wheelset model, explain how if a single railroad wheel were made to be tapered/conical, its diameter will change depending on where it sits on top of the rail (Figure 3).

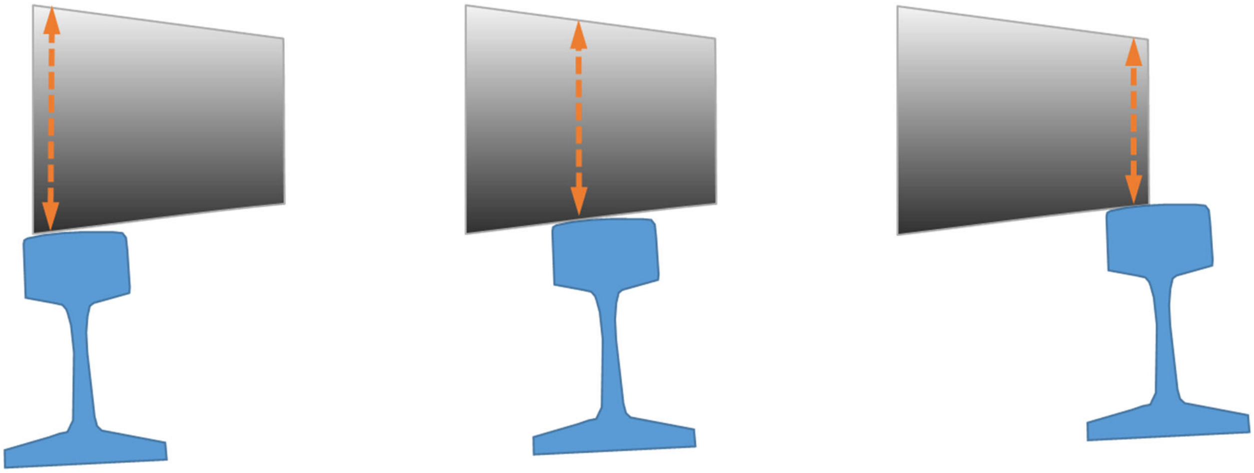

Figure 3: A tapered conical wheel can change its rolling diameter depending on where it contacts the top of the rolling it is rolling on.

14. Explain that this is why railroads use tapered conical wheels, but the questions remains of how to place the wheels on the axle: with the tapers facing in or out (Figure 4)? This leads to the demonstration in the main wheel-rail dynamics activity.

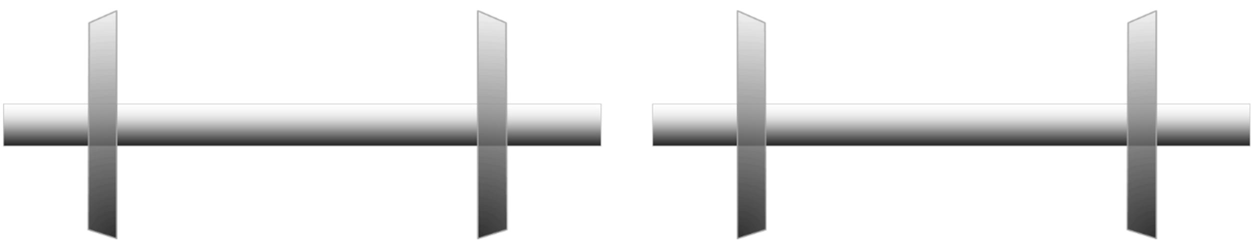

Figure 4: Two possible arrangements for a railroad wheelset with tapered wheels: tapers facing out (left) or tapers facing in (right).

<u>Script for Main Wheel-Rail Dynamics Activity:</u>

15. Before starting the main activity, assemble a track section that includes both a section of tangent (straight) track and a curve.
    a. If using PVC pipe and/or wooden dowels, the wooden dowels work well for straight sections of track but PVC is needed for curves. You may need to heat and bend the PVC pipe to create a curve. Glue the PVC pipe to the popsicle sticks as shown (Figure 5).
    b. If using G scale or O scale model railroad track, you should purchase several tangent sections and several curve sections.

16. Elevate the straight/tangent end of the track section to make the wheelsets roll down the track at a steady speed but not too fast (or wheelsets will become unstable and derail).

Figure 5: PVC pipe and popsicle stick track setup.

17. For setups using only the cups with PVC pipe and popsicle stick track, the demonstration will consist of the two wheelset configurations shown in Figure 6 below. A third shape that can be tested is a simple cylinder which can be represented to by an empty paper towel roll. These three shapes correspond to the first three shapes on the worksheet. Ask the students to predict which wheelset(s) will derail on both the tangent and curved track.

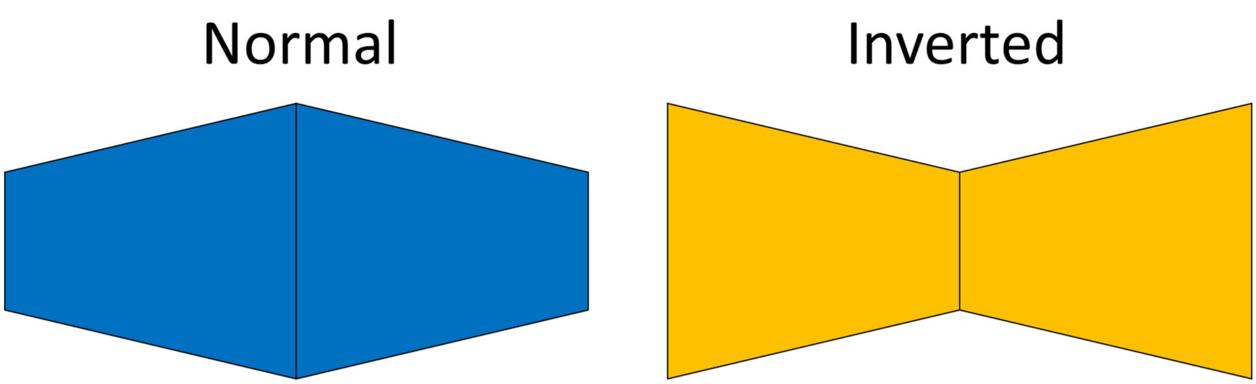

Figure 6: Wheelset configurations

18. Test each wheelset (Figure 7). The normal one should be able to make it to the end of the track and through any curves, while the inverted one will likely derail before reaching the end of the tangent track. A simple cylinder may make it down the tangent track but will roll right off the curve since it has no mechanism to steer around the curve and keep it on the track.

Figure 7: Testing a wheelset with normal conicity.

19. Explain that the normal configuration shown in Figure 6 can shift to match the radius of the “wheel” to the length of the “rail” that it is riding on in a curve. However, this leads to a back-and-forth motion while it travels down straight tangent track. This sinuous motion, called Klingel motion (Figure 8), is the result of the wheelset constantly trying to correct itself to the middle of the track, overcorrecting, and trying to re-correct again. This is a *stable equilibrium* because the wheelset will try to bring itself back to the middle of the track (the equilibrium state).

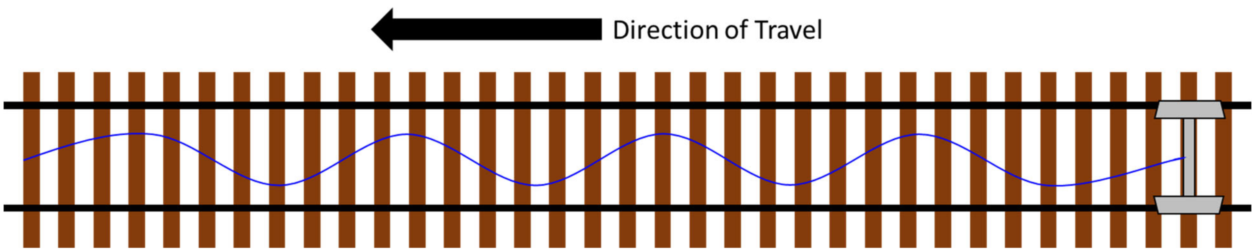

Figure 8: The (exaggerated) path of a railroad wheelset due to Klingel motion.

20. Explain that the inverted wheelset does not work because it is in an *unstable equilibrium*. If it was perfectly and symmetrically placed relative to the middle (centerline) of the track so that each wheel had the exact same rolling radius, the wheelset would be able to follow straight portion of the track. However, this is nearly impossible, meaning that the wheelset will pull itself off the track. If the wheelset did manage to reach a curve, it would immediately derail because the wheelset would shift in the wrong direction (smaller wheel radius would be matched with a longer rail and vice versa).

21. Allow the students to try rolling any of the wheelsets down the track themselves to get a better understanding of why the normal wheelset follows the track!

Questions to Stimulate Student Thought

1. How does the railroad wheelset steer itself around the curve?
2. What do you think happens as the wheelset wears?
3. Even though the wheelset steers itself around curves, do you still think it needs a device to keep itself on the rail?

Adjusting for Time and Participant Age

1. This activity can be expanded by including other wheelset configurations as shown on the attached worksheet. These wheelsets can be machined (for use with G scale model railroad track) or, for use with O scale model railroad track, made using icing tips held together with modeling clay and an axle material of your choice (such as wooden dowel rod). As with the other wheelset types, ask students to predict which wheelsets pictured on the worksheet will follow the tangent and curved track sections.
    a. Wheelsets three, four and five on the worksheet are in the "normal" configuration but have different amounts of taper.
        i. Wheelset three with the largest taper can achieve a large amount of rolling radius difference and is thus less stable than the others on straight tangent track but has good performance on curved track.
        ii. Wheelset five with the slightest taper can only achieve a small amount of rolling radius difference and is thus more stable than the others on straight tangent track but has difficulty on curved track.
    b. Wheelsets six and seven represent different conditions that arise when railroad wheels wear at different rates. See if you can predict which ones will work well!

2. An additional task for the students could be to construct the track before testing the wheelsets. This expansion would allow for the students to learn about rail and crossties. See our *Railroad Track Construction* Activity for more information on track components and the track structure.

Performance of Railway Wheelset Shapes

	Tangent (Straight) Track	Curved Track