MAGLEV MODULE

Updated and revised in 2017 for the Michigan Department of Transportation (MDOT)

This manual was originally composed as part of the Transportation and Civil Engineering (TRAC) Program created by the American Association of State Highway and Transportation Officials (AASHTO). For more information on the original manual, see the complete final report, NCHRP 20-52.

The manual was updated and revised in 2017 by the Center for Technology & Training (CTT) at Michigan Technological University for the Michigan Department of Transportation (MDOT).
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Executive Summary

This module contains five activities to provide a comprehensive overview of basic physics concepts as they apply to moving vehicles. Concepts are introduced independently in the activities and then pulled together in experimental demonstrations, hands-on projects, and computer-based simulations. Each activity contains the following sections:

1. Instructor’s Reference. This section is intended for both instructor and volunteer use and contains an activity summary and preparation information for the activity.
2. Instructor’s Answer Key & Discussion Ideas. This section serves as an instructor companion to the Research Manual and Research Notes and contains all answers to the questions given to students. It also contains suggested points of discussion that relate to the activity.
3. Research Manual. This section is intended for student use and contains all background, setup, and procedure information and instructions for completing the activity.
4. Research Notes. This section is intended for student use while working on the activity and lists the same questions found in the Instructor’s Answer Key & Discussion Ideas section.

This manual also contains a complete activity overview table, instructor introduction to the module, and a copy of the National Education Standards. Below are summaries and potential volunteer topics for each activity.

Activity 1: Timing Newton’s Apple

Activity 1 demonstrates to students that there is some reaction time required to perform an action, no matter how instantaneous the response may seem. Students will do their best to start and stop a stopwatch as quickly as they can, and then average their reaction times, as they will more than likely differ each time. Reaction times, as they relate to different roadway situations, will also be discussed.

Volunteer Topics

A traffic engineer could discuss how reaction times can compound with other roadway conditions to cause significant accidents, or how reaction times to a car in front of you slowing down could ripple backwards to cause delays.

Activity 2: Running the Gauntlet

Activity 2 validates Newton’s First Law, which states an object in motion will remain in motion unless acted upon by an outside force. Students will verify this by observing how a maglev car moves with minimal resistance from friction. They will then plot position vs. time data, and use that plot to determine velocity vs. time.

Volunteer Topics

A physicist could talk about how Newton’s Laws apply to space travel. Since there is no resistance, spacecraft continue moving along their initial trajectory until acted upon by another force.
Activity 3: Caution—6% Grade Ahead

Activity 3 explores Newton’s Second Law and introduces the concept of acceleration due to gravity through observation of how gravity affects vehicles traveling on an inclined surface. Using an angled track, students will measure the increase in velocity of the maglev car due to the acceleration of gravity as the car moves down the ramp. This activity is designed for students who have not yet had Trigonometry.

Volunteer Topics

A traffic engineer could explain why it is important to avoid building roads with significant grades in order to increase safety and fuel efficiency.

Activity 4: Graphing the Grade

Activity 4 is similar to Activity 3. Students will explore Newton’s Second Law and will be introduced to the concept of acceleration due to gravity through the observation of how gravity affects vehicles on an inclined surface. Using an angled track, students will measure the increase in velocity of the maglev car due to the acceleration of gravity as the car moves down the ramp. This activity varies from the last activity through the application of more advanced topics and use of trigonometry to explore the relationship between time, position, velocity, and acceleration.

Volunteer Topics

A physicist could explain how constant acceleration is used in practical applications and how they use calculus in their work to understand more about the relationship between acceleration and velocity.

Activity 5: Float Like a Butterfly, Sting Like a Bee

Activity 5 will challenge the students to use the skills they have learned to create a maglev car and race against their peers. Students will observe how aerodynamics affect the speed of cars and will learn how this applies to actual vehicles.

Volunteer Topics

A mechanical engineer could talk about how cars are produced, from design to manufacturing. They could talk about what factors are considered when designing the vehicles, such as the fuel efficiency of a vehicle and the overall aesthetic appeal.
Instructor’s Introduction

Engineering is not simply about solving problems. It is about solving problems in the most efficient and elegant manner possible, while not creating new problems along the way. In order to come up with the most efficient solution, some amount of prior knowledge is usually needed. Frequently, this knowledge is mathematical or experiential.

For centuries, scientists, mathematicians, and engineers have studied the physical world and recorded their observations. They have derived mathematical formulas that describe the way materials and systems behave. They have also conducted experiments and drawn conclusions from their results. This body of knowledge that has accumulated over time is what engineers study and apply to solve problems every day. This process is what differentiates engineering from tinkering.

Tinkering is what we do when we try to solve problems by relying on trial-and-error. Tinkering can be fun, but it is usually not the most efficient way of solving a problem. Although solutions to engineering problems can sometimes be found by tinkering, these solutions tend to be neither efficient nor optimal.

Engineering can be fun, too. There is a great deal of satisfaction to be gained from approaching a problem theoretically. Typically, an engineer will try to find a set of equations that describe the problem mathematically. These equations will give the engineer clues about how to solve the problem at hand. Using these clues, engineers can arrive at the optimal solution much more quickly than they could have if they had relied on tinkering alone.

As part of the TRAC & RIDES Program it is key to understand where funding comes from and how decisions are made in the world transportation planning/engineering. Transportation plays a huge role in our everyday lives, and Metropolitan Planning Organizations/Transportation Planning Organizations (or MPOs/TPOs) are a critical component of a city’s transportation system. MPOs help plan the future of transportation in a region, and chances are, there is a MPO in your city making decisions that affect all of us and how we get around. MPOs are made up of local elected officials, elected by the people of a city or region, who decide how to spend taxpayer money on transportation projects. MPOs plan all types of transportation, from roads and highways to public transit and bike lanes. Public involvement is very important to decision makers, and your voice matters! Learn more about your local MPO, and find out how you can get involved in planning the transportation system of the future. As you implement any of the TRAC & RIDES modules we suggest you investigate the MPO/TPO in your area and encourage your students to do the same. It will open up a whole new area where students can explore career opportunities in transportation planning and engineering.

Two websites to begin your student’s research:

- Association of Metropolitan Planning Organizations [www.ampo.org](http://www.ampo.org)
- National Association of Regional Councils [www.narc.org](http://www.narc.org)

In this module, students will explore how magnetic fields are used to eliminate surface friction and provide motion for magnetic levitation (maglev) trains. Newton’s First and Second Laws will be used to observe how an object in motion stays in motion and how the acceleration of gravity causes a vehicle to accelerate down a ramp. The module builds up to a racing competition where students will design and construct their own maglev cars and race against other students to see who can run the course in the fastest time.
National Education Standards

National Science Education Standards: Physical Science

Grades 5-8

Science as Inquiry

• Use appropriate tools and techniques to gather, analyze, and interpret data.
• Use technology and mathematics to improve investigations and communications.
• Think critically and logically to make the relationships between evidence and explanations.
• Formulate and revise scientific explanations and models using logic and evidence.

Science Content

• Motion and Forces: The motion of an object can be described by its position, direction of motion, and speed. That motion can be measured.
• If more than one force acts on an object along a straight line, then the forces will reinforce or cancel one another, depending on their direction and magnitude. Unbalanced forces will cause changes in the speed or direction of an object’s motion.

Grades 9-12

Science as Inquiry

• Design and conduct scientific investigations.
• Use technology and mathematics to improve investigations and communications.
• Formulate and revise scientific explanations and models using logic and evidence.
• Recognize and analyze alternative explanations and models.

Science Content

• Motion and forces: Objects change their motion only when a net force is applied. Newton’s Laws of Motion are used to calculate precisely the effects of forces on the motion of objects.

Technology Foundation Standards

Basic Operations & Concepts

• Students demonstrate a sound understanding of the nature and operation of technology systems.
• Students use technology tools to enhance learning, increase productivity, and promote creativity.
• Students use productivity tools to collaborate in constructing technology-enhanced models, prepare publications, and produce other creative works.
• Students use technology resources for solving problems and making informed decisions.
• Students employ technology in the development of strategies for solving problems in the real world.

Technology

International Technology Education Association Standards for Technological Literacy

The Nature of Technology
• Standard 3: Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.

Design
• Standard 8: Students will develop an understanding of the attributes of design.
• Standard 9: Students will develop an understanding of engineering design.
• Standard 10: Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

Abilities of a Technological World
• Standard 11: Students will develop abilities to apply the design process.

The Designed World
• Standard 18: Students will develop an understanding of and be able to select and use transportation technologies.

For the full documentation of TRAC and the National Education Standards, see the TRAC/Michigan Education Standards page on the MDOT website: http://www.michigan.gov/mdot/0,4616,7-151-9623_38029_38059_41397-184233--,00.html.
Activity 1: Timing Newton’s Apple

<table>
<thead>
<tr>
<th>Activity Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Instructor Prep Time</strong></td>
</tr>
<tr>
<td><strong>Class Time</strong></td>
</tr>
<tr>
<td><strong>Grade/Class</strong></td>
</tr>
<tr>
<td><strong>Suggested Activity Grouping</strong></td>
</tr>
<tr>
<td><strong>Technology</strong></td>
</tr>
</tbody>
</table>
| **National Science Education Standards** | Appropriate tools  
Technology and mathematics  
Think critically  
Motion and forces |

Introduction

Most stopwatches are designed to measure time to the nearest 0.01 second. Students often develop the misconception that they are able to measure with that degree of accuracy when using a stopwatch because they do not consider the error resulting from reaction time. This activity demonstrates human error as students measure the time it takes a ball to fall from a given height. A minimum of three trials should be conducted to gather data from handheld stopwatches. The Research Notes section is to be used for recording results and calculating the average time.

Objective

Students will learn to identify human factors that make their measurements less accurate than the value displayed on the stopwatch.

Background

Human reaction time is approximately 0.1 to 0.2 seconds, which is slower than the average stopwatch, measuring to the nearest 0.01 second. The purpose of this exercise is to show students that their instrument is far more accurate than their ability to use it, hence the need to consider error in all measurements.

Suppose two students each have an “average” reaction time of 0.15 seconds. The students time a sprinter in the 50 m dash whose actual time is exactly 10.00 seconds. It is quite possible that student A might record 9.85 seconds and student B might record 10.15 seconds, meaning that students A and B could record a difference of 0.3 seconds. This assumes a potential error due to reaction time alone. There are other sources of error as well, such as the perception of when the sprinter actually crosses the line or the delay from starting the timer based on the sound of the gun rather than the flash or smoke.
Activity Expansion Ideas

What is the largest source of error?
One methodology to identify the largest source of error is to identify all the possible elements of error and then time them. For example, students might develop a three column table similar to what is shown below:

<table>
<thead>
<tr>
<th>Source of Error</th>
<th>Procedure to Estimate Error</th>
<th>Possible Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand-eye coordination for starting and stopping the watch.</td>
<td>Press the start and stop button as quickly as possible.</td>
<td>Probably will be less than 0.20 seconds.</td>
</tr>
<tr>
<td>Knowing when to stop the watch.</td>
<td>One talented student holds three watches and starts them at the same time. Then hands the running watches to three other students. Then drops the ball and they all record the time of impact.</td>
<td>Probably will be larger than the error above (perhaps as much as 1 second).</td>
</tr>
<tr>
<td>Knowing when to start the watch.</td>
<td>Similar to the previous sources of error, the same talented student holds three watches and starts them at the same time, and then hands the running watches to three other students. This time the students press the stop clock when the ball is released.</td>
<td>Probably comparable to the error above.</td>
</tr>
<tr>
<td>Line of sight for viewing the experiment.</td>
<td>This could be difficult to test in the classroom but could be discussed in terms of the ability of students in the room to pick up on slight indicators that the ball is about to be dropped, such as the opening of fingers or a movement of the wrist. Knowing when the ball hits the floor would be easier to evaluate from a viewpoint close to the floor. If you were looking down on the ball it would be more difficult to know when it first made contact with the floor.</td>
<td>If an engineer is present, he/she can discuss how parallax error affects measurement of vehicle speeds when one is standing on a high building looking down at traffic.</td>
</tr>
</tbody>
</table>

How are sporting events timed?
Students will likely bring up the accuracy of timing at sporting events, such as the Olympics where the difference between silver and gold can be thousandths of a second. Students could conduct research and report on how instruments are used to make these measurements by removing the factor of human error from the equation.
Activity 1: Timing Newton’s Apple

Questions

1) How did the group’s times compare to your times?
   Individual students should simply remark whether their time was higher or lower than the group as a whole.

2) What is the benefit of conducting several trials when taking time measurements?
   Conducting several trials and averaging the results is better than just conducting one trial because it helps to balance errors that might occur.

3) What factors can contribute to time differences between trials and students?
   Several factors are plausible:
   • the definition of what constituted the starting point and ending point.
   • difficulties in seeing the ball fall or hit the floor, especially if a shorter student’s view is obstructed (this becomes critical when designing and placing signs that must be visible from all vehicles, even if there are large trucks that may obstruct a driver’s view).
   • variations in stop watch design, especially if different brands are used.

Discussion

Typical results from this activity will provide a fairly wide range of time values differing by as much as plus or minus 0.2 seconds. Students will be able to draw conclusions on the amount of common error in this type of measurement and recognize why measuring times to the hundredth or thousandth of a second serves little purpose, even though the stopwatch is capable. To clarify the topic, drawing connections to other types of measurements, such as speed or temperature would be beneficial.

There will probably be several cries of “oops” where a student forgets to press the start or stop button or where the ball follows a different trajectory. This may not be a big problem when it is averaged out with four normal trials, although it is a problem if it is the only trial. Also, there may be a student who has unusually fast reaction times, and just because they are agile does not mean that everyone else is. (When a road is designed, it must be designed for the average or below-average driver rather than the best, or ideal, driver.)

It is critical to indicate that a person with an outlying time is not necessarily “wrong” or “better than others.” Instead, focus on the definition of the starting and ending point. For example, could everyone see the ball being dropped from the same angle? Did everyone agree on what instant they should stop the watches? The lesson that should emerge is that a consistent approach among the group is the most important element.
Activity 1: Timing Newton’s Apple

Introduction
When measuring time with a stopwatch, it may seem logical to believe that you are able to measure with the same degree of accuracy that your stopwatch is designed to measure, timed to the nearest 0.01 second. However, your own perception and reaction time are just two factors that affect the accuracy of measurement. This activity will demonstrate how inaccuracies can be introduced by human factors.

Objective
You will learn to identify human factors that make your measurements less accurate than what the stopwatch is designed to measure.

Background
People cannot react instantaneously to an event, but instead must mentally process what is occurring, decide what they should do next, and then take action. A sprinter may appear to leave the starting blocks as soon as he or she hears the sound of the gun beginning the race, but in reality he or she uses a very small amount of time, perhaps less than a tenth of a second, to hear the gun, leap from the starting blocks, and begin the race. In this activity, you will find that the tiny amount of time required to react to an event will affect the measurements you take in the lab.

In practice, transportation professionals face similar problems when designing roadways, but the consequences are far more serious. Drivers, just like lab technicians, are human beings who need a small amount of time to react to any given situation: a command to stop, the sudden appearance of a deer in the roadway, or a traffic signal that changes from red to green. Some of these events may be expected (a steep hill that a driver recognizes on the way home) and some may be unexpected (a car that suddenly turns in front of you).

The human response to events such as these can be described in a relatively quick four step sequence: perception, identification, emotion, and volition. The first step, perception, is to notice a problem. For example, an object of some type is suddenly in front of the driver when it wasn’t there before. The second step, identification, is to comprehend the problem. In this case, the driver might identify (understand) that the object in front of them is a deer. The third step, emotion, is to make a decision about what to do: swerve, hit the brake, scream, or do nothing. The fourth step, volition, is to take action; such as stepping on the brake to avoid hitting the deer. Although human beings react so quickly that they may not consciously think through these four steps, there is a small amount of time that is required before an action can occur. These four steps are known as “PIEV” (perception, identification, emotion, and volition) or, simply, perception-reaction time.

Consider the two very different traffic situations shown in Figure 1-1. Depending on whether one is traveling south in the left five lanes or north in the right five lanes, the amount of traffic traveling in the same direction differs a great deal. Suppose a sudden event occurs, such as a truck encroaching on your lane. The perception-reaction time (the speed with which you can mentally observe the truck coming into your path of travel and then make a decision about what action you should take) is affected by the other distractions already on the roadway and in your vehicle. You could probably react more quickly if
you were traveling in the lanes on the left than in the lanes on the right side, where traffic is heavy, assuming the heavy traffic is distracting.

![Figure 1-1: Differing traffic volume north and south bound (Photo courtesy of the Virginia Department of Transportation)](image)

However, the sheer amount of traffic is not the only factor that affects perception-reaction time. In addition to whether the event is expected or not, a third factor is the complexity of the driving environment. Consider, for example, Figures 1-2 and 1-3 shown below.

![Figure 1-2: Consistent lanes, no merging or diverging traffic (Photo courtesy of the Virginia Department of Transportation)](image)  ![Figure 1-3: Merging and diverging traffic can be distracting (Photo courtesy of the Virginia Department of Transportation)](image)

Figures 1-2 and 1-3 both show traffic moving through a freeway; however, in Figure 1-3 you’ll notice that there are both exits and lane merges. Even if the road was not crowded, there would still be delays due to the added complexity of this section of road.

Most drivers have perception-reaction times of 1.5 seconds or less. In other words, a driver traveling at 100 km/h (60 mph) who sees a deer and suddenly chooses to apply the brakes could travel at 100 km/h (60 mph) for 1.5 seconds before the car even begins to slow down. During this 1.5 seconds, the car will have traveled about 40 meters (132 feet). Perception-reaction time will increase for people who are in unfamiliar or unexpected situations. For roadways to be relatively safe, it is critical to understand how perception-reaction time can vary among people and situations.
Activity 1: Timing Newton’s Apple

Materials

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stopwatches</td>
<td>1 per student</td>
</tr>
</tbody>
</table>

Procedure

You may use a stopwatch or one on your watch or phone. Become familiar with starting, stopping, and resetting the instrument.

Press the start button and then immediately press the stop button on the stopwatch. See how quickly you can do this! Some students may be able to do this in about 0.07 seconds, whereas adults may require up to 0.15 seconds. If a variety of stopwatches are available, then one can compare the times obtained with different types of watches. The phenomenon being timed here is volition—the amount of time required to react to a situation. Different values that you and your classmates obtain may be written on the board. This small amount of time is only part of the complex perception-reaction process.

Next, you will measure and record the entire perception-reaction time. Your teacher, or a student volunteer, will hold a ball in the air and say “Ready, Set, …” but will NOT say “Go!” before dropping the ball. Start your stopwatch when the ball is released and stop when it strikes the floor. The only “go” clue is a visual one; auditory response times are different than visual ones. A minimum of three trials should be conducted to gather data. Record and average your times in the data table in the Research Notes section. Compare times within a small group; then record average times on the board in an orderly fashion.

Part 1
1. Get a stopwatch from the instructor or use one on your watch or phone.
2. Get familiar with starting, stopping, and resetting the stopwatch.
3. Then, when instructed by your teacher, press the start button as quickly as you can and then immediately press the stop button.
4. Compare the amount of time it took to stop the stopwatch with other students’ times.

Part 2
1. Using your stopwatch, time a ball as your instructor, a student, or a volunteer drops it.
2. Record the time in the table provided in the Research Notes section.
3. Repeat steps 1 and 2 two more times so that three trials have been recorded.
4. When you have finished timing all the trials, find the average time.
5. Form groups of 3 to 4 to compare times.
6. Answer the questions in the Research Notes section.
Activity 1: Timing Newton’s Apple

Data Sheet

<table>
<thead>
<tr>
<th>Trial</th>
<th>Measured Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td></td>
</tr>
<tr>
<td>Trial 2</td>
<td></td>
</tr>
<tr>
<td>Trial 3</td>
<td></td>
</tr>
<tr>
<td>Average Time</td>
<td></td>
</tr>
</tbody>
</table>

Questions

1) How did the group’s time compare to your times?

2) What is the benefit of conducting several trials when taking time measurements?

3) What factors can contribute to time differences between trials and students?

Discussion Notes
Activity 2: Running the Gauntlet

Activity Summary

<table>
<thead>
<tr>
<th>Instructor Prep Time</th>
<th>25 minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class Time</td>
<td>20 minutes to collect data</td>
</tr>
<tr>
<td></td>
<td>15 minutes to graph</td>
</tr>
<tr>
<td>Grade/Class</td>
<td>6 - 8 Intermediate, 9 - 12 Physics</td>
</tr>
<tr>
<td>Suggested Activity Grouping</td>
<td>Classroom demonstration or as a lab activity</td>
</tr>
<tr>
<td>Technology</td>
<td>Low-High Tech</td>
</tr>
<tr>
<td>National Science Education Standards</td>
<td>Appropriate tools Technology and mathematics Think critically Forces and motion</td>
</tr>
</tbody>
</table>

Introduction

This activity may be presented as either a demonstration or a hands-on lab to illustrate Newton’s First Law of Motion. Students measure the time in which a maglev car travels between intervals along a horizontal track. Students plot their data on a position vs. time graph and measure the slope, verifying the car was traveling at a constant velocity and, thus, supporting Newton’s First Law of Motion. Students may graph the data on graph paper or by using a software program such as Excel. As a pre-lab, it is suggested that Activity 1: Timing Newton’s Apple be completed before this lab.

Objective

Students will collect position vs. time data and use it to verify Newton’s First Law.

Background

Observing Newton’s First Law at work in the classroom requires that we eliminate some of the friction forces normally present in sliding or rolling objects. We will accomplish this by using the maglev track, which allows a car to levitate due to repulsive magnetic forces. With the track on a level surface, a small push given to the vehicle should allow it to glide down the track at an almost constant velocity for the length of the track.

Consider a hockey player standing on the ice. The player will continue to stand still until something, such as an opposing player, hits him or her with a body check.

Now consider a scenario where a hockey player is moving in a straight line and at a constant speed. According to Newton’s First Law, the hockey player will continue to move in that direction and speed until acted upon by an outside force. Now imagine that this hockey player is hit by another player. The original player may have initially been skating in one direction, but, after being checked, goes off at an angle. The second player in this situation is the outside force that acted upon the original player.
Even a hockey puck sliding across the ice follows this law. If you watch the hockey puck moving with no one touching it, it goes in a straight line until it hits the hockey stick as shown in Figure 2-1.

![Figure 2-1: Puck sliding across ice](image)

**Activity Expansion Ideas**

Although this lab can be done as a class time exercise within a 50-minute period, you might also consider having the students write this up as a full lab, containing objective, materials list, procedure, data table, graph, error analysis, and conclusion. If enough equipment is available, this activity is well-suited for group work.

The concepts in this activity can be shown to students through interactive models available online.

Some examples are provided below:

- [https://phet.colorado.edu/en/simulations/category/physics/motion](https://phet.colorado.edu/en/simulations/category/physics/motion)
Activity 2: Running the Gauntlet

1) Compare the average velocities of the maglev car at each position. Were the velocities consistent or was there variation among them?
   Recall that velocities are the interval distance divided by the travel time. For example, if the car takes 1 second to move from the 40 to 120 cm mark, then its velocity is 80 cm/1 sec = 80 cm/sec. If using different interval lengths (e.g. 60 cm) then students should be reminded to use that interval length in the calculations.
   Some variation can be expected in the velocity calculations due to air resistance, friction, and human error in measuring the time between intervals. However, if a particular run has a speed of 100 cm/sec at the 80 cm mark, then the speed should be close to 100 cm/sec at the 120 cm mark.

2) How does Newton's First Law of Motion relate to the time comparison between positions?
   Objects in motion tend to stay in motion; therefore, an object’s velocity remains constant. This is true—unless acted upon by an outside force—and in a perfect experiment where there are no outside forces, we would have a perfectly constant velocity forever. However, in this activity, as in real life, friction and air resistance would eventually cause an object to come to rest. The maglev track reduces many of these outside forces; however, we cannot remove them all.

3) How close were your data points to falling on the straight line of best fit?
   Answers here may certainly vary, though we could hope for the data to fall fairly close to a straight line. On the other hand, be prepared for the data that does not.

4) Since these measurements were taken using a stopwatch, what factors need to be considered that may add to an error in measurement? How does this relate to how straight your data on the graph appears to be?
   If Newton’s First Law is correct, then an object traveling at a constant velocity should yield a straight line and slope equal to the value of that velocity. Given an individual data point, its location could be off by 0.1 to 0.2 seconds in any direction, shifting its horizontal location on the graph. Errors in starting and stopping could also be off by as much as a cm or more depending on how fast the car is going. Again, this would shift the data point’s location; this time in the vertical direction.
   At least three factors may be considered:
   • Human reaction time to start and stop the stopwatch
   • The definition of when the car had “passed” the beginning and endpoint
   • Whether or not the car “hit” the side of the track as it traveled (or whether it wobbled)

5) An alternative method of doing this activity would have been to simply start and stop the watch every 40 cm. Had one done that alternative method, what additional sources of error would result?
   Two sources of error should be noted:
   First, the time between the stopwatch starting and stopping would be less. As the activity is presently done, for example, a student at the 120 cm mark starts the stopwatch at 40 cm and stops it at 120 cm. By contrast, was the alternative method to be undertaken, the student would start the
watch at 80 cm and stop it at 120 cm. At higher speeds, this can be difficult to do reliably because of perception-reaction time requirements.

Second, the distance interval would be less. Suppose, for example, students tend to “misread” the point at which the car passes a marker. An observation error of 2 cm for an 80 cm interval (the way the lab was just done) is not as severe a problem as an observation error of 2 cm for a 40 cm interval (the alternative method). Because the errors are presumed to be the same (e.g. 2 cm), the error will have a greater effect for a shorter interval.

6) Newton’s First Law of Motion states that an object will remain moving in a straight line at a constant speed unless acted upon by an external force. Explain how this is an important concept to understand for a driver traveling on an icy road.

When a road is icy, the force of friction between the tires and the road surface becomes less than when the pavement is dry. This means it will take a greater distance to come to a stop on ice than dry pavement. If the traction between tires and road surface becomes small enough and the tires start to slide, then the car will, consequently, travel in a straight line and maintain its current speed.

7) How does the slope of the line on your graph compare to the calculated velocity for each trial?

The graph shows time on the x axis and position on the y axis. An object traveling at a high velocity will achieve a greater position in a shorter period of time. An object traveling slow will take much longer to travel between two points. On the graph, a greater velocity (faster object) will have a steeper (more vertical) slope and a lesser velocity (slower object) will have a flatter (more horizontal) slope.

Discussion

Compare student data. Discuss measurement error. A position vs. time graph with a straight trend line indicates a constant velocity, the value of which can be determined from the slope. Reiterate Newton’s First Law and the fact that once in motion, an object such as a car wants to maintain that straight-line motion at a constant speed. The low amount of friction on a maglev track allows us to see this law in action, but the implications in real life point to the necessity of having good traction between tires and pavement, as well as good brakes and an adequate stopping distance. These are among primary considerations when transportation engineers design roads for highway safety.

Air resistance and friction against the sides of the track may affect the results. This activity illustrates a realistic occurrence in transportation, where just as friction eventually slows the vehicle to a stop, transportation professionals must account for friction when they consider the ability of a vehicle to stop on varying surfaces during varying conditions. The friction between the tires of your automobile and the road determines your maximum acceleration and, more importantly, your minimum stopping distance.
Activity 2: Running the Gauntlet

Introduction

In this activity, you will measure the time in which a maglev car travels between intervals along a horizontal track. The data collected will help demonstrate Newton’s First Law of Motion. As you plot your data on a position vs. time graph and measure its slope, you’ll be able to verify that your car was traveling at a constant velocity. The data may be graphed in either the Research Notes section or using a spreadsheet. It is suggested that Activity 1: Timing Newton’s Apple be completed before this lab.

Objective

You will collect position vs. time data and use it to verify Newton’s First Law of Motion.

Background

Observing Newton’s First Law at work in the classroom requires that we eliminate some of the friction forces normally present. One way to accomplish this is by using the maglev track, which allows the vehicle to levitate in the air due to repulsive magnetic forces. With the track on a level surface, a small push given to the vehicle will allow it to glide down the track at an almost constant velocity for the length of the track.

Consider a hockey player standing on the ice. The player will continue to stand still until something, such as an opposing player, hits him or her with a body check.

Now consider a scenario where a hockey player is moving in a straight line and at a constant speed. According to Newton’s First Law, the hockey player will continue to move in that direction and speed until acted upon by an outside force. Now imagine that this hockey player is hit by another player. The original player may have initially been skating in one direction, but, after being checked, goes off at an angle. The second player in this situation is the outside force that acted upon the original player.

Even a hockey puck sliding across the ice follows this law. If you watch the hockey puck moving with no one touching it, it goes in a straight line until it hits the hockey stick as shown in Figure 2-1.

Figure 2-1: Puck sliding across ice

Considering Newton’s First Law of Motion, if an object travels at a constant velocity then it travels an equal distance over a constant time interval (without any outside forces acting on it). Therefore, if you plot your data on a position vs. time graph, you should see a straight trend line with a slope value...
corresponding to the velocity. For example, consider the data shown in Table 2-1. When this data is plotted on a Position vs. Time graph, it would look like Figure 2-2:

<table>
<thead>
<tr>
<th>Position</th>
<th>Centimeters (cm)</th>
<th>40</th>
<th>80</th>
<th>120</th>
<th>160</th>
<th>200</th>
<th>240</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>Seconds (sec)</td>
<td>0</td>
<td>0.2</td>
<td>0.4</td>
<td>0.6</td>
<td>0.8</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 2-2: Position vs. Time graph

If we remember the definition of slope (rise/run) and the definition of velocity (change in position/time), we can see how the slope of the graph and velocity are the same. Take the furthest position traveled by the object and subtract the nearest position from that value, producing the total distance traveled. Then, divide the distance by the time it took to travel that distance (take the final time and subtract the initial time). Using the points (0 sec, 40 cm) and (1 sec, 240 cm), we get a slope:

\[
Slope = \frac{Y_2 - Y_1}{X_2 - X_1} = \frac{240 \text{ cm} - 40 \text{ cm}}{1 \text{ s} - 0 \text{ s}} = \frac{200 \text{ cm}}{1 \text{ s}} = 200 \text{ cm/s}
\]

Thus, 200 cm/sec was the velocity of the car. Please note for the purpose of collecting reasonably accurate data, your car should go much slower than 200 cm/sec!!
Materials

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maglev track</td>
<td>1</td>
</tr>
<tr>
<td>Maglev car</td>
<td>1</td>
</tr>
<tr>
<td>Vertical Reference Lines</td>
<td>6</td>
</tr>
<tr>
<td>Graph paper or Computer with spreadsheet program</td>
<td>1 per student</td>
</tr>
<tr>
<td>Stopwatches</td>
<td>5 or more</td>
</tr>
<tr>
<td>Pencil</td>
<td>1 per student</td>
</tr>
</tbody>
</table>

Setup

The maglev track should be setup on a level surface as shown in Figure 2-3. Place a maglev car with either a vertical marker or a reference line drawn across the top of the car on one end of the track. Student volunteers will record the time interval as the maglev car passes between various points along the track as defined in the procedure section. If enough stopwatches are available, several students can share in the time measurement and average their results.

![Figure 2-3: Maglev track](image)

Procedure

1. Five students will time the maglev car between intervals. To reduce measurement errors, all students will start timing at 40 cm. The first student will time the interval starting at 40 cm and ending at 80 cm. The remaining four students will start timing at 40 cm and end at 120 cm, 160 cm, 200 cm, and 240 cm intervals, respectively.
   Note: With more or fewer timers, you can choose different distance intervals as long as those intervals are equal in size.
2. Give the car a small push.
   Note: You don’t want the velocity to be too fast or the timing error will be too large. A push that results in the car taking about 3 seconds to run the length of the track has worked well in the past, although you can experiment with different amounts of push until you have a velocity that is quick enough that the car does not stop but is slow enough that the car can be measured accurately.
3. All five students will begin timing at the 40 cm mark (at the same time) and stop at their designated interval.
   Note: Within the range of timing errors, times for each distance interval should increase by approximately the same amount.
4. Record the results in the data table in the Research Notes section.
5. Repeat the test for a total of three trials to obtain a larger data set.
6. Share your data on the board for discussion.

**Graphing the Data**

Graph the data in the space provided in the *Research Notes* section.

**Part A**

Plot the cumulative time for all three trials against the position. The horizontal axis should be time and the vertical axis should be position. Your graph will have three lines on it. Variation of the speed of the car between each trial is acceptable. The focus of this activity is that, regardless of the speed, the velocity is constant (ideally) for the duration of each trial. As for the velocity of each trial, it is related to the slope of the line. A fast car produces a steeper (more vertical) line and a slow car produces a flatter (more horizontal) line on the graph.

**Part B**

Use the data table from Part A to calculate the velocity of the maglev car at each position along the track and enter the calculated velocity in the Part B data table. Calculate the average velocity at each position using the velocities from each trial.

The horizontal axis should be time and the vertical axis should be velocity. Graph the data from each of your three trials, as you did in Part A.

A “line of best fit” is a line drawn on a graph which best represents the data collected in a trial or over several trials. The line of best fit can be straight or curved and should have approximately the same number of data points on both sides of the line. Graph the average of the computed velocities and draw a line through those data points, this will serve as the line of best fit for your data.
Activity 2: Running the Gauntlet

Part A: Data Table

Record the trial times in the data table and calculate the average time at each position.

<table>
<thead>
<tr>
<th>Position (cm)</th>
<th>Cumulative Time (s)</th>
<th>Average Time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trial 1</td>
<td>Trial 2</td>
</tr>
<tr>
<td>40</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>120</td>
<td></td>
<td></td>
</tr>
<tr>
<td>160</td>
<td></td>
<td></td>
</tr>
<tr>
<td>200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>240</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Part A: Graph

Position vs. Time

Time (s)
Part B: Data Table

Calculate the velocity for each position on the track then determine the average velocity.

<table>
<thead>
<tr>
<th>Interval</th>
<th>Average Time</th>
<th>Calculated Velocity (cm/s)</th>
<th>Average Velocity (cm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(from Part A)</td>
<td>(from Part A)</td>
<td>Trial 1</td>
<td>Trial 2</td>
</tr>
<tr>
<td>40cm-80cm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40cm-120cm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40cm-160cm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40cm-200cm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40cm-240cm</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Part B: Graph

![Velocity vs. Time Graph](image)
Questions

1) Compare the average velocities of the maglev car at each position. Were the velocities consistent or is there variation among them?

2) How does Newton’s First Law of Motion relate to the time comparison between positions?

3) How close were your data points to falling on the straight line of best fit?

4) Since these measurements were taken using a stopwatch, what factors need to be considered that may add to an error in measurement? How does this relate to how straight your data on the graph appears to be?

5) An alternative method of doing this activity would have been to simply start and stop the watch every 40 cm. Had one done that alternative method, what additional sources of error would result?
6) Newton’s First Law of Motion states that an object will remain moving in a straight line at a constant speed unless acted upon by a force. Explain how this is an important concept to understand for a driver traveling on an icy road.

7) How does the slope of the line on your graph compare to the calculated velocity for each trial?

Discussion Notes
Activity 3: Caution — 6% Grade Ahead!

### Activity Summary

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Instructor Prep Time</strong></td>
<td>20 minutes</td>
</tr>
<tr>
<td><strong>Class Time</strong></td>
<td>20 minutes</td>
</tr>
<tr>
<td><strong>Grade/Class</strong></td>
<td>6 - 8 Physical Science</td>
</tr>
<tr>
<td><strong>Suggested Activity Grouping</strong></td>
<td>Classroom demonstration or small group work (lab)</td>
</tr>
<tr>
<td><strong>Technology</strong></td>
<td>Low Tech</td>
</tr>
</tbody>
</table>
| **National Science Education Standards** | Appropriate tools  
|                       | Technology and mathematics  
|                       | Think critically  
|                       | Motion and forces |

**Introduction**

This activity may be presented as either a demonstration or a hands-on lab to illustrate Newton’s Second Law of Motion. The activity is designed to demonstrate Newton’s Second Law of Motion using an inclined maglev track. Either a student or the teacher sets the maglev car in motion while five to ten additional students record the time it takes the car to travel a given distance down the track. Equal distances traveled in progressively shorter increments of time indicate that the car is accelerating, confirming Newton’s Second Law: an object accelerates when subjected to an unbalanced force, in this case gravity. The data is collected to graph position vs. time. The data may be plotted by hand on graph paper or with the aid of a spreadsheet. Though the data is collected by five to ten students, all students in the class will graph and analyze the data. Data analysis will verify Newton’s Second Law of Motion.

**Objective**

Students will collect position vs. time data and use it to verify Newton’s Second Law.

**Background**

Often roads are created at specific grades in order to accommodate geographical constraints such as hills or valleys. Students will learn how a road grade is calculated, as well as important information such as how velocity will change as a result of different grades. This activity can be combined with the concept of momentum to explain why minimizing grade can help reduce the severity of impacts.

**Activity Expansion Ideas**

To explore how design decisions for roadway grades are made, students could research climbing lanes and runaway truck ramps. These design options are used to create a safer environment on the roadway. When looking into these topics, students could relate them to associated terrain, to how they make the roadway safer, and to the effect of certain weather conditions on their use.

In order to further understand climbing lanes and runaway truck ramps, videos are linked below:
Climbing lanes: https://www.youtube.com/watch?v=wWtWBjgYMUI

Runaway truck ramps: https://www.youtube.com/watch?v=RAnhWmi1Eml
Activity 3: Caution – 6% Grade Ahead!

Questions

1) Explain what happened to the speed of the maglev car as it traveled down the maglev track incline.
   As the car moved down the track, it accelerated due to gravity. That is, its velocity increased—the car was traveling faster at the 200 cm position than it was at the 20 cm position.

2) Newton’s Second Law states that the acceleration of an object is directly proportional to the force acting upon it and will move in the direction of the applied force. What force is acting on the maglev car and in what direction?
   The only force acting on the car is gravity. Engineers use the term “normal” to refer to a force perpendicular to a surface. Imagine if the ramp was flat, the normal (perpendicular) force would be exactly equal to gravity and the car would stay in place. Since the normal force always acts away from the surface of the track, and the track is at an angle, the normal force due to gravity does not act in the same direction as gravity itself. If an object is sitting motionless on an incline plane the force of friction is equal to the component of gravity parallel to the incline. In the case of our maglev track, this surface friction is not present which causes an unbalanced force, and so the car moves.

3) Using Newton’s Second Law of Motion, explain what happens to a truck if it loses its brakes as it descends a steep grade.
   The truck will continue to accelerate, since there will be no force acting to stop it. Runaway truck ramps exist for this reason. When the maglev car came to the end of the track, it did not stop on its own but rather kept going until it crashed into something (a student catching it) or stopped due to friction on a level surface (the table or desk). Similarly, a truck ramp uses a combination of friction (gravel or sand) and an upwards ramp to stop a truck whose brakes have failed.

4) Which timed interval likely had the greatest inaccuracy due to human error? The first or last interval? Why?
   Human error will be a factor in all measurements. Over the first interval the car will be moving slower and therefore human error is likely to be less. The car will be moving faster over the last interval and as a result the likelihood of human error is greater. However, the first interval is shorter and will be more subject to the human error in perceiving the location of the car relative to the position marks and the reaction time of the timer when considered as a percent error of the measured value. The last interval, being a longer duration in time, will have the same sources of error but will be smaller when considered as a percentage of the measured value.

5) How could this experiment be changed in order to reduce error?
   The easiest way to reduce error would be to remove human timers and, instead, install electronic sensors that would measure the velocity at specified points. In addition, we could factor in forces such as wind resistance and try to reduce friction as the car rubs against the sides of the track.
Discussion

Compare student data. Discuss measurement error. Reiterate Newton’s Second Law, which states that when an object is subjected to an unbalanced force it will accelerate. Reinforce the notion that acceleration occurs not just when you speed up, but also when you slow down. Transportation engineers must confront a similar scenario when they design a road with a certain grade. Ask if any students have ever seen a runaway truck ramp, and ask them to explain how they think it works.
Activity 3: Caution – 6% Grade Ahead!

Introduction
In this activity, you will time a maglev car’s acceleration down an inclined track to illustrate Newton’s Second Law of Motion. You will then graph your data to verify Newton’s Second Law.

Objective
You will collect position vs. time data and use it to verify Newton’s Second Law.

Background
Engineers use the term grade to define the steepness of a hill. In Figure 3-1 below, we can see the progression that a grade can take. You have probably seen or even driven on roads with significant grades and have noticed the steepness.

Figure 3-1: Grade is a measure of the steepness of a hill

Grade is the slope of a hill. Much like the slope you calculate in math class and in Activity 2, grade is the slope (rise/run) expressed as a percent.

\[
\frac{\text{rise}}{\text{run}} \times 100\% = \text{grade}
\]

For example, imagine going on a long hike where you begin at sea level and then reach the peak of a mountain. If the base of the mountain is 10 miles away from the top (i.e. the horizontal distance is 10 miles) and the height of the mountain is 0.5 miles high, then the overall grade is

\[
(0.5 \text{ miles/10 miles}) \times 100\% = 5\%
\]

For roads, the grade tends to be relatively flat in order to allow cars to be more fuel efficient; however, the grade of a road is highly dependent on the natural topography of the area.
**Materials**

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maglev track</td>
<td>1</td>
</tr>
<tr>
<td>Maglev car</td>
<td>2</td>
</tr>
<tr>
<td>Boxes/books to support track</td>
<td>As needed</td>
</tr>
<tr>
<td>Stopwatches</td>
<td>1 per interval</td>
</tr>
<tr>
<td>Vertical Reference Lines</td>
<td>6</td>
</tr>
<tr>
<td>Pencil</td>
<td>1 per student</td>
</tr>
<tr>
<td>Graph paper or Computer with spreadsheet program</td>
<td>1 per student</td>
</tr>
</tbody>
</table>

**Setup**

Place the maglev track on supports to provide a uniform slant as shown in Figure 3-2. It is important that there are no bends in the track and that the angle is reasonably small. A grade of 10% is a recommended starting point. You can elevate the beginning of the track such that a point 100 cm away from the beginning is about 10 cm high (or any distance as long as the 1:10 rise to run ratio is consistent). Place a maglev car with a vertical marker or a reference line drawn across the top of the car on the track. Obtain a stopwatch from the instructor.

![Figure 3-2: Inclined maglev track with vertical reference lines to aid in accurate timing](image)

Use tape to attach popsicle sticks or straws to the track as vertical reference lines. Your instructor will assign you a length of the track (interval) to time. Before beginning the activity, note which length of track you will be timing, for example starting at 0 cm and stopping at 120 cm. The vertical reference lines will help identify the location of the car relative to the track for more accurate timing.

**Procedure**

1. Release the car from the top of the track. Do not push the car, allow gravity accelerate the car from rest. Begin timing as the car is released.
2. Stop the stopwatch when it gets to the second mark on your interval. (For instance, if you are timing the interval from 0 cm to 120 cm, you should time from the start of the track to the 120 cm mark.) Intervals are shown in Figure 3-3.
3. To find the time it took the car to travel through your interval, subtract the time measured from the start to the first mark on your interval.

\[(\text{Time from 0 cm to 120 cm}) - (\text{Time from 0 cm to 80 cm}) = \text{Time from 80 cm to 120 cm}\]

4. Record the time for your interval in the appropriate row in the data sheet provided in the Research Notes section.

5. Share your results with the other students, and record all times on the data sheet in the Research Notes section.

6. Repeat steps 1–5 for trials two and three.

7. Calculate velocity by dividing the distance traveled by the time it took to travel.

8. Use the grid provided in the Research Notes section to graph the data from all three trials.

9. Continue to the questions in the Research Notes section.
Activity 3: Caution – 6% Grade Ahead!

Data Sheet

<table>
<thead>
<tr>
<th>Position (cm)</th>
<th>Trial Time (s)</th>
<th>Average Time (s)</th>
<th>Average Velocity (cm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trial 1</td>
<td>Trial 2</td>
<td>Trial 3</td>
</tr>
<tr>
<td>40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>120</td>
<td></td>
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<td></td>
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<td>160</td>
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</tr>
<tr>
<td>200</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>240</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Graph

Position vs. Time

- Trial 1
- Trial 2
- Trial 3
Questions

1) Explain what happened to the speed of the maglev car as it traveled down the maglev track incline.

2) Newton’s Second Law states that the acceleration of an object is directly proportional to the force acting upon it and will move in the direction of the applied force. What force is acting on the maglev car and in what direction?

3) Using Newton’s Second Law of Motion, explain what happens to a truck if it loses its brakes as it descends a steep grade.

4) Which timed interval likely had the greatest inaccuracy due to human error, the first or last interval? Why?

5) How could this experiment be changed in order to reduce error?
Discussion Notes
Activity 4: Graphing the Grade

<table>
<thead>
<tr>
<th>Activity Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instructor Prep Time</td>
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<td>Class Time</td>
</tr>
<tr>
<td>Grade/Class</td>
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<td>Suggested Activity Grouping</td>
</tr>
<tr>
<td>Technology</td>
</tr>
<tr>
<td>National Science Education Standards</td>
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</tbody>
</table>

Introduction

This activity may be presented as either a demonstration or a hands-on lab to illustrate Newton’s Second Law of Motion. The activity is designed to demonstrate Newton’s Second Law of Motion using an inclined maglev track. Either a student or the teacher sets the maglev car in motion while five to ten additional students record the time it takes the car to travel a given distance down the track. Equal distances traveled in progressively shorter increments of time indicate that the car is accelerating, confirming Newton’s Second Law: an object accelerates when subjected to an unbalanced force, in this case gravity. The data is collected to graph velocity or position vs. time. The data may be plotted by hand on graph paper or with the aid of a spreadsheet. Though the data is collected by five to ten students, all students in the class will graph and analyze the data. Data analysis will verify Newton’s Second Law of Motion.

Objective

Students will collect data to graph the position vs. time of an object moving at constant acceleration, as well as a velocity vs. time graph using the same data. Results will be used to illustrate Newton’s Second Law of Motion, while giving students a better understanding of graphical interpretation by having them determine the slope of their trend line.

Background

Often roads are created at specific grades in order to accommodate geographical constraints. Students will learn how a road grade is calculated, as well as important information such as how acceleration of gravity affects a vehicle’s velocity as it travels down a slope. You can combine this information with the concept of momentum to explain why it is important to minimize grade to reduce the severity of impacts.

Grade and slope are two different ways of expressing the steepness of an incline. Grade is the steepness expressed in percent and is typically used by highway engineers. A grade of 5.5% means that
for every 100 horizontal feet of roadway a user will ascend or descend 5.5 feet vertically. If you think of this as a right triangle, the horizontal leg would be 100 feet and the vertical leg would be 5.5 feet, and, using the inverse tangent function, you’ll find that a grade of 5.5% corresponds to a slope of 3.15 degrees. Slope is typically measured in terms of an angle in degrees.

Activity Expansion Ideas

Spreadsheet software could be used as an alternative to graphing the data by hand. Students could also use the spreadsheet to calculate average values.
Activity 4: Graphing the Grade

Questions

1) What happens to the car’s velocity as it travels down the track?
   The car’s velocity will continue to increase, and the rate at which it increases is exponential. For example, the velocity from 20cm to 40cm will be less than the velocity from 40cm to 60cm. Since gravity accelerates an object at 9.81m/s², we know that some component of this, based on the angle of the ramp, will accelerate the car.

2) Errors often occur during data collection in an experiment. What are some of the potential sources of error in this experiment?
   There are some basic sources of error, such as
   - Human error, both in the ability to start and stop timing accurately, as well as consistency regarding at what point the car passed each marker
   - Factors such as wind resistance and friction are not considered in our experiment.

3) Newton’s Second Law states that the acceleration of an object is directly proportional to the force acting upon it and will move in the direction of the force. What force is acting on the maglev car and in what direction?
   The only force acting on the car is gravity. Engineers use the term “normal” to refer to a force perpendicular to a surface. Imagine if the ramp was flat, the normal (perpendicular) force would be exactly equal to gravity and the car would stay in place. Since the normal force always acts away from the surface of the track, and since the track is at an angle, the normal force due to gravity does not act in the same direction as gravity itself. If an object is sitting motionless on an incline plane the force of friction is equal to the component of gravity parallel to the incline. In the case of our maglev track, this surface friction is not present which causes an unbalanced force, and so the car moves.

4) What was the value of the acceleration of the car as determined by the slope of the velocity vs time graph?
   The acceleration of the car is the slope of the line that represents velocity vs time. This is calculated by taking the difference in velocity between two points and dividing that number by the difference in time between the two points. The acceleration of the car down the ramp should equal the component of the acceleration of gravity in the direction of the ramp (g*sinθ, where g = acceleration of gravity and θ = the angle of the maglev track).

5) In Figures 4A, 4B, and 4C, a frictionless truck that was traveling at 50 mph has suddenly lost its brakes. The only force now acting on the truck is gravity. Assume that a positive velocity is moving towards the left.
   (a) In Figure 4A, place a “+” in front of the acceleration term if the acceleration and velocity are in the same direction. If they are in different directions, place a “-” in front of the acceleration term.
Acceleration = +13 ft/s²

(b) Similarly, in Figure 4C, place a “+” in front of the acceleration term if the acceleration and velocity are in the same direction. If they are in different directions, place a “-” in front of the acceleration term.
   Acceleration = -13 ft/s²

(c) Suppose the incline in each figure is infinitely long. In which figure will the truck eventually switch directions?
   Figure 4C

(d) In designing a runaway truck ramp, should the angle of the surface be more similar to Figure 4A, 4B, or 4C, and what kind of material (water, mud, sand, loose gravel, wood chips, concrete, asphalt, large rocks, etc.) would you recommend for the surface of the runaway truck ramp?
   Figure 4C

The truck will eventually come to a stop in Figure 4C, and then switch directions, as the velocity and the acceleration have opposite signs. In Figure 4A, the truck will keep going indefinitely and at a faster and faster speed, and in Figure 4B, the truck will continue to travel at a constant speed of 50 mph, assuming no friction.

A runaway truck will be accelerating down an incline, so it will travel faster and faster. In fact, its velocity will increase until it finally is forced to come to a stop. Runaway truck ramps exist for this reason. When the maglev car came to the end of the track, it did not just stop but rather kept going until it was caught by a student or stopped due to friction on a level surface (the table or desk). Thus, a runaway truck ramp should be inclined upward, similar to Figure 4C, and should use a material that increases friction (such as gravel). In short, a runaway truck ramp uses a combination of friction (gravel or sand rather than a smooth, almost friction-free surface) and an obstacle (a pile of sand or gravel) to stop the truck whose brakes have failed.

6) Newton’s Second Law also states that acceleration is inversely proportional to the mass of the object. Suppose one day a truck travels uphill and the next day it goes up the same hill with a load that is twice as heavy. What would happen to the truck’s acceleration as it climbs the hill?
The truck will travel slower up the hill. If we consider the formula $F=ma$ and we assume the force applied to the truck from its engine is constant and the mass doubles, the acceleration must halve in order for the equation to remain valid.

<table>
<thead>
<tr>
<th>Newton’s Second Law</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F = ma = 2m \times \frac{a}{2}$</td>
</tr>
</tbody>
</table>

Where:
- $F =$ force
- $m =$ mass
- $a =$ acceleration

**Discussion**

Compare student data. Discuss measurement error. Reiterate Newton’s Second Law, which states that when an object is subjected to an unbalanced force that it will accelerate. Reinforce the notion that acceleration occurs not just when you speed up, but also when you slow down or turn. Transportation engineers must confront this same scenario when they design a road with a certain grade. Ask students what would happen if they were coming down a hill and their brakes failed. Ask if any students have ever seen a runaway truck ramp, then ask the students to make predictions of what happens when an out of control vehicle uses one. Show video of a runaway truck ramp being used.

Although this lab can be done as a class time exercise within a 50-minute period, you might consider having the students write this up as a lab report containing objective, materials list, procedure, data table, graph, error analysis, and conclusion. A lab report requires more time; which students can do outside of class. If you have enough equipment available, this activity could be done in small groups.
Activity 4: Graphing the Grade

Introduction

In this activity, you will time a maglev car’s acceleration down an inclined maglev track to illustrate Newton’s Second Law of Motion. You will then graph your data to verify Newton’s Second Law.

Objective

You will collect data to graph the position vs. time of an object moving at constant acceleration, as well as velocity vs. time. Results will be used to illustrate Newton’s Second Law of Motion, while giving you a better understanding of the uses of slope to analyze data.

Background

If an object travels with constant acceleration, it will continue to increase in speed. If you plot a graph of position vs. time for an object with constant acceleration, you will see that the object’s position will increase exponentially. If you plot the velocity with respect to time, for an object with constant acceleration, the slope of the data will be linear, since the slope of a velocity vs. time graph is the acceleration. For example, consider the data presented in Table 4-1 which is graphed in Figure 4-1.

<table>
<thead>
<tr>
<th>Position</th>
<th>Centimeters (cm)</th>
<th>40</th>
<th>80</th>
<th>120</th>
<th>160</th>
<th>200</th>
<th>240</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>Seconds (sec)</td>
<td>0</td>
<td>0.80</td>
<td>1.17</td>
<td>1.45</td>
<td>1.69</td>
<td>1.90</td>
</tr>
</tbody>
</table>

Figure 4-1: Position vs time graph
The curved line indicates that the object was not moving at a constant velocity but was instead accelerating, traveling the same distance in less and less time. Its rate of acceleration can be found by looking at a graph of velocity vs. time for the same event.

You can determine the average velocity at certain points based on the data from the position graph. By finding the distance traveled in an interval, divided by the time of that interval, you can determine the approximate velocity between two points. For example, if you know the object traveled from 60cm to 80cm between 0.4s to 0.8s, then we know that it moved \( \frac{(80\text{cm} - 60\text{cm})}{(0.8\text{s} - 0.4\text{s})} = 50 \text{ cm/s} \)

A second method for obtaining the velocity is to measure the slope of a tangent line drawn to the curve at particular points on the position vs. time graph. Figure 4-1 shows a tangent line drawn at the 0.8 second data point. The angle between the tangent and the line connecting the data points should be the same on both sides of the data point. We know that the slope of a position vs. time graph is the velocity, rather than measuring the average velocity between two data points we can estimate the velocity at each data point by drawing a tangent line and determining the slope of that line. This is somewhat more difficult to do with precision but, if done carefully, yields a quality graph. The data shown in Table 4-2 comes from the tangent method applied to determine the average velocity at each data point in Figure 4-1.

### Table 4-2. Using the tangent method to determine average velocity

<table>
<thead>
<tr>
<th>Velocity (cm/sec)</th>
<th>10</th>
<th>90</th>
<th>127</th>
<th>155</th>
<th>179</th>
<th>200</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (sec)</td>
<td>0</td>
<td>0.80</td>
<td>1.17</td>
<td>1.45</td>
<td>1.69</td>
<td>1.90</td>
</tr>
</tbody>
</table>

A velocity vs. time graph of the data from Table 4-2 is shown in Figure 4-2.
Determine the slope of the velocity vs. time graph by using two points along the line. The slope indicates that this particular object was accelerating at a rate of 100 cm/sec². This would be quite a bit faster than you would want to work with since the short time intervals typically lead to larger errors in measurement.

Advanced Background Material

The term grade reflects the steepness of a hill. Grade is computed as vertical distance divided by the horizontal distance, expressed as a percentage. For example, consider a road similar to that shown in Figure 4-3, where the horizontal distance is 300 feet and the vertical distance is 42 feet. The overall grade is

\[
\frac{42 \text{ feet}}{300 \text{ feet}} \times 100\% = 14\%
\]

Sometimes the grade is written as a ratio rather than a percentage. For example, in this case, it would be \(42\text{ft}/300\text{ft} = 1 : 7.1428\). For a computed grade, it is usually easier to state the grade in terms of a percentage. However, a ratio can be helpful when stating a required grade for a slope, such as 1:10 where the vertical distance increases by one foot for every 10 horizontal feet which is a value that can easily be measured with land surveying equipment or even a yard or meter stick and a carpenter’s level.

Take note that the grade and the angle are NOT the same thing, as this is an important part of the concept to grasp. Grade is a measure of slope, while the angle is a measure of the rotation between two lines. Using Figure 4-4, we will explore the difference.
Tangent Relationship Formula

\[ \tan(\theta) = \frac{o}{a} \]

Where:
- \( o \) = opposite side height
- \( a \) = adjacent side length

Figure 4-4: Trigonometric terms

When \( o \) (opposite side) is the vertical distance and \( a \) (adjacent side) is the horizontal distance, we can rearrange the equation to solve for the angle theta (\( \theta \)).

\[ \theta = \tan^{-1}\left( \frac{o}{a} \right) \]

\[ \theta = \tan^{-1}\left( \frac{42}{300} \right) = 8^\circ \]

Measuring either the angle or the grade of the maglev track could prove difficult. But if you know the length of the track (hypotenuse) you could calculate the vertical height of the raised end of the track needed to produce either a percent grade or a specific angle relative to a horizontal surface.

The definition of sine can be used to solve for the vertical height ('opposite side' in Figure 4-4) based on the length of the track. For example, if we know that the end of the track is 36 cm off the ground and the track is 240 cm long, we can use the following equation to determine the angle of the track:
**Sine Relationship Formula**

\[
\sin(\theta) = \frac{o}{h}
\]

Where:
- \(o\) = opposite side height
- \(h\) = hypotenuse

\[
\theta = \sin^{-1} \left( \frac{o}{h} \right)
\]

\[
\theta = \sin^{-1} \left( \frac{36}{240} \right) = 8.63^\circ
\]

These trigonometric definitions can be rearranged to solve for the vertical height, grade, or angle of the maglev track. Table 4-3 shows grade and angle of a 240 cm maglev track for a variety of vertical distance measurements.

**Table 4-3. Grade and angle values for various vertical height placements of a 240 cm long maglev track**

<table>
<thead>
<tr>
<th>Vertical Height</th>
<th>Track Distance</th>
<th>Grade</th>
<th>Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 cm</td>
<td>240 cm</td>
<td>0% or 0:0</td>
<td>0°</td>
</tr>
<tr>
<td>7.2 cm</td>
<td>240 cm</td>
<td>3% or 1:33.3</td>
<td>1.72°</td>
</tr>
<tr>
<td>12 cm</td>
<td>240 cm</td>
<td>5% or 1:20</td>
<td>2.87°</td>
</tr>
<tr>
<td>24 cm</td>
<td>240 cm</td>
<td>10% or 1:10</td>
<td>5.74°</td>
</tr>
<tr>
<td>34 cm</td>
<td>240 cm</td>
<td>14% or 1:7.06</td>
<td>8.14°</td>
</tr>
<tr>
<td>36 cm</td>
<td>240 cm</td>
<td>15% or 1:6.66</td>
<td>8.63°</td>
</tr>
</tbody>
</table>

**Materials**

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maglev track</td>
<td>1</td>
</tr>
<tr>
<td>Maglev car</td>
<td>2</td>
</tr>
<tr>
<td>Boxes/books to support track</td>
<td>As needed</td>
</tr>
<tr>
<td>Stopwatches</td>
<td>1 per interval</td>
</tr>
<tr>
<td>Vertical Reference Lines</td>
<td>6</td>
</tr>
<tr>
<td>Pencil</td>
<td>1 per student</td>
</tr>
<tr>
<td>Graph paper or Computer with spreadsheet program</td>
<td>1 per student</td>
</tr>
</tbody>
</table>
Setup

Place the maglev track on supports to provide a uniform slant in the best location observable by the class, as shown in Figure 4-5. It is important that there are no bends in the track and that the angle is reasonably small. A grade of 10% is a recommended starting point. The track should be elevated such that a point 100 cm away from this beginning is about 10 cm high (or any distance as long as the 1:10 rise to run ratio is kept). Obtain a stopwatch and use straws or popsicle sticks provided to mark each interval with the vertical reference lines.

![Inclined maglev track with vertical reference lines](image)

**Figure 4-5: Inclined maglev track with vertical reference lines to aid in accurate timing**

Procedure

1. Release the car from the top of the track. Do not give it a push; let gravity accelerate the car from rest. Begin timing as the car is released.
2. Stop the stopwatch when it gets to the second mark on your interval. (For instance, if you are timing the interval from 0 cm to 120 cm, you should time from the start of the track to the 120 cm mark.) Intervals are shown in Figure 4-6.

<table>
<thead>
<tr>
<th>Timer</th>
<th>Interval</th>
<th>Time to Complete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timer 6</td>
<td>Measured time from 0 cm to 240 cm</td>
<td>Time from 200 cm to 240 cm</td>
</tr>
<tr>
<td>Timer 5</td>
<td>Measured time from 0 cm to 200 cm</td>
<td>Time from 160 cm to 200 cm</td>
</tr>
<tr>
<td>Timer 4</td>
<td>Measured time from 0 cm to 160 cm</td>
<td>Time from 120 cm to 160 cm</td>
</tr>
<tr>
<td>Timer 3</td>
<td>Measured time from 0 cm to 120 cm</td>
<td>Time from 80 cm to 120 cm</td>
</tr>
<tr>
<td>Timer 2</td>
<td>Measured time from 0 cm to 80 cm</td>
<td>Time from 40 cm to 80 cm</td>
</tr>
<tr>
<td>Timer 1</td>
<td>Measured time from 0 cm to 40 cm</td>
<td>Time from 0 cm to 40 cm</td>
</tr>
</tbody>
</table>

**Figure 4-6: Interval timing**

3. To find the time it took the car to travel through your interval, subtract the time measured from the start to the first mark on your interval.
(Time from 0 cm to 120 cm) – (Time from 0 cm to 80 cm) = Time from 80 cm to 120 cm

4. Record the time for your interval in the appropriate row in the data sheet provided in the Research Notes section.
5. Share your results with the other students, and record all times in the data sheet in the Research Notes.
6. Repeat steps 1–5 for trials two and three.
7. Calculate velocity by dividing the distance traveled by the time it took to travel.
8. Use the space provided in your Research Notes to graph the data from all three trials.
   a. For the position vs. time graph, graph the data points and draw a smooth curve through the points.
   b. For the velocity vs. time graph, first create a data table of velocity and time using your activity data. Graph those points and draw a line of best fit through them. A line of best fit should hit as many data points as possible while keeping an equal number of missed points on either side of the line.
9. You will now find the velocity by using the collected data (a) or analyzing the graph (b). Examples of what the graph should look like can be found in the background section of this activity. Remember that time should be the x-axis of your graph.
   a. Find the average velocity between two points, this is done by finding the amount of time it took to move a set distance. For example, if it took 2 seconds to move from 40 cm to 80 cm, then you know that your velocity is $\frac{80 \text{ cm} - 40 \text{ cm}}{2 \text{ s}} = 20 \text{ cm/s}$
   b. Measure the slope of the position vs. time graph. This slope is the velocity, and can be found by dividing the rise of the graph (in this case, distance) by the run of the graph (in this case, time).
10. Continue to the questions in the Research Notes section.
Activity 4: Graphing the Grade

Data Sheet

<table>
<thead>
<tr>
<th>Position (cm)</th>
<th>Trial Time (s)</th>
<th>Average Time (s)</th>
<th>Average Velocity (cm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trial 1</td>
<td>Trial 2</td>
<td>Trial 3</td>
</tr>
<tr>
<td>40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>120</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>160</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>200</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>240</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Graphs

Position vs. Time

- Trial 1
- Trial 2
- Trial 3
- Average Time
Questions

1) What happens to the car’s velocity as it travels down the track?

2) Errors often occur during data collection in an experiment. What are some of the potential sources of error in this experiment?
3) Newton’s Second Law states that the acceleration of an object is directly proportional to the force acting upon it and will move in the direction of the force applied on it. What force is acting on the maglev car and in what direction?

4) What was the value of the acceleration of the car as determined by the slope of the velocity vs. time graph?

5) In Figures 4A, 4B, and 4C, a frictionless truck that was traveling at 50 mph has suddenly lost its brakes. The only force now acting on the truck is gravity. Assume that a positive velocity is moving towards the left.

(a) In Figure 4A, place a “+” in front of the acceleration term if the acceleration and velocity are in the same direction. If they are in different directions, place a “-” in front of the acceleration term.

(b) Similarly, in Figure 4C, place a “+” in front of the acceleration term if the acceleration and velocity are in the same direction. If they are in different directions, place a “-” in front of the acceleration term.

(c) Suppose the incline in each figure is infinitely long. In which figure will the truck eventually switch directions?

(d) In designing a runaway truck ramp, should the angle of the surface be more similar to Figure 4A, 4B, or 4C, and what kind of material would you recommend for the surface of the runaway truck ramp?
6) Newton’s Second Law also states that acceleration is inversely proportional to the mass of the object. Suppose one day a truck travels uphill and the next day it goes up the same hill with a load that is twice as heavy. What would happen to the truck’s acceleration as it climbs the hill?
Activity 5: Float Like a Butterfly, Sting Like a Bee

**Activity Summary**

<table>
<thead>
<tr>
<th>Instructor Prep Time</th>
<th>10 minutes prep</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Class Time</strong></td>
<td>20 minutes lesson time</td>
</tr>
<tr>
<td></td>
<td>50 minutes building time</td>
</tr>
<tr>
<td></td>
<td>30 minutes racing time</td>
</tr>
<tr>
<td><strong>Grade/Class</strong></td>
<td>6 - 12 Intermediate</td>
</tr>
<tr>
<td><strong>Suggested Activity Grouping</strong></td>
<td>Individual</td>
</tr>
<tr>
<td><strong>Technology</strong></td>
<td>Low Tech</td>
</tr>
<tr>
<td><strong>National Science Education Standards</strong></td>
<td>Appropriate tools</td>
</tr>
<tr>
<td></td>
<td>Technology and mathematics</td>
</tr>
<tr>
<td></td>
<td>Think critically</td>
</tr>
<tr>
<td></td>
<td>Forces and motion</td>
</tr>
</tbody>
</table>

**Introduction**

This activity is designed to encompass all of the knowledge that you have gained throughout the previous activities focused on Newton’s Laws. Through practical application of their prior knowledge, the introduction of aerodynamics, and the implementation of the design process, students will design and construct their own maglev cars. By testing and racing the vehicles, the physical principles learned throughout the module can be observed.

**Objective**

Students will:

- Design, build, and modify Styrofoam vehicles by applying what they have learned about Newton’s Laws.
- Discover how key principles from the previous activities are put into practical use to design the fastest car.
- Explore the creativity involved in the design process, which can be applied to many disciplines beyond transportation.

**Background**

Aerodynamics is important in the design of vehicles. The size of the engine and fuel economy are two design considerations affected by aerodynamics. The noise within the car is a user experience affected by aerodynamics. Automotive designers look for ways to deflect the air around the car in an attempt to reduce the air resistance. This is why you will see very few, if any, advanced car designs that do not allow for ways that the air can move around the vehicle.

Automobile manufacturers also have to abide by the CAFE (Corporate Average Fuel Economy) Law, which states that the average fuel efficiency for a company’s fleet of vehicles must be at least 40.3 mpg.
(https://www.transportation.gov/mission/sustainability/corporate-average-fuel-economy-cafe-standards). The important safety regulations, to which vehicles must adhere, are outlined by the Federal Motor Vehicle Safety Standards (FMVSS). These laws include hundreds of regulations for everything from gas tanks to child safety seats. After the manufacturers ensure that their car meets the legal standards for safety and the environment, the designers continue to balance these and factors that they believe will be important to their consumers.

**Activity Expansion Ideas**

As mentioned in the background of this activity, maglev trains relate closely to this topic. Within the background, there is a general description of the maglev trains. In this activity expansion, students are challenged to write a report encompassing the history behind maglev trains, the regions that maglev trains are being implemented in, and the innovations associated with the maglev train. Questions that could be asked during this research project include (but are not limited to): when the maglev train was first invented, what the constraints of maglev trains are, and where the fastest maglev trains are used.
Activity 5: Float Like a Butterfly, Sting Like a Bee

Questions for Middle School Students

1) List the design steps you took in making your car.

   Gathered information (data), created sketches, made detailed drawings of all sides, cut out car, tested car, made changes, and decorated car.

2) Which is the most aerodynamic?

   a) Van
   b) School bus
   c) Sports car

3) Why did you choose your answer from Question 2? Support your answer.

   The sports car should be chosen as the most aerodynamic because it provides the air with the path of least resistance, comparatively to the other choices. You can see that, with the sports car, there are fewer perpendicular surfaces for the air to push against.

4) In your opinion, what was the most important discovery you made during this activity and why?

   Students’ answers will vary but may include any topic studied from the challenges of teamwork to a specific instance of how they fixed a design flaw to their amazement about how real maglev trains work.

Questions for High School Students

1) Suppose you were designing maglev cars that you were to sell to 3rd graders. You want to sell as many cars as possible and earn as much profit as possible. What characteristics would influence your design?

   There are no incorrect answers, however the students should mention that they would have to ask the 3rd graders in order to understand what would sell. Engineers have much to consider during design, including material selection, structural integrity, aerodynamics, usability, and style.

2) How did the shape of your car affect its speed? How is this concept applied in commercial cars?

   Shapes that allow for the wind to flow around the vehicle instead of directly impacting the vehicle should perform better. You can see this idea in the design of cars, especially in the design of sports cars or race cars.

3) How did your car design differ from the actual car? Why was this? How would this translate to a commercial setting?

   The designs the students come up with will likely have smoother lines than they can create by hand. This is an example of human error. In the commercial world, this could be analogous to designing a car that is too difficult to produce, even though the concept could be very good.
4) Why are aerodynamics a more important consideration for the real maglev trains than they were for your cars? In what other sorts of technology is aerodynamics important?

Real trains are going much faster than the students’ cars. Students may refer to greater air resistance at high speeds. Aerodynamics is important for airplanes, rockets, racecars, land speed record cars, and many other fast moving vehicles. It also has an effect on a car’s gas mileage.

5) In your opinion, what was the most important discovery you made during this activity and why?

Students’ answers will vary, but may include any topic studied, from the challenges of teamwork to a specific instance of how they fixed a design flaw to their amazement about how real maglev trains work.

Discussion

If time allows after the activity or during the racing, students should get a chance to comment on their performance in the race and what they have learned from the activity. The teacher may also want to re-emphasize the main topics studied in this activity: the design process, Newton’s Laws, and aerodynamics.

The application of Newton’s Laws to this activity, in particular, may be hard for students to grasp on their own. They should understand that gravity is the ‘unbalanced force’ acting on the cars and know why acceleration is constant for cars that go smoothly down the track.

This is a good time to ask the students to think about teamwork as well. If students worked in groups, especially larger groups, they will realize that cooperation and compromise can be difficult but is part of being a successful team. If a volunteer is available, they may be able to talk about how they work in teams in their jobs.
Activity 5: Float Like a Butterfly, Sting Like a Bee

Introduction
This activity is designed to allow you to put to practical use your knowledge gained in previous activities on Newton’s Laws of Motion. You will also get an introduction to aerodynamics and the design process by building your own maglev car and racing it.

Objective
You will:

- Design, build, and modify Styrofoam vehicles by applying what you have learned about Newton’s Laws.
- Discover how key principles from the previous activities are put into practical use to design the fastest car.
- Explore the creativity involved in the design process, which can be applied to many disciplines beyond transportation.

Background
In the previous activities, we learned about **velocity** and **acceleration**; however, **wind resistance** was not covered. In this activity, you will combine what you learned earlier about velocity and acceleration, along with what you will learn from a short discussion on wind resistance, in order to create the fastest maglev car.

In the real world, maglev trains can be found to be analogous to the maglev cars in this activity. Maglev trains are energy efficient because they minimize the friction between the train and the track however, drag is still a design concern. Drag is defined as a resisting force acting on a body moving through a fluid (air is a fluid), parallel and opposite to the direction of motion. The drag force is also referred to as air resistance. Maglev trains are designed to travel at extremely high speeds of around 450 to 500 kph (280 to 310 mph). At these speeds they encounter much more air resistance than ordinary vehicles. Have you ever stuck your hand out of a car window while you were riding down the highway at 55 mph (88.5 kph)? The feeling of pressure against your hand is air resistance. Now compare that to a train going 450 to 500 kph! A maglev train has to overcome the air resistance by consuming more energy. Therefore, reducing drag leads to higher efficiency and potentially higher speeds. Although your car will obviously not be traveling at the top speed of actual maglev trains, drag may be an important design factor to consider, along with what you have learned about Newton’s Laws.

Design engineers try to minimize drag by making maglev trains aerodynamic. This means that the trains travel smoothly through the air. Think about your hand out the window at 55 mph again. Would you feel more pressure if your hand is in a “stop” position (palm out, facing and stopping the airflow) or if you extended your fingers toward the front of the car? As engineers we look for ways to deflect the air around the car in an attempt to reduce the air resistance. During the design process, you should consider how the air would flow around your car.

In commercial car design, there are additional regulations that car manufacturers must meet, which adds another level of complexity to design. The design team must consider other components, such as
environmental regulations, safety, cost, and appearance. For example, the Clean Air Act controls **emissions** standards. If car companies do not meet these environmental standards, they cannot legally sell their cars. Automobile manufacturers also have to abide by the CAFE (Corporate Average Fuel Economy) Law, which states that the average fuel efficiency for a company’s fleet of vehicles must be at least 40.3 mpg ([https://www.transportation.gov/mission/sustainability/corporate-average-fuel-economy-cafe-standards](https://www.transportation.gov/mission/sustainability/corporate-average-fuel-economy-cafe-standards)). The important safety regulations—to which vehicles must follow—are outlined by the Federal Motor Vehicle Safety Standards (FMVSS). These laws include hundreds of regulations for everything from gas tanks to child safety seats. After the manufacturers make sure that their car meets the legal standards for safety and the environment, the designers continue to balance these and other concerns that they believe will be important to their customers.

**Maglev Racing: An Introduction to the Design Process**

When engineers and design specialists set out to create a new product, they know that improving one aspect of a design will often come with unintended losses to another aspect; therefore, they must find a balance in their design. When engineers design an automobile they must make a product that runs well, is aesthetically pleasing, is environmentally conscious, and is cost-effective to produce. Therefore, engineers sometimes have to make trade-offs, accepting losses in one area in order to gain an advantage in a more important category. Your maglev car, however, will be graded on only one metric: speed.

In commercial car design, companies employ marketing specialists to try and understand what consumers want. This data-gathering phase is very important for commercial products. The marketing specialists will survey people about what factors matter to them, such as speed, appearance, and fuel efficiency to determine what should be put on the market. Once this data has been collected, they will then design a car in order to meet the needs of the consumers.

The design process begins by sketching design ideas. These designs are then analyzed until a design is decided upon as the best solution, which is then made into a prototype. A prototype is a test model of the design which will be put into full-scale production, assuming the prototype successfully meets design criteria. You will go through much of the same process when you work on your car. You should develop sketches based on what you believe will be successful—consider how the air would travel around your car—then decide on a finished, detailed design. You should also spend plenty of time testing and refining your car.

**Materials**

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maglev track</td>
<td>1</td>
</tr>
<tr>
<td>Standard Styrofoam Maglev blocks</td>
<td>1 per student</td>
</tr>
<tr>
<td>Boxes/books to support track</td>
<td>As needed</td>
</tr>
<tr>
<td>Magnetic tape</td>
<td>20cm per car/student</td>
</tr>
<tr>
<td>Hot-wire Styrofoam cutting tools with batteries</td>
<td>6</td>
</tr>
<tr>
<td>Stopwatches</td>
<td>varies</td>
</tr>
</tbody>
</table>
Setup

Use boxes to elevate one end of the maglev track. (If two tracks are available, place them side-by-side). Use timers or stopwatches to record the time that each car takes, and create a table on paper or a whiteboard to record the times for all cars.

Procedure

1. Begin by reading the Background section. This will ensure you have sufficient knowledge about aerodynamics in order to create the best maglev car.
2. Design your car.
   a. Consider the information you learned about mass, velocity, and drag to come up with ideas for the car.
   b. Draw a concept model of the car and analyze this model, making any changes deemed necessary until design is finalized.
3. Now build the car using the materials provided. Remember that the best design in the world means nothing if craftsmanship is sloppy.
4. Race your cars against each other. Have your teacher or a classmate begin each race with “Ready, Set, Go!” Begin the stopwatches for each race at “Go!”, when the racers release their cars. Record the times.
Activity 5: Float Like a Butterfly, Sting Like a Bee

Questions for Middle School Students

1) List the design steps you took in making your car.

2) Which is the most aerodynamic?
   a) Van
   b) School bus
   c) Sports car

3) Why did you choose your answer from Question 2? Support your answer.

4) In your opinion, what was the most important discovery you made during this activity and why?

Discussion Notes
Activity 5: Float Like a Butterfly, Sting Like a Bee

Questions for High School Students

1) Suppose you were designing maglev cars that you were to sell to 3rd graders. You want to sell as many cars as possible and earn as much profit as possible. What characteristics would influence your design?

2) How did the shape of your car affect its speed? How is this concept applied in commercial cars?

3) How did your car design differ from the actual car? Why was this? How would this translate to a commercial setting?

4) Why are aerodynamics a more important consideration for the real maglev trains than they were for your cars? In what other sorts of technology is aerodynamics important?

5) In your opinion, what was the most important discovery you made during this activity and why?

Discussion Notes
Appendix A: Document Links

NCHRP 20-52

The NCHRP 20-52 final report details the completion of the original TRAC PAC 2 program, including the original manual.

TRAC/Michigan Education Standards
Link: [http://www.michigan.gov/mdot/0,4616,7-151-9623_38029_38059_41397-184233--,00.html](http://www.michigan.gov/mdot/0,4616,7-151-9623_38029_38059_41397-184233--,00.html)

The Michigan Education Standards are outlined in terms of how TRAC meets the benchmark goals. This page includes the standards for 6th, 7th, and 8th grades as well as high school standards. Both the TRAC modules and bridge building competition are listed.
Appendix B: Glossary of Terms

**Acceleration (a):** Physical vector quantity that is defined as the rate at which an object changes in velocity. (velocity/time)

**Coefficient of Friction:** Unit-less value representing the ratio between the force necessary to move one surface over another and the force applied to the two surfaces.

**Emissions:** Something that is produced as a byproduct of a process which is usually undesired. For example: Carbon Dioxide (CO₂) is produced as a result of fuel combustion in cars.

**Exponentially:** When something is increasing or decreasing at a growing rate of change. On a graph this would be represented as a curve that continuously becomes more vertical or more horizontal.

**Friction Forces:** Forces that resist motion, generated when two surfaces are in contact and slide against each other.

**Frictionless:** Not resisted by or creating friction forces; smooth.

**Linear:** When something is increasing or decreasing at a constant rate of change. On a graph this would be represented as a straight line. Can also be used to describe something acting in a straight line.

**Newton’s First Law (Law of Inertia):** An object at rest stays at rest, while an object in motion stays in motion with a constant velocity unless acted upon by a force.

**Newton’s Second Law (Law of Motion):** The magnitude of a resultant force acting on an object is equal to the mass of the object multiplied by the acceleration of the object. This resultant force is the sum of all forces acting on the object.

**Surface Area:** Total area of an object.

**Tangent:** A line or plane that intersects with a circle or curve at exactly one point. This line or plane runs at a 90° angle to the radius of the circle or curve.

**Topography:** Arrangement of the physical features of an area. Typically displayed through contour lines on a map that represent changes in elevation.

**Trigonometry:** Branch of mathematics dealing with the relationship between the size of a triangle’s sides and angles.

**Velocity (v):** Physical vector quantity that is defined as the speed and direction of an object in motion. (distance/time)

**Wind resistance:** A force resisting motion that acts on an object as it moves through air. This is a unique type of friction force. Also known as drag or air resistance.
This manual was updated and revised in 2017 by of the Center for Technology and Training (CTT) at Michigan Technological University for the Michigan Department of Transportation (MDOT).