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Increasing The Participation And Success Of Struggling Students In High School Physics Courses

Ian O'Neill

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INCREASING THE PARTICIPATION AND SUCCESS OF STRUGGLING STUDENTS IN HIGH SCHOOL PHYSICS COURSES

By

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A capstone project submitted in partial fulfillment of the requirements for the degree of Master of Arts in Teaching.

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TABLE OF CONTENTS

Abstract...........................................................................................................................................3

Understanding by Design Framework...............................................................................................4

Topic #1: Simple 1-D Kinematics........................................................................................................5
    Dream Vacation Project..................................................................................................................7
    Trip to Your Favorite Restaurant...............................................................................................8
    Teacher Guide...........................................................................................................................9

Topic #2: Forces and Newton’s Laws of Motion.............................................................................10
    Friction Force Lab.......................................................................................................................12
    Rocket Sledder Lab....................................................................................................................14
    Balloon Rockets.........................................................................................................................15
    Teacher Guide...........................................................................................................................17

Topic #3: 2-D Kinematics................................................................................................................19
    Height of the Gym Ceiling...........................................................................................................21
    Projectile Launcher - Target Challenge.....................................................................................22
    Teacher Guide...........................................................................................................................24

Topic #4: Energy, Work, and Power...............................................................................................27
    Energy Ramp Challenge...............................................................................................................29
    Teacher Guide...........................................................................................................................31

Topic #5: Electricity and Circuits...................................................................................................33
    Circuit Exploration Lab................................................................................................................35
    I can see the Light!......................................................................................................................36
    Teacher Guide...........................................................................................................................41

Topic #6: Light, Reflection, and Refraction..................................................................................43
    Lazer Maze.................................................................................................................................44
    Teacher Guide...........................................................................................................................45
Abstract

Physics is the most mathematically complex science course offered in the high school setting. Due to the higher level of mathematical proficiency needed to succeed in physics, it is common for school districts to place it as the final science course offered to high school students. Minnesota only requires students to take three years of science in order to graduate and has no specific requirement for physics. This has led to low enrollment and the negative stigma that physics is an unnecessary and difficult challenge, rather than an interesting and crucial field of science. This capstone uses current research to answer the question, *How can a curriculum be created that will increase the participation and success of struggling students in high school physics courses?* The result was the development of new physics curriculum that focuses on the pedagogy of problem based learning, inquiry based learning, and culturally responsive teaching. This new approach should boost enrollment and make physics more accessible and engaging for a wider range of students.
Understanding by Design Framework

The Understanding by Design Framework served as the foundation on which the following new curriculum was built. It focuses on teaching and assessing for understanding and learning transfer and is built around the backward design model. This strategy ensures that curriculum is created with the end goal in mind. The three stages of the Understanding by Design Framework are summarized below to highlight the process that was followed during the creation of the curriculum that follows.

- **Stage 1: Identifying Desired Results**
  - Set goals
  - Examine content standards
  - Clarify priorities
  - Develop essential questions
    - Questions are intended to guide learning and help students make meaning out of the curriculum
  - Create clear objectives
    - Students need to have a clear understanding of what they are trying to understand and accomplish

- **Stage 2: Determine Assessment Evidence**
  - Reflects the desired results from Stage 1
  - Fair and consistent evaluation of student performance and understanding
  - Clearly defined for both teacher and students
  - Six facets of understanding
    - Explain, Interpret, Apply, Perspective, Empathy, Self-knowledge
    - Each subject area covers its distinct subset of applicable facets of understanding
    - Facets are meant to guide over the length of a project or unit and not daily learning
  - Traditional Assessments
    - Still contains traditional forms of assessment such as quizzes and tests
  - Performance Tasks
    - Includes application of learning in new and authentic situations to assess transfer of learning

- **Stage 3: Plan Learning Experiences and Instruction**
  - Includes several opportunities for learning through multiple different forms
  - Learner must actively construct meaning
  - Expanded role of the teacher
    - Facilitator of meaning
    - Coach giving feedback and advice
    - Not meant to only deliver content
Topic #1: Simple 1-D Kinematics

- Minnesota State Standards
  - 9P.2.1.2.1 Use vectors and free-body diagrams to describe force, position, velocity and acceleration of objects in two dimensional space.

- Essential Questions
  - What is the difference between distance and displacement, conceptually and mathematically?
  - What is the difference between a scalar quantity and a vector quantity?
  - What is the difference between speed and velocity?
  - What is the difference between instantaneous velocity and average velocity, conceptually and mathematically?

- Learning Targets - (SWBAT = Students will be able to)
  - SWBAT describe the difference between a scalar quantity and a vector quantity.
  - SWBAT explain the conceptual difference between distance and displacement.
  - SWBAT calculate the displacement between multiple locations.
  - SWBAT calculate the distance between multiple locations through several different routes.
  - SWBAT explain the difference between speed and velocity and their relationship to distance and displacement.
  - SWBAT calculate speed and velocity through the use of word problems.
  - SWBAT explain the difference between instantaneous and average in terms of speed and velocity.
  - SWBAT calculate instantaneous velocity and average velocity.
  - SWBAT create an accurate graph of distance vs time and displacement vs time for the motion of a given object.
  - SWBAT explain the significance of the slope of a distance vs time graph and a displacement vs time graph.
  - SWBAT create an accurate graph of speed vs time and velocity vs time for the motion of a given object.

- Rationale
  - One dimensional kinematics forms the bedrock of classical physics. Any introductory physics course needs to start with the most simple aspects of this topic in order to have a strong base of knowledge for the students to build on during the rest of the course. While this topic is a critical place to start in order to correct misconceptions and set students up for future success, it is not exciting relative to other physics topics. Examples and problems that highlight the difference between distance and displacement are inherently simple. However, this topic is taught at the beginning of a semester when teachers are looking for students to get interested and involved with the material.
  - The dream vacation project gives students the chance to be involved in their own learning through choice and personality. Simple questions about distance, displacement, speed, and velocity are turned on their head because the students get to choose the location and how they’re going to get there. This project also serves as a fantastic way for teachers to get to know their students. Questions about why students
choose a specific location, who and what they would bring along, and how long they would stay all help the teacher learn the individual personal preferences, hobbies, and interests. It brings physics into the lives of the students and more importantly it allows students the chance to bring their lives into the classroom. The project is not graded based on which location they choose or the reasons why they choose it, so it embodies culturally responsive teaching.

● Possible modification
  ○ A second version of this assignment is also posted if time is an issue or a shortened option is wanted the first time implementing this project in the teaching of kinematics.
Dream Vacation Project

Where would you go if you could travel to anywhere in the USA? How would you get there? How long would you stay? In this project you will plan the trip of your dream vacation.

Guiding Questions: (Answer each of these questions and explain why)
- Where would you go?
- What time of year would you go there?
- How would you travel there?
- How long would you stay?
- Who and what would you bring?
- What would you do when you got there?

Physics Requirements: (All must be included in finished product)
- Screenshot of a map showing starting and finishing locations
- Total distance of the trip
- Total displacement of the trip
- Calculations for all forms of transportation (car, plane, boat, bike, canoe, etc.)
  - Average speed
  - Average velocity
  - Highest instantaneous speed
  - Highest instantaneous velocity
- Distance vs Time graph of the outward travel
- Speed vs Time graph of the outward travel
- Explanation of which values change if you were to include the trip back home. Why?

Reminder: All physics calculations must include appropriate units.
Trip to Your Favorite Restaurant

Create a map of the directions from the high school to your favorite restaurant using Google Maps.

a. The restaurant must be more than 1 mile and less than 10 miles from the school

2. Take a screenshot of the map and copy and paste it into this document.
   a. Screenshot Directions:
      (Ctrl+window switch key) ---->
   b. Click [Copy to Clipboard] then paste it below

3. What is the total distance traveled during the trip?

4. Use the scale in the bottom right of the Google map to measure the total displacement.

5. What is the average speed of the trip to visit your favorite restaurant?

6. What is the average velocity of the trip to visit your favorite restaurant?

7. What is the highest instantaneous speed you will experience during your trip? (without getting pulled over by the police.)

8. What is the highest instantaneous velocity you will experience during your trip? (Hint: this answer will be different than question 7)
Teacher Guide

- **Number of Days**
  - The first version of the assignment should take 3-4 days of class time to complete. It requires more from the students both in calculations and in forming a rationale for their choice and what they’d do on the trip. This can be a wonderful resource to use in getting to know your students and building a relationship, but it takes time.
  - The second version of the assignment should only take 1-2 days of class time to complete. It is the same general idea of the project, but is broken down to the bare bones and stripped of the opportunity for students to include their interests. The first version is strongly recommended.

- **Sequence**
  - One dimensional kinematics is the first unit of the year and this project should take place early on in the unit. The main conceptual hurdle of the unit is the difference between vector quantities and scalar quantities. This project could follow shortly after explaining this critical concept. By turning to this project instead of practice problems a teacher can hold the interest of the student and increase their buy-in to the course and the subject.

- **Variations**
  - The two versions of this project present a distinct difference in the way it could be introduced. However, the first version doesn’t need to be the final stopping point of innovation.
  - Possible inclusions
    - Mandatory travel on at least two forms of transportation
    - Mandatory calculation of at least two different routes
    - A minimum distance requirement to increase complexity
    - Allowing travel outside of the US so plane or boat travel is necessary
    - Etc.

- **Warnings**
  - The easiest way for students to find the correct value for displacement will be to try to look it up on Google. Make sure to require them to use a map and measure it by using the scale of the map key.
  - This should be an individual project. Students are likely to pick the same location of their friends so they can share the work or only rely on one person. Consider require each student to pick a separate location or at least a separate travel route.
    - Focusing on the guiding questions will help mitigate everyone choosing the same place. After all, they need to have definite reasons why they picked that location.

- **Key Equations / Definitions**
  - Distance - total length traveled
  - Speed = \( \frac{\text{distance}}{\text{time}} \)
  - Displacement - change in position - (round trip = 0)
  - Velocity = \( \frac{\Delta \text{displacement}}{\text{time}} = \frac{\Delta x}{\Delta t} \)
  - Average Speed = \( \frac{\text{total distance}}{\text{total time}} \)
Topic #2: Forces and Newton’s Laws of Motion

- Minnesota State Standards
  - 9.2.2.2.1 Recognize that inertia is the property of an object that causes it to resist changes in motion.
  - 9.2.2.2.2 Explain and calculate the acceleration of an object subjected to a set of forces in one dimension (F=ma).
  - 9.2.2.2.3 Demonstrate that whenever one object exerts a force on another, a force equal in magnitude and opposite in direction is exerted by the second object back on the first object.
  - 9P.2.2.1.1 Use vectors and free-body diagrams to describe force, position, velocity and acceleration of objects in two dimensional space.
  - 9P.2.2.1.2 Apply Newton’s three laws of motion to calculate and analyze the effect of forces and momentum on motion.
  - 9P.2.2.1.3 Use gravitational force to explain the motion of objects near Earth and in the universe.
  - 9P.1.3.4.1 Use significant figures and an understanding of accuracy and precision in scientific measurements to determine and express the uncertainty of a result.

- Essential Questions
  - How does the application of a force affect the motion of an object?
  - What is inertia and how does it impact the motion of an object?
  - What is the relationship between the mass of an object, the total force applied to that object, and the acceleration of the object?
  - Can a force be applied that is only felt in one direction? Or must forces always come in pairs?
  - What different categories of forces are there? How many specific forces fall within those categories?

- Learning Targets
  - SWBAT explain the idea inertia and how it relates to the motion of an object.
  - SWBAT define force in simple terms.
  - SWBAT find and calculate the net force acting on an object.
  - SWBAT explain the relationship between force and acceleration.
  - SWBAT explain the relationship between force and mass.
  - SWBAT calculate values for force, mass, and acceleration by using Newton’s 2nd Law.
  - SWBAT explain which of Newton’s 3 Laws of Motion apply in a given scenario.
  - SWBAT identify the Newton’s 3rd Law force pair to any given force.
  - SWBAT list all types forces within their overarching force categories.
  - SWBAT use free-body diagrams to calculate the value of unknown forces.
  - SWBAT explain the difference between accuracy and precision using text and data.

- Rationale
  - Forces are interactions between objects that are responsible for the motion of everything around us. Understanding the way a force affects the motion of objects is crucial in understanding the world around us and shaping it to fit what we’re trying to accomplish. These goals can range from finding how to accelerate a rocket out of the atmosphere to
ensuring that a building can withstand a tornado and still not move. The ability of a society to progress is due in part to how well it understands forces.

○ Newton’s Laws of Motion guide society through an understanding of forces and serve the foundation for all classical physics. These three laws by Newton are an insight into the inner workings of the world around us. Therefore, it’s critical that students have a firm understanding of the nuances of these laws before moving forward. The math involved in an introduction of Newton’s Laws of Motion is fairly simple algebra, but the conceptual complexity is far more difficult. As a result, the most important aspect of teaching this topic is ensuring the strongly held misconceptions of students are broken down and is replaced by a deep understanding of the fundamental processes of forces and motion.

○ With the focus of this topic being the breakdown of misconceptions and the building of new understandings, the decision was made to create new inquiry labs for each of Newton’s Laws. Students often enter an introductory physics course with a misunderstanding of the way force affects velocity and acceleration. One possible route to teaching students would be to explain the true nature of forces. However, this often leads to momentary recognition and not a long term shift in understanding to the correct fundamentals. In order to break down misconceptions and build new learning, students need to actively participate in activities that allow them to find the truth. A new breakthrough in learning is far more likely to take hold in a student if they feel they found it on their own. The Angle of Repose Lab, the Rocket Sledder Lab, and the Balloon Rocket Lab are inquiry activities that guide students through building a new understanding of Newton’s fundamental laws of forces and motion that govern the world around them.
**Angle of Repose** is an acclaimed work of modern American fiction by Wallace Stegner. The title is in reference to the angle at which a pile of sand naturally lies. We would like to determine how the angle of repose (between a block and a wooden board) is related to the coefficient of friction.

**Goal:** Find the coefficient of friction ($\mu$) between the board and the block.

**Step 1:** Measure the mass of your block. Use the scales in the back of the room.

*Hint:* Remember to convert your mass into kilograms (kg). Divide by 1000.

$$m = \text{_________ kg}$$

**Step 2:** Slowly increase the angle of the board until the block starts to slide. Use the protractor to measure the angle of the board.

- Do this 3 times and average the results to make sure you get an accurate measurement.
- Fill out the table below.

<table>
<thead>
<tr>
<th>Trial Number</th>
<th>Angle $\Theta$ - (as the block slides)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
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<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
</tr>
</tbody>
</table>

**Step 3:** Draw an accurate Free Body Diagram (force arrows) for the block in this situation.

*Hint:* Look at the FBDs from notes yesterday and on WS#2

Sketch of lab set up:

Free Body Diagram:
Step 4: Calculate the Force of Gravity ($F_g$) on the box using the mass you found earlier in the lab.

*Hint:* $F_g = m \times g$

Step 5: Calculate the value of the Friction Force ($F_f$) acting on the block.

*Hint:* $F_f = (F_g) \times \sin(\Theta)$

Step 6: Calculate the value of the Normal Force ($F_n$) acting on the block.

*Hint:* $F_n = (F_g) \times \cos(\Theta)$

Step 7: Use these forces to calculate the value of the coefficient of friction between the board and the block.

*Hint:* $\mu = \frac{F_f}{F_n}$

Step 8: Have one person in your group write your solution on the front whiteboard. Turn in this lab sheet.

Example:

- $m = \underline{\hspace{2cm}}$ kg
- $\Theta = \underline{\hspace{2cm}}$ $^\circ$
- $F_g = \underline{\hspace{2cm}}$ N
- $F_f = \underline{\hspace{2cm}}$ N
- $F_n = \underline{\hspace{2cm}}$ N
- $\mu = \underline{\hspace{2cm}}$
Rocket Sledder Lab

How to get to the website:
- Perform a Google search for Rocket Sledder.
- Click on the link from physicsclassroom.com
- Click on launch interactive and expand the interactive simulation so it fills the screen.

Directions: Record observations for every step.
1. Take some time to get used to the simulation and everything that can be changed. Make a list of aspects of the system you can observe. (Hint: List all physics vocab, there should be 7-10)

(Get sled back to motionless with no added mass.)
2. Using the blue slide lever, apply a force of 50N to the right. Record observations.

3. Maintain the 50N applied force and turn the friction ON. What changed? How do you know?

(Get sled back to motionless with no added mass.)
4. Leave the friction force ON and pick a new applied force that is 60-80N. Record your observations.

5. Slowly add weight to your sled and record the changes you observe.

6. Make a list of variables that can cause a change to the sled.

7. Make a list of variables that react and change because of your manipulations to the sled.
Balloon Rockets!

Goal #1: Make a balloon rocket that travels across the classroom to an exact spot.

Materials - (pictured above)
- 1 balloon, 5 meters of string, 1 straw, 20 cm of tape, 1 pair of scissors

Group Planning
- Meet with your group of 3 and plan how you’ll create the balloon rocket.

Pre-launch check:
- Get teacher approval for take off!

Perform 5 Trials:

<table>
<thead>
<tr>
<th>#1: Observations/Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>#2: Observations/Results</td>
</tr>
<tr>
<td>#3: Observations/Results</td>
</tr>
<tr>
<td>#4: Observations/Results</td>
</tr>
<tr>
<td>#5: Observations/Results</td>
</tr>
</tbody>
</table>

Lab Questions:
1. Look through the notes for your 5 trials. Was your balloon rocket accurate? Why or why not?

2. Look through the notes for your 5 trials. Was your balloon rocket precise? Why or why not?

3. What caused the balloon rocket to “launch” forward? Was there anything being pushed the other direction? If so, what was it and how do you know?

4. Could the balloon have moved forward without something being pushed the other direction? If so, how?
**Bonus Goal:** Make a balloon rocket that travels forward and then travels backward.

**New Material Set-up:**
- 2 balloons, 5 meters of string, 1 straw, 30 cm of tape, 1 pair of scissors, 1 rubber band

**Changes:**

**Group Planning**
- Get back with your group and plan how you’ll create this more complex balloon rocket.

**Sketch:**
- Draw a sketch of your new double balloon rocket in the space below.

**Pre-launch check:**
- Get teacher approval for take off!

**Perform 3 Trials:**

<table>
<thead>
<tr>
<th>Trial</th>
<th>Observations/Adjustments</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td></td>
</tr>
<tr>
<td>#2</td>
<td></td>
</tr>
<tr>
<td>#3</td>
<td></td>
</tr>
</tbody>
</table>

**Lab Questions:**

1. How were you able to get the rocket to travel forward and then backward?

2. If you weren’t able to get it to work, what went wrong? What would you have done differently to get it to work?
Teacher Guide

- **Number of Days**
  - All three of these lab activities should take place within the span of a single class day.

- **Sequence**
  - The activities within this topic all have a focus on inquiry based learning. This means these activities should take place prior to any direct instructions on the concepts they cover. In order, they serve as an inquiry based introduction to Newton’s 1st, 2nd, and 3rd Law of Motion.

- **Helpful Directions / Guidelines**
  - **Friction Force Lab**
    - The activity is written so it can be accomplished prior to any in depth work with vectors and vector addition. However, if students are already proficient at free-body diagrams (FBDs) and vector addition, it can be altered easily by removing the hints. This lab activity should provide a substantive discussion about Newton’s 1st Law. Namely, in order for an object to change its motion it must be acted on by an unbalanced force. The block won’t move until the ramp is steep enough that the lowering friction force is overcome by the force of gravity.
  
  - **Rocket Sledder Lab**
    - This online simulation should be experimented with by the teacher prior to teaching the lesson. The students will need to be reminded to follow the directions carefully or the sled will reach velocities that make it difficult to make accurate observations.
    - This inquiry lab should lead the students to the fundamentals of Newton’s 2nd Law of Motion. Ideally they realize that a larger applied force will lead to a greater increase in velocity (acceleration), but only if the total resultant force is larger. This is highlighted when they add on friction and air resistance. This should build the foundation for the direct relationship between the net force on an object and the acceleration of that object. When mass is added students should see the force stay the same but the acceleration decrease. This starts to build the concept of mass and acceleration in an indirect relationship. It is possible for students walking away from this lab to have a strong understanding of \(F = ma\) even if they don’t know that equation yet.
  
  - **Balloon Rocket Lab**
    - If students don’t arrive at the correct conclusion it’s crucial to hint at the string being used as a path for the balloon to travel along. Once they understand how the string is used, it’s easier for them to understand how the straw is used to connect the balloon to the string and allow movement.
    - Students should have a good understanding of accuracy and precision at this point of the year, so those questions serve as a check to see if students are retaining knowledge.
    - There are two different ways to make the double balloon rocket achieve forward motion followed by a backward motion. The first option involves using the rubber band as a constriction around the mouth of one of the balloons. This restricts air flow and extends how long one balloon releases air compared to the other. The second option involves wrapping the rubber band around the middle
of one of the balloons. This forces the air out of one balloon faster than the other creating a similar result. Neither of these options will result in extremely successful working products, but it puts students in the mindset of an engineer while engaging in an inquiry lab.

■ The lab questions are meant to guide students to the understanding that air must be forced out of one end of the balloon in order for the balloon itself to be pushed the other direction. This introduces Newton’s 3rd Law of Motion - Every action force must have an equal and opposite reaction force.

● Warnings
  ○ Friction Force Lab
    ■ It is critical that the students know exactly where they need to place the protractor in order to get an accurate measurement for the angle of the board.
  ○ Rocket Sledder Lab
    ■ The simulation has no upper limit for the speed of the sledder, it will continue to accelerate for hours. Students will attempt to see how fast they can get the sled to go, so informing them of no upper limit may be helpful for them to remain focused on the tasks at hand.
  ○ Balloon Rocket Lab
    ■ The materials required come with mandatory rules about how they can be used and what won’t be tolerated. It must be clear that balloons can’t be intentionally popped or filled with water. Also, the rubber band can’t be “shot” at another student or used to snap against the skin of another student.

● Key Equations/Definitions
  ○ Net Force
  ○ Equilibrium
  ○ Inertia
  ○ Newton’s 1st Law of Motion
  ○ Newton’s 2nd Law of Motion
  ○ Newton’s 3rd Law of Motion
  ○ F = ma
Topic #3: 2-D Kinematics

- Minnesota State Standards
  - 9P.2.2.1.1 Use vectors and free-body diagrams to describe force, position, velocity and acceleration of objects in two dimensional space.
  - 9P.2.2.1.3 Use gravitational force to explain the motion of objects near Earth and in the universe.

- Essential Questions
  - How does gravity affect an object in free fall?
  - What does it mean to have a value be a vector quantity instead of a scalar quantity?
  - How can free-body diagrams be used to explain the motion of an object?
  - How does the force of gravity affect an object during two dimensional projectile motion?

- Learning Targets
  - SWBAT describe the difference between a vector and scalar quantity.
  - SWBAT find the vertical and horizontal components of a vector.
  - SWBAT find the magnitude and direction of a vector given its components.
  - SWBAT add vectors by using components in the x-direction (horizontal) and y-direction (vertical), both graphically and analytically.
  - SWBAT draw an accurate free-body diagram for an object in free fall, using force, acceleration, and velocity
  - SWBAT describe what, if any, impact gravity has on the rate of horizontal motion.
  - SWBAT calculate displacement, velocity, time, and acceleration for objects in motion, using the four kinematic equations.

- Rationale
  - Projectile motion and two dimensional kinematics are physics concepts that inherently capture the imagination of students of all ages. From basketball shots to catapults to skydiving, projectile motion has something to interest any student. The fastest way to dampen that excitement is to cover it up with theoretical practice problems. Students might get better at the mathematics involved by practicing solving word problems on paper, but they lose the thrill and motivation created when they experience it themselves. Therefore the two activities I present for this chapter are both representatives of problem based learning. They are specifically designed to present students with a real-world problem that doesn’t have a simple answer. Students have to get up out of their seat and take some control over their own learning. Instead of following cookie-cutter instructions that dictate the process of a lab, the students must reason through their options and ask questions to decide how they will proceed. When they find a solution it doesn’t feel fake or manufactured, but earned as an achievement. This type of lab is exciting, but can also be daunting. To ensure that students aren’t presented with an impossible challenge, the teacher must provide all necessary structural knowledge prior to each activity and be willing to offer guidance when students are lost. These types of activities simulate the process undertaken by science
and technology professionals everyday and improve students’ ability to persevere through challenges.
Goal: Find the height of the gym ceiling.

But how? Without the use of any ladders, measuring tape, or laser measuring technology, how can we find an accurate value for the height of the gym in only one short class period?

Before we find a way to solve this, give your best guess…

Height of the gym: ____________ meters

Materials:
- 1 tennis ball
- 1 stopwatch

And that’s it! Just a tennis ball, a stopwatch, and your brain power! Think… What can you do with the two materials you have?

Step 1: Draw velocity vectors on this diagram of the flight of a tennis ball.

Step 2: Circle which kinematic equation(s) might be most helpful in trying to find the height of the gym ceiling.

Important key … a = ?

The Kinematic Equations

\[ d = v_i \cdot t + \frac{1}{2} \cdot a \cdot t^2 \]
\[ v_f^2 = v_i^2 + 2 \cdot a \cdot d \]

\[ v_f = v_i + a \cdot t \]

\[ d = \frac{v_i + v_f}{2} \cdot t \]

Step 3: Record three good trials of the tennis ball going through the full path from floor to ceiling.

#1: ___________ seconds  #2: ___________ seconds  #3: ___________ seconds

*Hint*: Think about the velocity of the tennis ball at the very top of the ball flight and how half the total time can be used in one of the kinetic equations in order to solve for the height of the gym ceiling.

Height = ____________ meters  (post this answer on the front whiteboard in the classroom)
Goal #1: Find the muzzle velocity of the projectile launcher. Initial velocity = ?

The velocity created by the projectile launcher must be found without the use of photogates or any device used to measure speed directly. Instead, the launcher must be set up in a way that vertical free fall isn’t affected in any way and we can use simple kinematic equations. How? A horizontal launch!

By shooting the projectile horizontally the launcher has no impact on vertical motion and we can approach the situation like a simple free fall problem.

Step 1: Place the projectile launcher on a flat table and measure the distance from the ground to the mouth of the launcher.

Height = ____________ meters

Step 2: Use a kinematic equation to calculate the time it will take for the projectile to fall that height.

Time = ____________ seconds

Step 3: Set up the projectile launcher so it’s pointed completely horizontal.

Step 4: Launch the projectile several times and find the average horizontal distance traveled.

<table>
<thead>
<tr>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
<th>Trial 4</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>m</td>
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Step 5: Use the time calculated in Step 2 and the average distance found in Step 4 to calculate the muzzle velocity of the projectile launcher.

Initial Velocity = ____________ m/s
**Target Challenge! : Find the correct distance so the projectile hits the bullseye!**

**Step 6:** Gather your group together and show your teacher the value you calculated for the muzzle velocity of the projectile launcher. Then collect the angle your group will be using during the target challenge.

Angle: __________ °

**Step 7:** The projectile launcher will be set at this angle for your group’s test. Using the velocity you found in Step 5, find the component parts of the velocity vector in the x-direction and y-direction.

\[ V_x = \underline{\phantom{0000}} \text{ m/s} \quad V_y = \underline{\phantom{0000}} \text{ m/s} \]

**Step 8:** Use the velocity component in the y-direction \((V_y)\) to calculate the total time of the launch.

Time = __________ seconds

**Step 9:** Use the velocity component in the x-direction \((V_x)\) and the total time found in Step 8 to calculate how far away you need to place the target.

Distance = __________ meters

**Step 10:** Place your target on the ground with the bullseye at the exact distance you calculated. Your group will get three launches to get as close to the bullseye as possible.

*Note*: Adjustments can only be made side to side. No changes in distance!

Circle your best result: A B C D F
Teacher Guide

- **Number of Days**
  - The activity set up to find the height of the gym ceiling should only require one class day. It involves travel throughout the school building, but a relatively small amount of data collection and mathematical problem solving. The projectile launch challenge will likely take 2-3 days of class to complete. Introducing the idea and allowing each group to gather data with the launcher would take up most of the first day. If the entire project is to be done in the classroom and not assigned as homework, then students would spend leftover time on day one and the entirety of day two finding the muzzle velocity of the projectile launcher and then using that value to find the correct distance for their given angle. My recommendation would be for the final calculations to be due at the start of the third day of the project. This allows the last day to be set aside for each group measure out the distance they calculated, place the target, and test the launcher.

- **Sequence**
  - **Height of the Gym Ceiling**
    - This activity should be completed after the students have been taught the kinematic equations and had some exposure to simple free fall problems. The goal for this activity is for it to be a conceptual challenge that requires thought and data, but mathematically simple once they understand the problem.
  - **Projectile Launcher - Target Challenge**
    - This project should be taught at the end of the unit focusing on projectile motion. In order to solve the complex real-world problem accurately, students need to have a full understanding of the conceptual aspects of velocity vectors, their components, and how they are impacted by gravity during flight. They also need to have a lot of experience using the kinematic equations so they can identify the best option for the problem in front of them and solve it accurately.

- **Helpful Directions / Guidelines**
  - **Height of the Gym Ceiling**
    - This activity is meant to be one of the first real-world problems students solve during this unit of study. It is an exploratory lab that is meant to challenge the students. In order to solve the problem of calculating the height of the gym, there is one piece of conceptual information the students have to figure out. The hint offered at the bottom of the worksheet leads the students in the correct direction. This hint can be removed if a teacher would like the students to engage in more productive struggle. Conversely, more verbal hints or guiding questions can be offered to the students to ensure they aren’t lost in how to approach the situation.
    - The activity is made even better if there is a true value known by the teacher before the start of the lab. This can be found through a laser measuring device or very careful testing. When students return to the classroom they post their answers on the front whiteboard and a prize of some sort can be given to the group that was the closest. This can also serve as an opportunity for the groups to calculate their percent error off the true value and discuss what could have been the cause of it.
● Projectile Launcher - Target Challenge
    ■ Depending on the available lab equipment for each teacher, the first step of this lab may be using department funds to purchase a projectile launcher. There are several different launchers targeted toward physics classrooms available on the market. Some of the more expensive launchers have multiple launch strengths which could be used to further diversify the criteria given to each lab group.
    ■ The lab worksheet offers a clear description of what needs to be found and the order it needs to be found in. Students are still required to have a full understanding of vectors, projectile motion, and the kinematic equations in order to solve each problem, but it takes away the opportunity of proposing a broad question with no direction. If this version is desired, it would be easy to simply present the goals to the groups of students and then have the step by step directions available if any one group is lost along the way.
    ■ During all testing it’s helpful if students have designated roles they must fill. When a group is using the launcher it’s helpful if one student is pulling the string, one student is watching carefully to mark the landing spot, and one student is far away from the launcher ready to catch the ball. This keeps things moving efficiently if you only have one launcher and helps ensure that none of the projectiles are lost as they bounce around the room.
    ■ Step 6 asks the students to present the muzzle velocity they calculated to the teacher prior to receiving the angle they will use for their target challenge. This is an opportunity for the teacher to stop each group and check their work before they move forward. In the event that a group has made a mistake, this is a good point to have them redo their work. Without a relatively close value for the initial velocity created by the launcher, it’s impossible for the students to land the projectile within the target.
    ■ The “bullseye” target was developed to increase the motivation and competitive of the students. Whether it is used as a part of the true grading process is up to each individual teacher. It could be used as bonus points if the data collection and calculations make up the majority of the grade or it could be a high stakes situation where the landing placement of the projectile is the grade each group receives for the entire project.

● Warnings
  ○ Height of the Gym Ceiling
    ■ Rules will need to be set up beforehand about what behavior and actions won’t be accepted when students are traveling through the hallways and given a tennis ball once they get to the gym. Without clear directions some students will end up throwing the tennis ball at the walls or each other.
    ■ This can be a good opportunity for students to use their phones as a part of class because all smartphones have nice stopwatches, but that also has the possibility of back firing as students lose focus on the task at hand by looking through Instagram and Snapchat.
  ○ Projectile Launcher - Target Challenge
    ■ Regardless of which type of projectile launcher is purchased for the class, strict rules need to be enforced about the proper use of the launcher. The projectiles are usually hard plastic balls that are launched at high speeds. This requires
careful directions for where students are allowed to stand during launches so they aren’t hit.

• Key Equations / Definitions
  ○ Scalar / Vector
  ○ Vertical component / Horizontal component
  ○ Acceleration of Gravity (g = 9.8 m/s²)
  ○ The Kinematic Equations
    ■ \( d = v_i \cdot t + \frac{1}{2} \cdot a \cdot t^2 \)
    ■ \( v_f = v_i + a \cdot t \)
    ■ \( v_f^2 = v_i^2 + 2 \cdot a \cdot d \)
    ■ \( d = \left(\frac{v_i + v_f}{2}\right) \cdot t \)
Topic #4: Energy, Work, and Power

- Minnesota State Standards
  - 9.2.3.2.2 Calculate and explain the energy, work and power involved in energy transfers in a mechanical system.
  - 9P.2.2.1.1 Explain and calculate the work, power, potential energy and kinetic energy involved in objects moving under the influence of gravity and other mechanical forces.
  - 9P.1.3.4.1 Use significant figures and an understanding of accuracy and precision in scientific measurements to determine and express the uncertainty of a result.

- Essential Questions:
  - What is the relationship between work and energy?
  - What is the relationship between work and power?
  - What is the definition for potential energy? Are there different types of potential energy?
  - What is the definition of kinetic energy?
  - How does an object or system transfer between potential and kinetic energy?
  - What are the major types of energy used in the physics of classical mechanics? (non-quantum)

- Learning Targets
  - SWBAT calculate the amount of work done on an object by a constant force, including all possible resulting motion created.
  - SWBAT describe the relationship between work and energy qualitatively and quantitatively.
  - SWBAT describe the relationship between work and power.
  - SWBAT calculate the amount of power necessary to complete a set amount of work in a set amount of time.
  - SWBAT define potential energy and identify its various types.
  - SWBAT define kinetic energy.
  - SWBAT calculate the gravitational potential energy of objects near the Earth’s surface.
  - SWBAT calculate the kinetic energy of moving objects.
  - SWBAT explain the Law of Conservation of Energy qualitatively and quantitatively.
  - SWBAT solve problems involving multiple forms of energy using the Law of Conservation of Energy.

- Rationale
  - The topic of energy can be challenging both mathematically and conceptually. In order for students to understand what energy is, teachers usually take students through the conceptual side of energy first. This offers a great base of knowledge to build on and ensures that students don’t dive into energy calculations without an understanding of what they’re actually solving for and how it works. Unfortunately, by the time students master the ability to calculate gravitational potential energy, elastic potential energy, kinetic energy, and thermal energy they lose sight of the larger conceptual picture.
  - The energy ramp challenge requires students to combine their mathematical ability with a fundamental understanding of the law of conservation of energy. Rather than providing students with theoretical energy values in order to complete several types of
practice problems, this challenge has students collect their own data in order to solve multiple complex steps on the way to one overarching goal. In order to succeed students must combine their lab skills along with all of their knowledge about the topic of energy to solve a real-world problem. It forces a deeper understanding that is at the heart of problem based learning.
Energy Ramp Challenge!

**Challenge:** Launch the car so it travels over the hill and stops exactly on target!

**Materials:**
- 1 rubber band
- 1 hot wheels car
- 2.5 meters of hot wheels track

**Measurement Tools**
- Force Sensor
- Meter Stick

**Day 1-2: Gather critical data on your materials.**

**Goal 1:** Find the spring constant of your rubber band when it’s doubled over.

- Place the rubber band on the end of two fingers and grab the center of the rubber band with the hook from the force sensor.
- Create a data table with several measurements of force and \(\Delta x\) (the stretch distance from equilibrium).
- Create a graph and use a best fit line and Hooke’s Law \(F = k \cdot \Delta x\) to find the spring constant \((k)\) of your rubber band.

**Goal 2:** Find the force of friction acting on the car as it travels on the ramp.

- Create a simple half pipe with 1-2 meters of track \(\rightarrow\)
- Release the car from various heights and measure the height it reaches on the opposite side of the track.
- Use these measurements to find the amount of energy transferred to thermal energy due to friction.
- Calculate the force of friction by measuring the distance traveled and using \(E_{th} = F_f \cdot \Delta x\)

**Day 3:** Create an energy map that shows values for all types of energy.

**Goal 3:** Create a sketch of the full car and track apparatus, including heights and energy values.

- This sketch will serve as a helpful visual and an organizational tool when undergoing necessary calculations to complete the challenge.
- Height parameters are shown in the example on the next page.
Gravitational Potential Energy ($E_g$) / Kinetic Energy ($E_K$) / Elastic Potential Energy ($E_{el}$) / Thermal Energy ($E_{th}$)

- All of the energy values of the system ($E_g / E_K / E_{el} / E_{th}$) must be found for each of the three critical points on the ramp.
  - Start
  - Top of the Hill
  - Finish

- The best strategy is to first find out how much of each type of energy is required at the very end in order to successfully beat the challenge. After those values are found, you can work backwards and find out how much energy will be required on the hill and finally how much will need to be generated at the start.

**Day 4: Attempt to beat the Energy Ramp Challenge!**

**Goal 4:** Find how far back the rubber band must be stretched to beat the challenge.

- Use the energy values calculated for the start of the ramp along with the elastic energy equation ($E_{el} = \frac{1}{2} \cdot k \cdot x^2$) to find out how far back the rubber band must be stretched in order for the car to stop exactly on the center of the target.

**Challenge Time!**

- Each group must place the target on the far end of the 2.5 meter ramp exactly where they have calculated the car will stop. Then each group will **three attempts** to achieve the best grade possible.

- Example of a trial that successfully beats the Energy Ramp Challenge!
Teacher Guide

● Number of Days
  ○ As stated in the student handout, this challenge will take four days of class to complete. It is possible it could take an extra day or two depending on the amount of productive struggle the students go through during the calculations and the amount of time given for optimizing the ramp apparatus before testing.

● Sequence
  ○ This challenge should be the very last thing introduced under the topic of energy. It is meant to combine all knowledge gained throughout the unit. It highlights a significant amount of the unit and could therefore be included as a part of the summative assessment.

● Helpful Directions / Guidelines
  ○ Similar to the projectile launcher challenge, the energy ramp challenge requires specific materials that might need to be purchased. Hot wheels cars and tracks were recommended, but substitutes for those items could also be used. Likewise force spring scales could be used instead of the Vernier force sensor. The specific items listed in the handout were chosen because of their availability, consistency, and accuracy.
  ○ Goals 1 and 2 are meant to be interchangeable. There isn’t a preferred order when completing these two tasks, so it could be an opportunity to split the class, with half of the groups working on Goal 1 first and the other working on Goal 2 first. This possibility can help with a shortage of materials and also give the teacher a chance to see what issues might arise before presenting both tasks to the entire class.
  ○ This challenge is a complex application of several different concepts within the topic of energy. The handout provided explains what needs to be done each day and sets goals for the students, but it doesn’t explain how the students are supposed to accomplish those goals. It serves as a template, but isn’t meant to stand alone with no additional instruction. The amount of added information and guidance provided is left up to each individual teacher. In depth demonstrations explaining each step could be done or the students could be set loose to attempt to solve the problem on their own. Each teacher is responsible for knowing what would be both challenging and attainable for their students.

● Warnings
  ○ This entire challenge should be completed by the teacher prior to attempting it with a class. The process of completing the challenge will drastically improve the teacher’s ability to understand different difficulties and struggles that the students might run into. The ability to confidently offer support and advice in those moments will reassure the students that their goal is attainable and save valuable class time. Depending on the materials chosen, there may also need to be adjustments made to the height of the hill or the total length of track provided to the students. If a teacher blindly picks a height that is too large, the students won’t be able to get the car to stop with the amount of track provided. The amount of work required to accurately execute the steps necessary to beating the challenge deserves a great pay off. It would be disappointing for the
students to spend four days of work only for the teacher to find out the parameters they set didn’t actually have a possible solution.

- **Key Equations / Definitions**
  - Definition for Energy
  - Unit for energy - Joules (J)
  - Law of Conservation of Energy
  - potential energy vs kinetic energy
  - Gravitational Potential Energy
    - \( E_g = m \cdot g \cdot h \)
  - Elastic Potential Energy
    - \( E_{el} = \frac{1}{2} \cdot k \cdot x^2 \)
  - Kinetic Energy
    - \( E_k = \frac{1}{2} \cdot m \cdot v^2 \)
  - Thermal Energy
    - \( E_{th} = F \cdot \Delta x \)
  - Work
    - \( W = F \cdot d \)
Topic #5: Electricity and Circuits

- Minnesota State Standards
  - 9.2.3.2.1 Identify the energy forms and explain the transfers of energy involved in the operation of common devices. For example: Light bulbs, electric motors, automobiles or bicycles.
  - 9.2.3.2.4 Explain and calculate current, voltage and resistance, and describe energy transfers in simple electric circuits.
  - 9P.2.3.2.1 Explain why currents flow when free charges are placed in an electric field, and how that forms the basis for electric circuits.
  - 9P.2.3.2.2 Explain and calculate the relationship of voltage, current, resistance and power in series and parallel circuits. For example: Determine the voltage between two points in a series circuit with two resistors.

- Essential Questions
  - How does the flow of electrons (current) explain the process of circuits and modern common devices?
  - What is the relationship between voltage, current, and resistance in a circuit?
  - What are common analogies for voltage, current, and resistance?
  - What are the structural and electrical differences between a series circuit and a parallel circuit?

- Learning Targets
  - SWBAT explain what electric current is and the units used to measure it.
  - SWBAT explain what electrical resistance is and the units used to measure it.
  - SWBAT explain what voltage is and the units used to measure it.
  - SWBAT describe the conditions needed for current to flow.
  - SWBAT identify if current will flow and which bulbs/devices will be functional given an electrical diagram.
  - SWBAT describe the relationship between current, resistance, and voltage in a circuit.
  - SWBAT use Ohm’s Law to calculate current, resistance, or voltage given the other two variables.
  - SWBAT identify and explain the difference between a series circuit and a parallel circuit.
  - SWBAT create both series and parallel circuits.
  - SWBAT give examples of devices that function better with a series circuit and devices that function better with a parallel circuit.

- Rationale
  - There are several good analogies to the idea of a circuit and the corresponding variables of current, resistance, and voltage, but none of them are convenient or accurate enough to explain the topic of electricity and circuits to students for the first time. This is one of the first physics topics that students can’t actually see taking place. The confusion and misconceptions around this topic are too great for the students to simply be told how everything works. The analogy of water filled pipes representing electrons in a circuit is a fantastic tool for clarification, but students need to get involved in their own learning in order to break down their misunderstandings.
The circuit exploration lab and *I can see the light* simulation are both meant to provide a guided inquiry based learning experience that break down misconceptions. The first exploration lab gives students the opportunity to create their own circuits and tinker with each piece of equipment until achieving the satisfying result of a working light bulb! The simulation dives into more complex types of circuits, but in an idealistic setting that makes it clear to the students if they are doing it correctly or not. Both activities allow students to build a base of knowledge through experimenting, rather than being told.
Circuit Exploration Lab

The goal for each setup is to complete the circuit with a working light bulb. After you complete each setup, answer the following question(s) with your group. You must switch off who is manipulating the circuit board and who is writing the answers. Rotate between group members.

Setup #1: one battery, one light bulb
Does the number of extra connecting wires change the brightness of the bulb?

Setup #2: one battery, two light bulbs
How did adding another light bulb affect the brightness of the first bulb?

Are the two bulbs the same brightness?

Setup #3: two batteries, one light bulb
How does this brightness compare to the first two setups?

What did you learn about the direction of the batteries?

Setup #4: two batteries, two light bulbs
Is the brightness of each bulb most like setup 1, 2, or 3? Why might that be?

Setup #5: two batteries, one light bulb, one resistor
How does the resistor change the circuit?

Are there differences between the different colored resistors? If so, what are they?

Challenge Problems
Setup #6: two batteries, two light bulbs
Design a circuit where both light bulbs are just as bright as if there were only one.
How is this design different from setup #4?

Setup #7: two batteries, one light bulb, one potentiometer (dial)
How does adding the dial change the circuit? What happens when you turn the dial?
I CAN SEE THE LIGHT!

Essential Questions:
This lab will help you to answer these questions:
1. What factor(s), in terms of circuits, determine the brightness of a light bulb?
2. If you were making a string of lights, how would you connect them so that if one or more of them burns out, the rest still work?

Terms to Know:
- Voltage
- Current
- Series circuit
- Parallel circuit

What you’ll do:
Part 1 – Setting the voltage.
Download and Run the simulation linked here.
Put one battery in the simulation and test the voltage. Use figure 1 to see how you should test your power source. What is the voltage of the battery?

Part 2 – Your first useful circuit!
After you have measured your power source voltage, you are ready to start connecting light bulbs. The first circuit you will make is shown in figure 2a. Set it up and make sure you can light up the light bulb.

Once you have successfully lit the bulb, disconnect the circuit and put an ammeter into the circuit as shown in figure 2b. This will tell you the amount of current going through the light bulb. Write the amount of current here:

Part 3 – Two bulbs in SERIES.
Now you are ready to deal with more than one light bulb. Build the circuit shown in figure 3a. This is known as two light bulbs in series. Write down your observations of this circuit and how the brightness of the bulbs compares to the single bulb in part 2.
Also, write down the amount of electrical current that your ammeter is reading flowing through the circuit.

How does this current compare to the single bulb in part 2? What does this tell you about the relationship between the amount of current through a light bulb and the light coming from it?

Now, connect the voltmeter to your circuit as shown in figure 3b. This measurement will tell you the amount of voltage that is provided across the first light bulb. What is the reading on the voltmeter?

Next, connect the voltmeter to the circuit as in figure 3c. This measurement will tell you the amount of voltage that is provided across the second light bulb. What is the reading on the voltmeter?

How do these readings compare to the total voltage provided to the whole circuit from the power source?

Now, what do you think will happen if just one of the light bulbs burnt out? Put your hypothesis here and tell me how you came up with your hypothesis.

To test your hypothesis, use the set-up shown in figure 3a. Disconnect any one of the light bulbs. This simulates a burnt out bulb. Reconnect the wire and see what happens. Record your observations here.

So, what do you think would happen if a light bulb burns out when two or more light bulbs are connected in series?
Part 4 – Two bulbs in PARALLEL
Connect your circuit as shown in figure 4a. This is known as putting two light bulbs in parallel. What do you notice about the brightness of the light bulbs in parallel as compared to the bulbs in series from part 3?

Now connect the voltmeter to the first light bulb as shown in figure 4b. This will tell you the amount of voltage that is across that light bulb. What is the reading?

Next, connect the voltmeter to the second light bulb as shown in figure 4c. This will tell you the amount of voltage that is across that light bulb. What is this reading?

How do the two voltage readings compare to the input voltage from the power source.

How is this different than the voltages across the two light bulbs in series in part 3?

So, which circuit, series or parallel, can provide the largest voltage across a light bulb? How does this affect the brightness?

Now, what do you think will happen if just one of the light bulbs burnt out? Put your hypothesis here and tell me how you came up with your hypothesis.
To test your hypothesis, use the set-up shown in figure 4a. Disconnect any one of the light bulbs. This simulates a burnt out bulb. Reconnect the wire and see what happens. Record your observations here.

How is this different than in the series circuit in part 3?

So, if you wanted to build a string of lights, how would you connect them: series or parallel and *WHY*?

**NOW YOU CAN SEE THE LIGHT!!!**

Part 5 – Fun with Circuits
One by one, build the circuits shown in figures 5a, 5b, 5c, and 5d. Record your observations of the brightness of the light bulbs here.

5a: Three bulbs in series.

5b: Three bulbs in parallel.

5c: Two bulbs in series, one in parallel.

5d: Two bulbs in parallel, one in series.
Teacher Guide

- Number of Days
  - The circuit exploration lab is an introductory activity that is meant to take only one day of class. On the other hand, the simulation goes into much greater detail, which requires at least two full days for students to properly complete the entire activity.

- Sequence
  - The exploration lab should be put early in the unit focusing on circuits and can even be the first day. It is designed to spark the interest of students and show them they can solve electrical problems before even getting into the nitty gritty of how everything works. After teaching the basics of current, resistance, voltage, and simple circuits the computer simulation re-introduces guided inquiry based learning as the students are able to create complex circuits with immediate results and no danger.

- Helpful Directions / Guidelines
  - Circuit Exploration Lab
    - This lab requires specific materials that are found in many different classroom focused circuit kits. Specifically each group needs a kit that has a circuit board, two batteries, two light bulbs, at least one resistor, a potentiometer, and several connecting wires.
    - (CPO circuit board: example of a possible set of materials)
    - This lab is meant to take place early in the circuit unit and be used as an inquiry experience, but it still requires some explanation and directions beforehand. The lab will go much more smoothly if a demonstration of how to use the equipment is given to the entire class prior to the start of the lab. This way students get the chance to experiment without the confusion of not knowing how to connect items on the circuit board.
    - I can see the Light!
      - This simulation offers a much wider range of possibilities than the real-world circuit board and therefore can be used to highlight more interesting and complex circuits. It’s tempting to skip straight to this resource, but by first using batteries and light bulbs with a circuit board, students build the base of their knowledge on reality and not a computer screen.
      - Much like the circuit board, the simulation goes much more smoothly if the teacher gives a short demonstration before sending students off to experiment.
- **Warnings**
  - Circuit Exploration Lab
    - Make sure to monitor each group to make sure nothing is being used in a way that could damage the materials or potentially be dangerous. Examples:
      - Creating a circuit with no resistance so the battery gets really hot.
      - Adding several batteries together to get the bulb as bright as possible
  - I can see the Light!
    - The simulation includes several features that tend to excite and distract students. The most prevalent of these features is that a circuit with no resistors will cause the battery to start on fire. The simulation also has several extra items that can distract students like a super battery, a dollar bill, a pencil, and a dog. These extra items don’t serve much of a purpose until students attempt to see how many super batteries need to be lined up to set the dollar bill on fire, or similar misadventures. A teacher’s awareness of these distractions and a plan to combat them when they appear will go a long way toward keeping students productively engaged and learning.

- **Key Equations / Definitions**
  - Current (I)
    - Rate of flow of electrical charge.
    - Unit: Amperes (Amps)
  - Resistance (R)
    - A measurement of the reduction in electrical flow caused by a material.
    - Unit: Ohms
  - Voltage (V)
    - The electric potential difference between points.
    - Unit: Volts
  - Circuit
    - Battery, light bulb, resistor, potentiometer, ammeter, voltmeter, ohmmeter, multimeter
  - Series vs Parallel Circuits
Topic #6: Light, Reflection, and Refraction

- Minnesota State Standards
  - 9P.2.3.3.2 Explain and calculate how the speed of light and its wavelength change when the medium changes.
  - 9P.2.3.3.3 Explain the refraction and/or total internal reflection of light in transparent media, such as lenses and optical fibers.
  - 9P.2.3.3.4 Use properties of light, including reflection, refraction, interference, Doppler effect and the photoelectric effect, to explain phenomena and describe applications.

- Essential Questions
  - How does light bounce off a reflective surface?
  - In what situations does light refract? What causes light to refract in those situations?
  - How do you figure out where light will bounce off a reflective surface?
  - How do you figure out how much light will bend during refraction?

- Learning Targets
  - SWBAT explain the difference between a luminous object and an illuminated object.
  - SWBAT use mathematical thinking to find the angles of incidence and reflection of light off of a reflective surface.
  - SWBAT list the conditions necessary for light refraction.
  - SWBAT explain how light bends during refraction.
  - SWBAT use a protractor to measure the angle of incidence and the angle of refraction.
  - SWBAT use Snell’s Law to solve for the index of refraction of a medium in a given system.
  - SWBAT use Snell’s Law to solve for the angle of refraction in a given system.
  - SWBAT explain a situation where constructive or destructive interference occurs in everyday life.

- Rationale
  - The reflection and refraction of light is an example of a physics concept that can produce fantastic visuals followed complicated equations. Unfortunately, when teaching the phenomena of light, the amazing visual reality of reflection and refraction are usually lost on students once they have to learn how to calculate the amount that light will bounce and bend. The “broken” pencil demonstration (shown on the right) is one of several fantastic examples to pique the interest of students. This topic isn’t missing shocking visuals to get students excited, it’s missing worthwhile connections between those visuals and the mathematics required to calculate exactly what the light will do when it encounters a mirror or a new medium.
  - The laser maze project is designed for students to apply the knowledge they gained throughout the unit in order to engineer a design and solve a real-world problem.
Laser Maze!

Now that you have learned how light bounces and bends from reflection and refraction, it’s time to put your knowledge to the test. You will be designing a maze, but not in corn, or for pen and paper, or even for a mouse. You will be designing a Laser Maze! Together we’ve learned how to calculate the angles light makes as it reflects off mirrors and refracts through glass or water. Now that you have the knowledge and the skills to know where light will go before it’s even turned on, it’s time to prove it using your own creativity.

What do we need to turn in?
You will each be responsible for turning in a detailed map of your maze and a full set of calculations for how the laser will travel.

What can we put in the maze?
Your maze must include at least 3 mirrors and 2 refractive mediums.
**WARNING: You must do the calculations for every obstacle the light will travel through, so don’t design for more than you have time to calculate.**

When do we get to test our mazes?
After we take our test on the properties of light, we will have an entire class period for testing your mazes!
**WARNING: You must be done with both map and calculations to check your maze with the laser.**

Scoring:
**Detailed Map: 20 points**
- This map must include all reflective and refractive materials chosen, the path the laser will take, and the angles the light will follow as it bounces and bends through the maze.

**Full Set of Calculations: 30 points**
- These calculations must include the angle of incidence and angle of reflection at each mirror and similarly the angle of incidence and angle of refraction through each refractive material.

**Bonus Points: 5 points**
- On Maze Day, if the laser follows your detailed map and hits the target, you get 5 bonus points!

**Full Project: 50 points**
Teacher Guide

● Number of Days
  ○ The lazer maze project will take four days for students to complete. The first day should be spent getting into groups, becoming familiar with the materials, and beginning to sketch a design based on the amount of space available for the maze. The second day students should finish a rough sketch of the design of their maze. Once this is done they can begin calculations on the incidence and reflection angles, as well as the distance the laser will shift when it travels through the refractive medium. By the end of the third day, the students should have a detailed map drawn with all necessary angles labeled along with a full set of calculations. With all of the work complete, the fourth day can be spent testing out all of the laser mazes to see which group will receive extra credit for hitting the bullseye of their target.

● Sequence
  ○ This project is the culmination of the unit focussing on light reflection and light refraction and as such should be completed at the end of the unit. If desired by the teacher, it can also serve as part of the summative assessment on the topic of light. The laser maze gives students the opportunity to showcase their recently acquired knowledge by solving a real-world problem with a possibly satisfying pay-off.

● Helpful Directions / Guidelines
  ○ Materials
    ■ A shoebox can serve as the perfect vessel for a laser maze. The relatively small space keeps measurements and calculations simple and increases the chance that students will hit their target.
    ■ Small mirrors or smooth flat pieces of metal can easily serve as the reflective surfaces.
    ■ Square test tubes filled with water are a great way to introduce the refractive medium. They have specific dimensions that can be measured and students should already have used the refractive index of water in example problems earlier in the unit.
    ■ Rulers and protractors should be made available to every individual student so everyone can help contribute to the many measurements and calculations.

●Warnings
  ○ The laser should only be used by the teacher at the time of testing. This allows tension to build because no group knows for sure if their maze will work and it also ensures student safety because no student will accidentally or intentionally have a laser pointed at their eyes.

● Key Equations / Definitions
  ○ Reflection
  ○ Refraction
  ○ Angle of Incidence, Angle of Reflection, Angle of Refraction
  ○ Index of Refraction
  ○ Snell’s Law - \((n_1 \sin \theta_1 = n_2 \sin \theta_2)\)