ELECTRIFYING MATH:

An Exploration of Physics, Math and Connections to the Electrical Trades

skills READY

The concept for Electrifying Math was born out of a conversation on how to support people in their journey to become electricians. Foundations of Math 11 and Physics 11 are the two highest academic courses required by BC colleges for entry into Level 1 Electrical programs. What would a teaching resource look like that could help make these challenging courses relevant and interesting for learners? Could a thematic approach to learning math and physics concepts through building electrical projects be possible? How can we help teachers guide students in safely experimenting with electricity? Can the FOM 11 and Phys 11 BC curricula be covered in their entirety using experiential learning? Could this resource benefit not only prospective electricians and hands-on learners, but also students with all sorts of learning styles and future career goals? The IBEW and Construction Foundation of BC decided to team up to create such a resource, and this is the result!

Electrifying Math is a series of 12 project resources that can be used individually, or, taught in their entirety, cover the Foundations of Math 11 and Physics 11 BC Curricula. Each of the projects include:

-A materials list, tool list, and procedure steps to build the project prototype

-Safety recommendations specific to each project

-**"Guided Exploration"**: a 6-step example lesson flow that teachers can draw from to lead students through the curricular competencies

-Example questions to ask students to pique curiosity and deepen understanding

-A **"Scientific Method Resource"** template for students to design scientific experiments on

-**"Suggested Assessment Strategies"**: detailed assessment ideas that cover the required curriculum content, including sample calculations to analyze data

-**"Science Challenge Opportunities"**: fun group challenges to help students play with and practice their newfound skills

-**"Take it further"**: ways to extend exploration on each topic

We hope you and your students enjoy the projects as much as we enjoyed making them!

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GLOSSARY TERMS

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- **Accelerate / acceleration** – The rate of change of the velocity of an object with respect to time
- **Ampere's Law** - A scientific law which states that the magnetic field around an electric current is proportional to the electric current, which serves as its source
- **The angle of launch** –the vertical angle (measured above horizontal) of the instantaneous velocity vector of a projectile at the moment of release
- **Anode** - (Battery) the negatively charged electrode/terminal
- **Applied force** – A force applied to an object by another object
- **Arduino UNO** - an open-sourced microcontroller board for electronics projects
- **Ballistics** - The science and study of projectiles
- **Calorie** – a unit of energy equal to 4.19 Joules, or the amount of energy required to raise the temperature of 1 gram of water by 1 degree Celsius. Often used in quantifying the energetic value of food
- **Catapult** – A ballistic device that utilizes stored potential energy to propel/launch an object a great distance
- **Cathode** - (Battery) the positively charged electrode/terminal
- **Central tendency** – A central or typical value for the probability distribution of statistical analysis
- **Coil** – wire arranged in a helical shape (sequence of same-sized rings)
- **Compound Simple Machine** - a machine consisting of two or more simple machines
- **Compression** – the part of a longitudinal wave where the medium's particles are closest together
- **Conservation of energy** - the concept that energy cannot be created nor destroyed, that it is constant in a closed system, and can be transformed between forms or types (i.e., kinetic to heat)
- **Core** – a piece of material with a high magnetic permeability used in electromagnetic devices to strengthen and confine magnetic fields
- **Coulomb** – Coulomb - 6.24 x 10^18 electrons
- **Current** –the rate of flow of electrically charged particles past a point, measured in amps

- **Dependent variable** – A variable whose value depends on that of an independent variable. Often assigned the y-variable on a graph
- **Doppler effect** - an effect produced when movement relative to a source of waves produces an apparent shift in wave frequency
- **Dynamo** – a mechanism that transforms kinetic (mechanical) energy into electricity (i.e., a generator)
- **Efficiency** – a comparison (as a %) of how much useful output a device or process can accomplish based on the input required
- **Electrochemical** - relating to the chemical changes brought about by the application of electricity or the production of electricity brought about by chemical change or reaction
- **Electromagnet** – a core of magnetic material wrapped with wire which becomes magnetized when electricity is supplied to the coil of wire and demagnetized when the electricity is removed
- **Force** - any push or pull on an object that changes its velocity (speed or direction)
- **Frequency (electrical)** - the number of times a sine wave repeats or completes a positive to negative cycle in one second
- **Frequency (wave)** - the number of times one wave cycle passes a point in a specified amount of time, often measured in Hertz (Hz)
- **Friction** – The force resisting the relative motion of objects sliding against each other
- **Generator** - a device that transforms energy from one type to another (often kinetic energy into electricity)
- **Graphite** – a crystalline form of carbon
- **Gravitational potential energy** – the amount of energy an object possesses (its ability to do work) based on its position in a gravitational field
- **Gravity** - a universal force of attraction between all objects with mass
- **Helix** - a 3-dimensional shape, similar to a wire spring
- **Hertz / Hz (electrical)** - the number of times a sine wave repeats in one second
- **Hertz / Hz (waves)** - a unit of frequency: the number of times a full wave cycle passes a point in one second, i.e., in sound waves, a “middle C” note is 262 Hz or 262 vibrations per second

- **Hypothesis** – An educated guess on an outcome that forms the basis of a scientific experiment
- **Independent variable** – A controlled input variable that is not changed by the other variables measured, controlled input variable. Often assigned the x-axis of a graph
- **Instantaneous velocity** – The velocity of an object in motion at a specific point in time
- **Joule** – a unit of energy equal to one watt-second, or the work done by a 1-newton force acting over a distance of 1 metre
- **Kilowatt hour** – a unit of energy measured as the amount of electricity a 1000-watt device uses in one hour
- **Kinetic energy** - the energy that an object possesses due to its motion
- **Lead** - An electrical connection usually consisting of a wire
- **LED** - Light Emitting Diode – an electronic device that emits light when an electric current pass through it
- **Longitudinal wave** - a wave in which the medium's particles move in a plane parallel to the direction of wave movement, e.g., sound waves
- **Magnetic levitation (maglev)** - A method by which an object is suspended with no support other than magnetic fields
- **Mechanical advantage** - a unitless ratio description of the effective force amplification of a simple machine
- **Negative acceleration** - the rate of change in velocity in the opposite direction to the velocity vector, or "slowing down"
- **Normal force** – The support force exerted on an object in contact with a stable object
- **Ohm's Law** – the principle that the voltage between two points in a conductor is directly proportional to the current running between them and also directly proportional to the resistance between the two points
- **Parabola** - A plane curve that is mirror-symmetrical and approximately U-shaped, described mathematically by a quadratic equation
- **Permanent magnet** – An object made from a magnetized material that creates its own magnetic field
- **Permeability** – The ability of a material to become magnetized

- **Pin socket cables** - formerly “male-to-female jumpers”; connector wires for electronic microcontroller setups
- **Pitch** – The specific quality of a sound in relation to its frequency, i.e., “middle C” played on a piano makes a sound wave with a frequency of 262 Hz. Higher pitched sound waves have a higher frequency, and lower pitched sound waves have a lower frequency
- **Potentiometer** – an adjustable voltage divider
- **Power** - the rate at which work is done (or energy is transferred). Power = work / Δ time, measured in watts
- **Propulsion (verb propel)** - The action or process of pushing or pulling to drive an object forward
- **Quadratic equation** – an equation in the form of $0 = ax^2 + bx + c$ where $a \neq 0$
- **Quadratic function** – a function described by an equation of the form $f(x) = ax^2 + bx + c$ where $a \neq 0$
- **Quadratic root or “zero**”- the x-value solution(s) of a quadratic function, or the x-intercept(s) of a quadratic function graph (where $y = 0$)
- **Quantify** – To measure the size or amount of something and express it as a number
- **Range** - The horizontal displacement of a projectile
- **Rarefaction** - the part of a longitudinal wave where the medium’s particles are furthest apart
- **Repel / repulsion** – Opposite of attraction, a push back or away by force such as magnetism.
- **Resistance (electrical)** - Anything in an electrical circuit that opposes the flow of current
- **Rheostat** – a variable resistor
- **RPM** – rotations per minute
- **Rube Goldberg machine** - a whimsical, overly complicated, and needlessly elaborate system that accomplishes a simple or even trivial goal
- **Servo motor** - a small electric motor with high efficiency and high precision rotary movement, often used in robotics, toys, and aircraft
- **Simple machine** – one of 6 devices (pulley, wheel and axle, wedge, lever, inclined plane, screw) that change the direction or magnitude of a force to perform work on an object
- **Sine Wave** – a graphical representation of the oscillation, from negative to positive of alternating current power

- **Soldering iron** - a heating tool used to join pieces of metal together using melted solder
- **Solenoid** - a coil of wire used as an electromagnet
- **Specific heat capacity** - the amount of heat energy input needed to raise the temperature of a specific amount of a certain material by one degree in temperature, often measured in Joules per kilogram per degree Celsius
- **Terminal** – The point at which an electrical wire or electrical component/device such as a battery comes to an end
- **Ticker tape** – 10mm wide paper strip roll used with ticker timers
- **Ticker timer** - an electric buzzer that makes dots on the ticker tape at a rate of 50 per second; used to quantify velocity and acceleration of objects
- **Trajectory** – The path followed by a projectile flying under the action of given forces
- **Transverse wave** – a wave in which the medium's particles move in a plane perpendicular to the direction of the wave movement, e.g., ripples on a pond
- **Ultrasonic** - sound with a frequency above the upper limit of human perception
- **Voltage** – electromotive force, the difference in electric potential between two points
- **Volume** – the degree of loudness or intensity of a sound, based on the amplitude or how far molecules in the medium are displaced as a longitudinal sound wave passes
- **Velocity** – a vector quantity indicating relative speed and direction
- **Vertex (of a quadratic function)** - tthe point at which a parabola's curve changes direction
- **Vesicle** – a small, fluid filled sac, e.g., the membrane-bound juice compartment in a citrus fruit
- **Work** - a measure of energy transfer when a force is applied to an object over a distance. Work = force x displacement. Measured in Joules
- **X and Y intercepts (graphing)** – X intercepts are where the line or curve crosses the X-axis, Y intercepts are where the line or curve crosses the Y-axis

MAGNETIZING METAL

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MAGNETIZING METAL

INSPIRATION

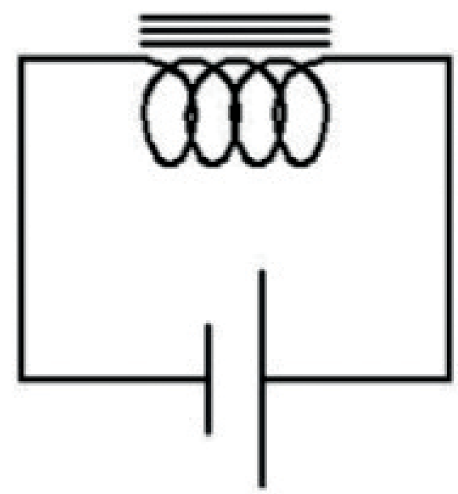
Electricity and magnetism are two inextricably linked phenomena that are harnessed constantly by appliances and machines throughout your daily life. Fridges, computers, even your headphones wouldn't work without them! How might the materials that make an electromagnet interact to create these forces? What makes an electromagnet strong? Can electromagnets defy gravity?

OBJECTIVE

Students will explore and experiment with variables that affect the strength of electromagnets through building a simple ferro-core electromagnet.

TRADES CONNECTION – THEORY

Electrical transformers, the big metal cylinders seen on telephone poles, use electromagnets to change the amount of voltage of the electricity passing through them. Wires from two separate circuits are wrapped around a metal core. When the voltage from the one circuit is applied to the core, it becomes magnetized, which in turn induces a voltage in the second circuit. The amount of voltage "stepped up" or "stepped down" is related to the number of wraps of wire from each circuit that are wound around the core. In this way, electromagnets can be used to increase or decrease voltages of an electrical supply depending on the purpose and use of the electricity.



SAFETY FIRST

Components of the electromagnet may become hot during this activity. Disconnect the electromagnet immediately after testing it and do not keep it connected for extended testing. Wear heat-resistant gloves if necessary.

VOCABULARY

Review the definitions with students at the beginning of the lesson and ensure that students have access to the glossary resource provided with this activity. Utilize these words often during the lessons to model how and where to use them.

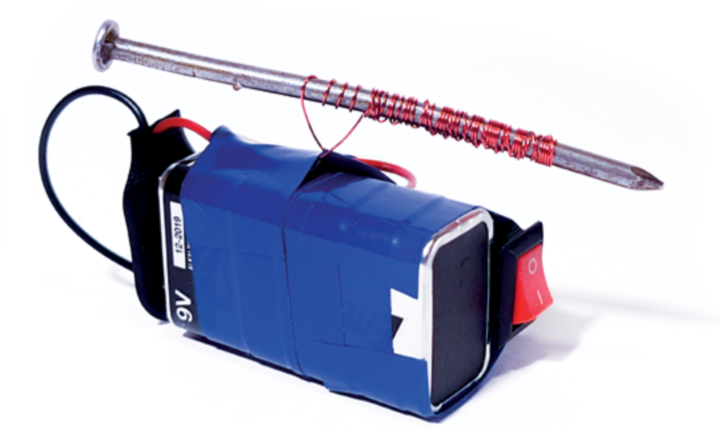
- Electromagnet
- Core
- Hypothesis
- Quantify
- Independent variable
- Dependent variable
- Central tendency

MATERIALS

1. ~1 meter of 22 AWG magnet wire (vary lengths and gauges for experimenting)
2. galvanized nail or steel nail (various length, thickness, and material for experimenting)
3. 9V battery
4. 9V battery connector
5. Small metal items to lift (paperclips, staples, pins, etc)
6. Optional: switch (style of your choice)

TOOLS

- Multimeter
- Electrical tape
- Sandpaper
- Scissors
- Scale (to quantify the mass of the items lifted by the electromagnet)
- Spring scale (optional)
- Magnetic compass (optional)



PROCEDURE TO BUILD

1. Place a pencil through the wire spool and lay it over a cup to enable easy winding.
2. Leaving a short tail (~5cm) of wire, wrap the magnet wire around the nail in one direction, keeping your wraps tidy and close together.
3. When you have wrapped about 5cm of the nail, switch directions and wrap over the first row of wire wraps with a second row of wraps.
4. Repeat step 3 until you have the number of wraps you choose (start with about 40 for your first version).
5. Using sandpaper, strip the insulation off the two tails of magnet wire.
6. Twist one end of the magnet wire to one of the battery connectors wires, and secure with a small piece of electrical tape. Repeat with the other wire and battery connector. (Optional: Include a switch between one of these connections).
7. Lay out the items you want to try lifting with your electromagnet.
8. Clip the 9V battery into the connector (and turn the switch to "on"), then bring it close to the objects to test its magnetism.
9. Turn your electromagnet off when you are finished testing. Do not leave your electromagnet connected any longer than necessary as it will become quite hot.

GUIDED EXPLORATION OF THE PROJECT (CURRICULAR COMPETENCIES):

Step 1: Demonstrate and Model

You could start the project by giving students all the materials for making simple electromagnets and giving them a 10-minute challenge along the lines of "move all these paperclips from this bowl to the next without touching them with your fingers or hooking them over the wire or nail". Some students may have seen how to make an electromagnet already; let them experiment and try to remember how it's done.

Next, show the students a photo or diagram of a simple electromagnetic design (iron nail wrapped in wire, hooked up to a battery), and discuss how they would re-design their challenge solution given the new information.

Questions to spark curiosity:

What happens when you bring a magnetic compass close to your electromagnet? What do you think it means if an electromagnet is “strong”? Which components of the electromagnet do you think you could change to make it stronger? How might you quantify the strength of the electromagnet? What are some risks or hazards you think might be associated with the building of this electromagnet?

Step 2: Predict and define

Brainstorm with students (and record on the board) to come up with a class list of variables that they could change that they think might affect the strength of the electromagnet (these are the independent variables, i.e., number of wraps of wire). Brainstorm another list: “methods to quantify the electromagnet’s strength” (these will describe the dependent variables, i.e., the maximum number of dried peas added to the metal basket before the electromagnet lets the basket fall). Assign units for each variable listed. As a class, make predictions for each independent variable: will it increase, decrease, or have no effect on electromagnetic strength. Discuss some strategies for designing and writing a clear, testable hypothesis statement.

Questions to help clarify:

What are three components that make a “good” hypothesis? Is it important that you correctly predict your results before conducting your experiment? Can you explain why it might be valuable to prove your hypothesis is incorrect? What exactly will you measure to quantify your dependent variable, and what tool(s) do you need to measure it?

Step 3: Plan and Conduct

Have students choose one independent variable and one dependent variable to use in their experimental design. You could write all the variables they came up with from step 2 on pieces of paper and have students draw them out of hats (this way, each experiment covers a different aspect of electromagnetic strength and through communicating their results to the class, everyone will contribute to a broader understanding of which variables affect electromagnetic strength).

Students use the Scientific Method Resource to design and conduct their own experiments. Encourage them to visualize their experiment and the results to help them plan effectively. Have them check in for teacher approval before beginning testing (check for a strong, testable hypothesis, appropriate risk analysis and safety gear, and an adequate data table including enough space to record repeat tests for statistical analysis of results). Students conduct their experiments and collect their data.

Questions to help refine the experiment:

What is the value in having each student/group test a different independent variable from the list? What quantity will you measure to quantify your dependent variable (and what units will this be in)? Why is it important to take multiple readings (of the dependent variable) for each value of your independent variable? Are there any environmental, ethical, or cultural considerations you need to consider when designing your procedure?

Step 4: Analyze and Solve

Using a sample data table, show the class the steps required to produce a graph using a computer graphing program. Give them examples of how to perform central tendency calculations. You could also show them some tips on drawing scale diagrams to illustrate their electromagnets.

Questions for analyzing:

What is the “cause and effect” relationship revealed in your experiment? What does the shape of your graph tell you about how your independent and dependent variables are related to each other (i.e., is it a linear relationship? An exponential relationship? How can you use mathematical vocabulary to describe this?). How might our classroom, school, community or family culture affect the way we analyze data?

Step 5: Evaluate and Reflect

Give students some examples of well-written conclusions for simple scientific experiments. Support students in writing their findings and learning how to reflect on their experimental process.

Questions to encourage reflection:

Was your hypothesis supported? Are there any alternative explanations that could account for your results? Can you identify any biases or assumptions you made during this process? Were there any unpredicted safety concerns that came up, and what would you do differently next time to minimize that risk? Can you think of a problem in your community that could be solved with the help of an electromagnet? While evaluating the results of an experiment, scientists may find that they reveal more questions about the cause-and-effect relationship they were studying. And what are some variables you would test if you were going to design a further inquiry experiment into how an electromagnet works? Can you think of a way you could maximize the strength of your electromagnet while minimizing the cost of the electrical energy or supplies needed?

Step 6: Communicating

Students hand in completed Scientific Method Resource write-ups. Consider letting the students choose how they will share their results with you, the class or with others – do some of them want to do a class demo or a mini-lesson? Do they want to make a short video? Do students want to collect the results from the entire class and develop a collective poster on the many variables that affect electromagnetic strength?

Keep in mind that the grade 7 science curriculum explores electromagnetism; your students could do a live online demo of their electromagnets, or produce an educational video, or visit a grade 7 classroom with the materials and tools needed to lead the younger class in a science challenge such as “How many paperclips can we possibly pick up with an electromagnet?”. They could design a simple game that incorporates an electromagnet and gift it to a grade 7 class.

Questions to consider:

How would you explain your results to a grade 7 student or someone who doesn’t know an electromagnet? What background knowledge would you need to give them to help them understand? If you used a drawing to help in your explanation, what would it look like?

SUGGESTED ASSESSMENT STRATEGIES (STRUCTURE TO DESIGN ASSIGNMENTS)

Application of statistics

Ensure students do enough tests to be allowed for relevant statistical analysis (to keep things simple, you could choose to have students do this for only one value of the independent variable instead of every value). Complete calculations for central tendency (mean, median, mode) and describe what each indicates about the electromagnet. For example, “At 15 wire wraps, the average number of peas that the electromagnet could hold in the magnetic basket was 17.7, etc.”

Students could also test one specific independent variable amount a certain number of times (e.g., 15) and note down a data set of their dependent variable measurements. They could then find the variance and standard deviation and assess which points are outliers (Should they be included in the data? Why or why not?). From there, you can get them to graph their data and make a histogram and ask them questions about distributions (is this a normal distribution? Why or why not?). If the data shows a normal distribution, you can ask them questions about the z-values and confidence intervals (i.e., “If you build an electromagnet to the same specifications, and you want to be 95% sure that your guess of how much mass it can lift will be correct. What would be the smallest mass you could guess, and the heaviest mass you could guess? I.e., Find a 95% confidence interval for the sample for the mean mass liftable by this type of electromagnet”)

GRAPHICAL ANALYSIS
Forms of mathematical reasoning

Graphical methods in physics

Students design graphs using the results of their tests (in their data tables) using computer software, including an appropriate title, labelled axes, units, line of best fit, etc. Students provide a written or oral analysis on the mathematical shape of the graph and what that may indicate about trends and relationships between the variables. They could identify axes intercepts and explain what they represent in the context of the experiment. If applicable, have them extrapolate for further data points, interpolate to find the information at one point within the graph, and calculate the area under the curve as appropriate depending on their graph type.

FOM 11 - SCALE MODELS

Create a “to-scale,” enlarged, or reduced design plan for their electromagnet.

PHYS 11 - Mass, the force of gravity, and apparent weight,
PHYS 11 - Newton’s laws of motion and free-body diagrams, and

By using the scale, students quantify the mass of the object(s) lifted by the electromagnet, then draw a free-body diagram of the thing (s) being held by the electromagnet. Have them identify and label the forces acting on the mass. Are the forces balanced? How do you know?

PHYS 11 - Electric circuits (DC), Ohm’s law, and Kirchoff’s laws

Students can analyze their electromagnets by using a magnetic compass, then draw diarams of their electromagnet, including the lines of force around the electromagnet and the north and south poles (when in the “on” setting). You may choose to have them calculate the resistance of their electromagnet (measure current and voltage with the multimeter while “on”, R= VI) and compare it to the resistance measured by the multimeter. What might be causing discrepancy between the two resistance values?

SCIENCE CHALLENGE OPPORTUNITY

Using the materials given, build an eletromagnet to lift the most paper clips as possible, or design an electromagnet that makes a metal object or magnet levitate within a clear plastic sleeve.

TAKE IT FURTHER!

- Hold a “sources of error” seminar: Students prepare a presentation for their classmates outlining their procedure and results, as well as their thoughts on how they would improve on their experimental design details to reduce error if they had to experiment again. Classmate’s practice giving healthy, constructive feedback suggesting amendments to mitigate sources of error. You could also expand this seminar to include a class discussion on brainstorming alternative explanations for each group’s results.

- Design and draw a robot or machine plan incorporating an electromagnet that contributes to filling a need or solving a problem in the local community or environment.

- Design (and build) a circuit that utilizes an electromagnet and performs a task (e.g., completes a course to turn a light on or sound a buzzer, etc.).

- Investigate a specific type of electromagnet used in the community or daily life and compare its design to the electromagnet made in this activity (answer in point form Venn Diagram).

- Research Hans Oersted, William Sturgeon, and Joseph Henry’s contributions to the history of electromagnets. Write a “from the future” thank-you letter illustrating the everyday uses of electromagnets and describing their legacy for them.

- Compare and contrast the properties and uses of permanent magnets versus electromagnets.

- It uses the class’s findings on the variable(s) that affect electromagnetic strength, design (and build) an electromagnet with adjustable power.

LEMON BATTERY

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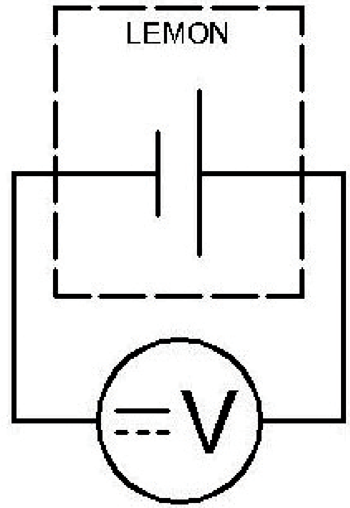
LEMON BATTERY



INSPIRATION

The flow of charged particles, specifically electrons. Electrons are part of atoms; they exist in the space around the nucleus of the atom. When we “make” electricity, we create a situation that dislodges electrons from their positions in atoms. If we can generate a positively charged atom and create a path for the free electrons to get to it, we have a flow of electrons which we call electricity. What are some different materials we can use to produce positively charged atoms? What are some objects and materials in which we can induce an electron flow?

OBJECTIVE

Students will explore and experiment to discover how lemon and different metals can produce a voltage potential (battery).

TRADES CONNECTION - TOOLS

Portable power has improved the range and ease of work for trades workers. Most trades and industries utilize batteries daily. Electricians are often responsible for maintaining, installing, and repairing batteries and battery banks. The growing popularity and affordability of alternate power sources, such as wind and solar and electric cars, means that our reliance on batteries is growing as the technology moves forward.

SAFETY FIRST

The citric acid in lemons and other fruit can be irritating to your eyes. Wear safety eyewear when inserting the anodes and cathodes into your food items.

VOCABULARY

Review the definitions with students at the beginning of the lesson and ensure that students have access to the glossary resource provided with this activity. Utilize these words often during the lessons to model how and where to use them.

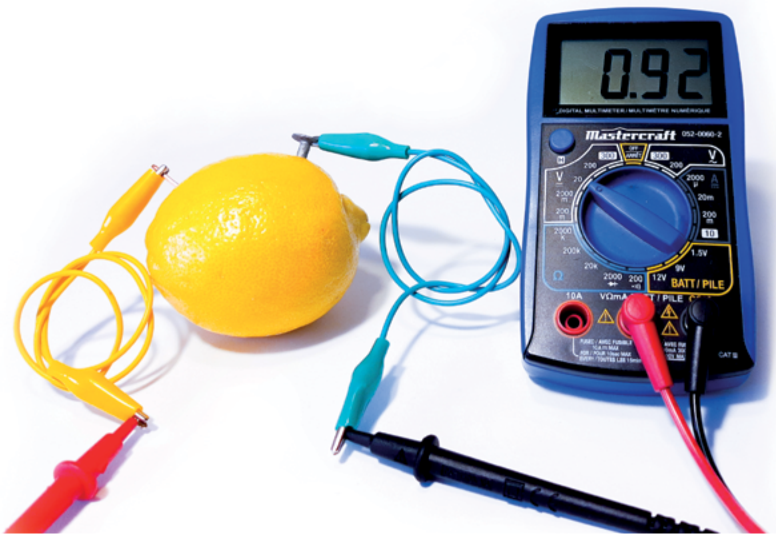
- Electrochemical
- Anode
- Cathode
- LED
- Lead
- Resistance
- Voltage
- Current
- Terminal
- Dependent variable
- Independent variable
- Vesicle (juice vesicles in the citrus fruit)

MATERIALS

- Various juicy foods: fruits, vegetables, tubers, etc. I.e., lemons, potatoes, cucumbers, beets, bananas, limes, oranges, strawberries, kiwis, whatever you choose to test!
- Connector wires with alligator clips (you will need the same number of wires as food items, plus one)
- Pieces of thick (e.g., 14 AWG) copper wire, 3cm long (one per food item)
- Galvanized (zinc) nails (one per food item)
- **Optional:** small LED or incandescent bulb

TOOLS

- Multimeter
- Wire cutters/strippers



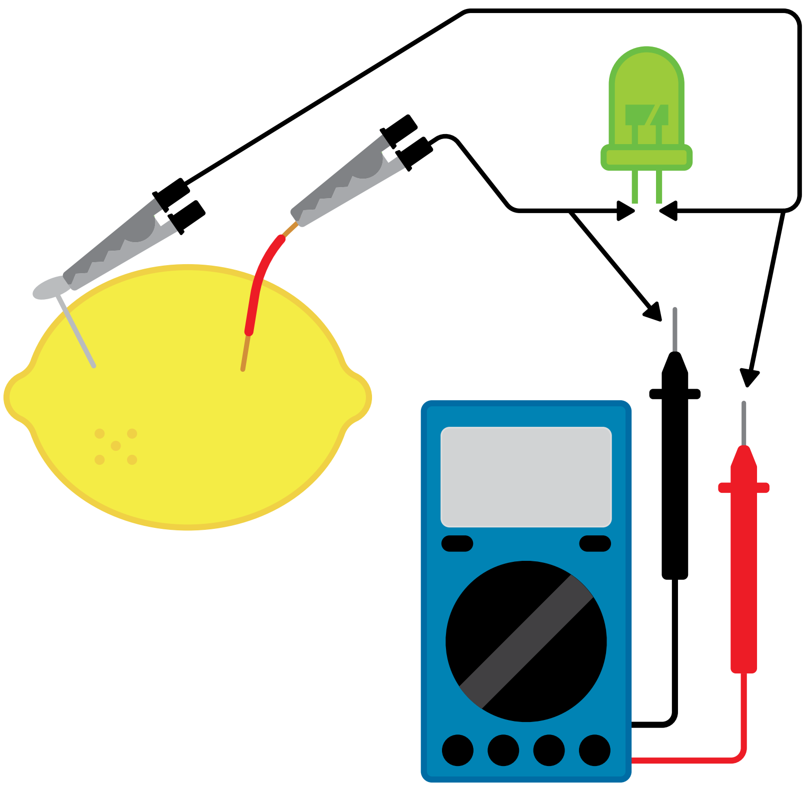
PROCEDURE TO BUILD

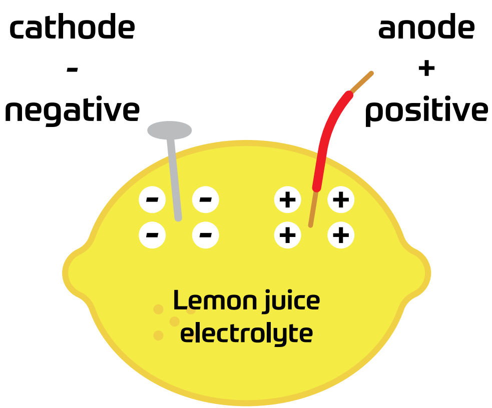
1. Choose a lemon or a piece of food you want to make your battery out of it. If you are using citrus fruit, try rolling it between your hand and a tabletop to break some of the tiny vesicles inside and release some of the juices within the fruit.
2. Insert your copper wire anode and your galvanized zinc nail anodes approximately 5cm apart, and push them in, leaving about 2cm. Make sure they do not contact one another inside the fruit. Attach one connector wire to the copper anode and a second connector wire to the zinc anode.
3. Set up your multimeter to read volts: plug the black cord into “COM” and the red cable into “VΩ.” Set it to read “DC” volts at the highest reading.
4. Clip the free ends of the wires to your multimeter probe ends. If no numbers appear on the screen, switch the multimeter dial down to read smaller voltage amounts until you get numbers appearing.
5. Try wiring up more than one piece of fruit in series. Ensure that you wire copper anodes to zinc anodes (don’t attach copper to copper or zinc to zinc, as you want all the electron flow to go in the same direction).
6. Try connecting the light bulb or LED into your circuit to see if you can make them light up! (Remember that LED bulbs won’t light up if you insert them in the wrong orientation – test them in both directions each time.)

GUIDED EXPLORATION OF THE PROJECT (CURRICULAR COMPETENCIES):

Step 1: Demonstrate and Model

Introduce the concept and basic construction of a fruit battery with the class – you may choose to discuss how different metals give up or attract electrons, where oxidization and reduction occur, and how they interact in an acidic environment (zinc anode releases electrons, while the copper cathode collects electrons). When the two terminals are connected, the electron can flow through the wire from the copper cathode to the zinc anode. Show the students a fruit battery you have made, or show them the diagram:





Questions to spark curiosity:

What chemical characteristics of metals help you decide whether to use them as a cathode or an anode? What kind of acid is present in the fruit, and what does it do to the metal? Do you think other types of acids could be used to create this same phenomenon?

Step 2: Predict and define

Discuss with the class which independent variables they think might affect the amount of voltage produced by their fruit battery. Some variables could include fruit type, fruit size, acidity (pH) of the fruit, cathode and anode diameter/size, the distance between terminals, fruit temperature, time used, time rolling the fruit to break down the juice “vesicles,” etc. Use voltage (measured with the multimeter) as the dependent variable.

Questions to help clarify:

What maximum voltage do you think a single lemon can produce? Can one lemon contain enough energy to light up a light bulb? Are there any other types of fruits or foods (or liquids?) you think could be used to produce electricity in this way?

Step 3: Plan and Conduct

Using the Scientific Method Resource, students decide on a quantifiable independent variable and design their experiment to see how it affects voltage (dependent variable). Help students write concise, testable hypotheses. Make sure that students’ data tables are accurately labelled and contain adequate headings and sufficient space to record enough data for statistical analysis.

Assist students with constructing their fruit batteries and ensure their circuit is safe before they connect it.

Questions to help refine the experiment:

Do you think it would be valuable to have each classmate test a different independent variable? What are some ways to quantify (measure) the amount of your independent variable? What will you use to measure the dependent variable (voltage)? Why do you think it could matter how long you leave your battery circuit connected during testing? Why is it important to keep all the variables except the independent variable constant throughout the experiment? Are there some variables that might be difficult to control? How many tests for each different value of your independent variable will you do to make sure that your voltage reading is accurate for each?

Step 4: Analyze and Solve

Students use their data to create graphs using computer programs and calculate the central tendency of their numerical results. (See “suggested assessment” section below for details).

Questions for analyzing:

If you wired in a light bulb light to your circuit, did it seem to have a similar brightness between tests? Do your graphs appear to support your hypothesis?

Step 5: Evaluate and Reflect

Help students write conclusions for their scientific experiments and complete the rest of their write-up. Hold a class discussion on why confirming a hypothesis to be accurate and disproving a theory are both valuable results of an experiment.

Questions to encourage reflection:

Were there any variables you could not control for, and how might this have affected your results? Do you think you tested each independent variable value enough times to give a relevant central tendency?

Step 6: Communicating

Encourage students to share their results with other groups. They may choose to do mini-presentations or demonstrations of their batteries in front of the class or design a collaborative classroom poster. As a challenge, you may also choose to host a discussion where groups present challenges they faced during their experiments and share how they overcame their difficulties. Students can also hand in their completed Scientific Method Resource write-up.

Questions to consider:

How would you communicate your results differently to a grade 4 student than you would to your teacher or your classmates? Would it be valuable to design a poster for your classroom summarizing the results of everyone's fruit battery experiment? Do you think sharing your mistakes and difficulties with the class could positively support and help with problem-solving?

SUGGESTED ASSESSMENT STRATEGIES (STRUCTURE TO DESIGN ASSIGNMENTS)

PHYS 11 - Electric Circuits (DC), Ohm's Law, and Kirchhoff's Laws

Students can use their data from their experiment to do some calculations using Ohm's Law. Have them measure both the voltage of their citrus battery and the current of their circuit (through a lightbulb, if they choose). They can use these two numbers to calculate the resistance of the light bulb and then compare that value to the light bulb's resistance as measured by a multimeter. Is the measured value of resistance the same as your calculated value, and if not, what might be the cause of any discrepancy? Does the LED light up? What happens if you wire it in reverse?

Have students use their multimeters to measure the resistance of their lemons. Use this to open a discussion on terminal voltage vs electromotive force and explore how batteries can have a resistive value.

PHYS 11 - graphical methods in physics
FOM 11 - Graphical analysis

Students complete a computer-generated graph for their data results to be included in their lab write-up. You may choose to have them analyze their charts in some of the following ways: describe what any x or y-intercepts mean with regards to their experimental set-up, define the shape of the curve and what that indicates, extrapolate to predict what the voltage might be for higher values of their independent variables, etc.

FOM 11 - Applications of statistics

Students' complete calculations of central tendency on their data. If they have enough test readings, they could develop a histogram to determine a normal distribution, then explore standard deviation, confidence intervals, z-scores, and distributions on their data readings.
(E.g.,, "If you were going to test your lemon battery again, what would you guess its voltage would be? Could you give a range of voltages you thought it could probably produce? If you wanted to be 95% sure that your answer would be correct, what would be the minimum and maximum voltage that you'd guess your lemon would produce?" Do you think your statistics would apply to a different lemon battery – why or why not?). Discuss as a class to ensure that they set up sufficient space in their results tables and tests in their procedure to amass enough data to perform these calculations.

PHYS11 - Power and efficiency

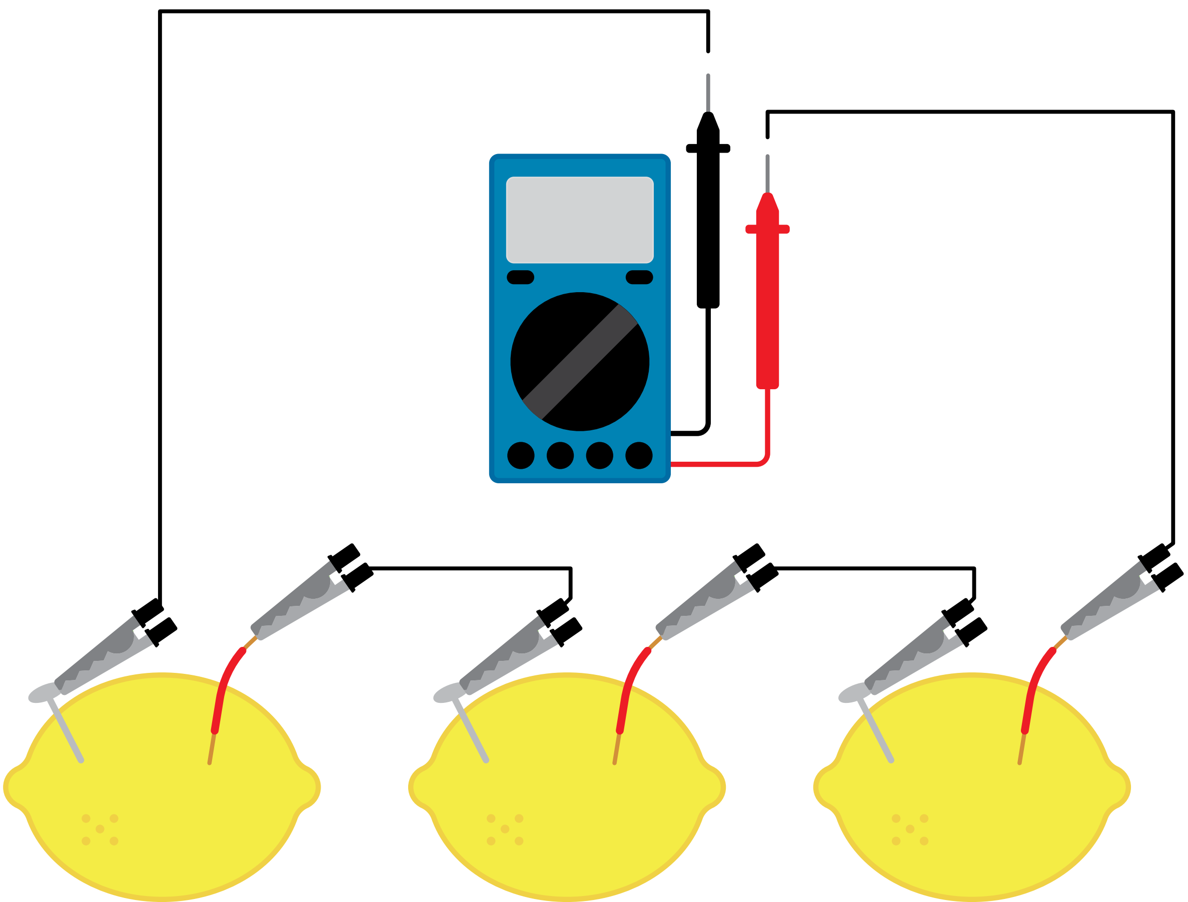
Have students calculate the power available in their lemon battery or fruit battery bank (power = voltage x current). How much power IS this? Have them research hobby motors and predict whether their fruit battery has enough power to make one work. Would 20 lemons in series provide enough power? They could look through a supply website at various LEDs, motors, and other electrical resistors to determine if their lemon battery bank would power each component.

SCIENCE CHALLENGE OPPORTUNITY

Challenge students to be the first to light up an LED bulb with a battery they make... Provide each student or group with a small LED (same for each participant), salt (¼ cup per group or so), various kitchen ingredients such as sugar/vinegar/etc., tap water, an assortment of glass or plastic containers (e.g., a set of beakers), several (5+) connector wires with alligator clips, a mixture of metal bits (copper wire, different types of nails and screws, paperclips, etc.), and a multimeter. Make sure they know not to get the alligator clips, or the multimeters wet.

Take it Further!

- Ask the students what they think might happen if they wire their fruit batteries together in series. In parallel? Which will produce the most voltage? The most current? How do they need to insert their multimeter to measure each value? Have them test their hypotheses. Predict how much voltage an 18-lemon circuit would produce. How many fruit batteries would it theoretically take to make the 120-voltage available in Canadian households? How many lemons would it take to provide the power necessary to run your home for a day? Is voltage the only variable you need to consider in these calculations?



- Research the simple voltaic cells invented by Alessandro Volta and compare and contrast the modern "lemon battery" to these first cells.
- Does this experiment work with a cup of lemon juice? Instead of making a fruit battery, clip anodes on the sides of a plastic cup so they are covered in liquid and test for voltage and current.
- Do you think this could work by trying different liquids, such as vinegar, coffee, seawater, etc.? Set up a system to test your hypotheses.
- Explore different metals other than copper and zinc – what other metals turn the fruit into a battery? Do they produce different voltage than copper and zinc do?

PENCIL RESISTORS

PENCIL RESISTORS

INSPIRATION

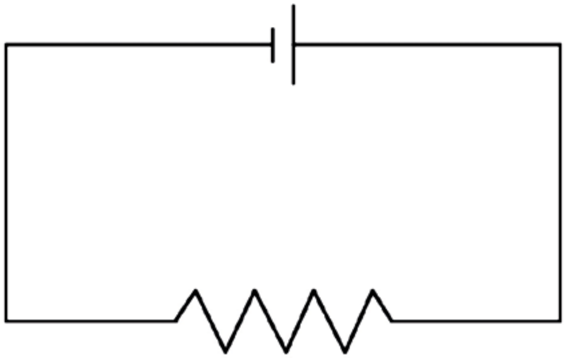
A basic electrical circuit consists of a power source, a load, and conductors. It can be as simple as a flashlight or as complex as an airport runway. A circuit's voltage, current, and resistance all vary in predictable ways relative to one another. How does changing any one of these variables affect the others? Is there a mathematical way to describe how these variables are related to one another?

OBJECTIVE

Using graphite from pencils, students will build and analyze circuits to experiment with Ohm's Law: how resistance, voltage, and current are related. Students can change the length of the pencils (the resistance) and measure their effect on current and voltage.

TRADES CONNECTION - TOOLS

The resistivity of a material describes how much resistance it has against electrical conduction. Electricians use what they know about the resistive properties of materials to decide what types of protective gear to use. For example, the resistivity of leather and rubber is very high; wearing boots and gloves made from these materials can help protect electricians from electric shocks.



SAFETY FIRST

Always have students check their circuits with a teacher before completing the final Connection. Only leave the circuit connected for a short time - just long enough to do a reading with the multimeter – as the pencil resistors can get hot quickly.

VOCABULARY

Review the definitions with students at the beginning of the lesson and ensure that students have access to the glossary resource provided with this activity. Utilize these words often during the lessons to model how and where to use them.

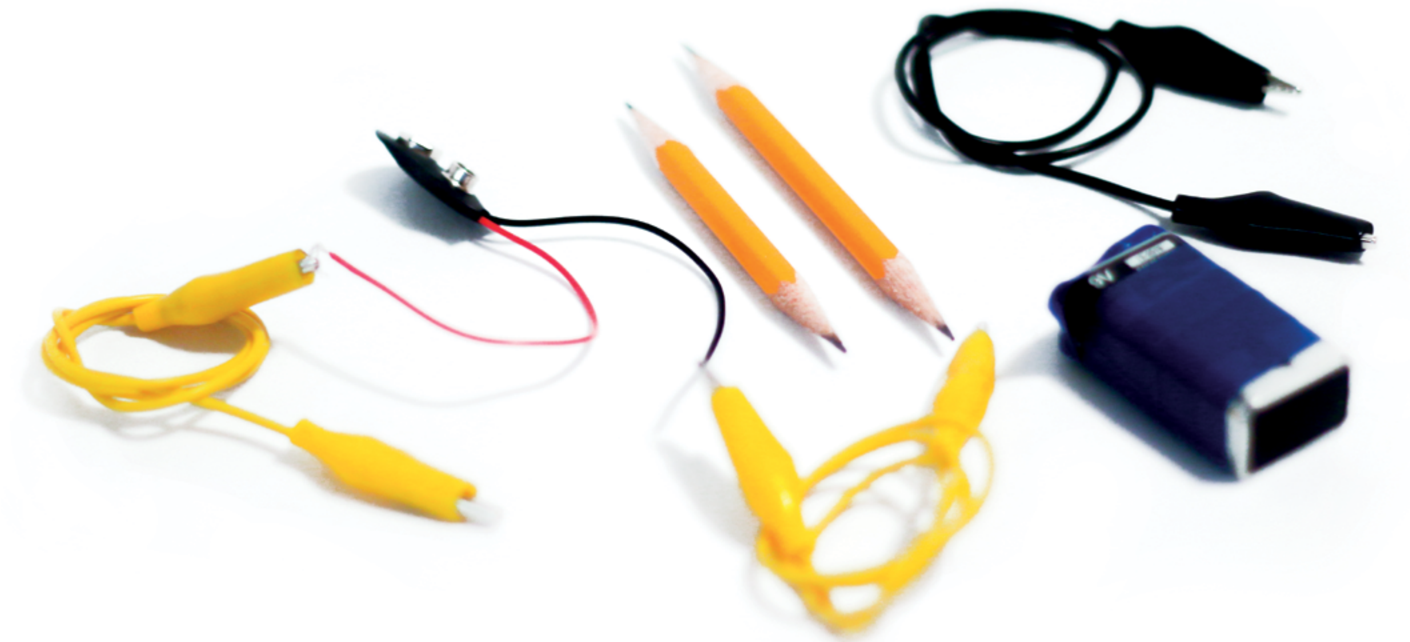
- Voltage
- Current
- Resistance
- Ohm's law
- Graphite
- Independent variable
- Dependent variable
- Potentiometer
- Rheostat

MATERIALS

- 5+Graphite pencils (ideally, the same type)
- Three connector wires with alligator clip ends
- New 9V battery (and spare)
- 9V battery connector
- **Optional:** Mini lightbulb (incandescent, 12V or less) and lightbulb base

TOOLS

- Small wood saw or sharp knife
- Pencil sharpener
- Multimeter



PROCEDURE TO BUILD

1. Use the saw to cut the metal eraser holder off your pencils and then sharpen each pencil at both ends.
2. Place your 9V battery into the connector.

To measure the current through one pencil:

3. Using one connector wire, clip one battery connector to one of your multimeter probes.
4. With another connector wire, clip the other battery connector to the graphite of your pencil.
5. Set up your multimeter to read current according to its instruction manual.
6. Check with your teacher to ensure your multimeter and circuit are set up correctly before connecting your circuit.
7. Connect your circuit by touching the free multimeter probe to the free pencil end. Read and record your current value.

8. Disconnect your circuit as soon as you've read your current so that the pencil doesn't heat up.

To measure the voltage, drop across the pencil:

9. Set up your multimeter to read voltage according to its instruction manual.
10. Use alligator clips and wires to connect each of the battery connectors to each end of the pencil.
11. Press the multimeter probes onto the graphite tips on the pencil ends.
12. Read and record the voltage across the pencil, then disconnect your circuit.

To measure the resistance of the pencil:

13. Set up your multimeter to read resistance according to its manual.
14. Press the multimeter probes to the graphite tips on either end of the pencil.
15. Read and record the resistance.

GUIDED EXPLORATION OF THE PROJECT (CURRICULAR COMPETENCIES):

Step 1: Demonstrate and Model

As a class, discuss what a circuit consists of and the different variables you can measure using the multimeter. Explain that the graphite in pencils is less conductive than copper wire and can be used as resistance in a circuit. Show them photos of the pencil resistor circuits and the circuit schematic.

Questions to spark curiosity:

Will the lightbulb be brighter if a shorter pencil is used? Will the pencil get hot? Is the wood in pencils conductive? How does electricity travel through graphite? Does the copper wire have resistance?
Were there any variables you could not control for? Does this make sense?

Step 2: Predict and define

Help students write a hypothesis based on what they think the relationship between pencil length and current is. (If you feel your students would relish a challenge, you could give them the option to explore any relationship they are curious about from the following variables: measured resistance of the pencils, calculated resistance of the pencils, the voltage drops across the pencils, current in the circuit, the diameter of pencil lead, type of pencil lead, etc.). Show students how a multimeter can measure current, voltage, and resistance. Decide as a class which settings would be best to use on the multimeter for measuring each of these three values, depending on the size of the battery (voltage) and their estimated current. Post these settings so students can refer to them throughout their experiment.

Discuss why measuring the current more than once for each pencil length might be necessary (minimizing human error and other unpredictable variables, providing enough data points to conduct statistical analysis, etc.). Also, discuss the importance of controlling and maintaining all variables except the one being tested. As a class, make two lists of variables: ones that they can control for and ones that they might not easily be able to (i.e., the graphite temperature).

Questions to help clarify:

Are there any variables that you think might be difficult to control? What measures could you take to keep those variables constant? Why does the multimeter need to be configured differently when measuring different characteristics of the circuit?

Step 3: Plan and Conduct

Students use the Scientific Method Resource to design an experiment. Have them use pencil length as the independent variable (x-axis) and current as of the dependent variable (y-axis) or get them to determine their variables. Ensure students also measure the resistance of each pencil length and the voltage across the pencil. Students can choose how many pencils and what lengths they wish to test. Help students design their data tables or use the example from “suggested assessment strategies” below. If you choose to have the students perform statistical calculations, be sure that they include enough space in the data table to collect good results for each pencil length. Monitor the students as they build their circuits and have them check in with you before connecting the final clip.

Questions to help refine the experiment:

Which procedural steps are imported essential in the correct order? What are some potential risks you can imagine facing during this experiment? Are there any safety measures or pieces of safety equipment you feel are necessary to include in the materials and procedure?

Step 4: Analyze and Solve

Using the voltage, current, and resistance they measured, challenge the students to develop a mathematical relationship between the three values (i.e., ci. e. they identify a pattern and create the Ohm's law formula on their own?).

Questions for analyzing:

Is there much difference between the resistance measured and the theoretical resistance calculated? What might account for any discrepancies you observe?

Step 5: Evaluate and Reflect

Students draw up graphs of their data using a computer graphing program and describe how the shape of the chart help to interpret their results. If all groups measured pencil length vs current, you could have them draw a graph using the entire class's data and perform statistical analysis on all points.

Help students draw up their conclusions from their results that directly refer to their hypothesis statement (i.e., describe the relationship they found between pencil length and current). Discuss the benefits of reflecting on an experiment (making it better or safer next time, refining procedural steps that may have been unneeded or in need of amendment, etc.).

Questions to encourage reflection:

What are three things you would do differently next time if you were to perform this experiment again? Would this experiment work with different materials used as resistors? Do you think that the relationship between voltage, current, and resistance is dependent on any other variables like temperature or material of resistor? Why or why not?

Step 6: Communicating

Students hand in a completed Scientific Method Resource write-up. They may also choose to make a poster of their experiment, including a wiring diagram for their circuits.

Questions to consider:

Did your results support your hypothesis? If they did not, is that still a valuable result? Have you accurately articulated your procedural steps so that someone else can easily replicate your experiment and confirm your results? Do you think that another physics 11 students could use your lab write-up as instructions to perform their exploration into Ohm's law and resistance? Do you think they would get the same results as you did?

SUGGESTED ASSESSMENT STRATEGIES (STRUCTURE TO DESIGN ASSIGNMENTS)

FOM 11 - Applications of Statistics

Have the students make multiple current (or resistance) measurements for each pencil length and then analyze their data (or the data collected from the entire class) to calculate central tendency. They may also use their data to draw a histogram, determine the normal distribution of current (or resistance) values for each (or one) pencil length, and then perform calculations of standard deviation, confidence intervals, z-scores. (E.g., "If you were going to test a pencil of X cm length with a 9V battery, what would you guess the current flowing through the circuit (or its resistivity) would be? Could you provide a range of amps that it would likely produce (or Ohms of resistance it might have)? If you wanted to be 90% sure that your prediction would be accurate, what would be the lowest and highest current (or resistance) you would guess?") These calculations could be performed as a class or included in a complete lab write-up.

PHYS 11 - Electric circuits (DC, Ohm's law, and Kirchoff's laws)
Forms of mathematical reasoning

Students use the Scientific Method Resource to organize and base their exploration on. Before giving them the formula for Ohm's Law, have them use their data to try and find their own mathematical patterns in their measurements that indicate a consistent mathematical relationship between voltage, current, and resistance. You could have them describe their thought processes and calculations verbally or in sentence form. Have them articulate any discrepancies they observe between measured resistance and their predicted (calculated) resistance.

They can then use the formula they discovered (or you can provide them with Ohm's Law formula) to calculate a predicted resistance for the last column in the data table.

Pencil length	The voltage ***drop*** across the pencil	Current (5+ readings per pencil length)	Average current	Resistance (as measured with a multimeter)	Calculated Resistance (Using your own or Ohm's law formula)
		1. **2.** **3.** **4.** **5.**			

To address Kirchhoff's Law, you could have students wire 2 or more pencils into a circuit, measure the voltage drop across each with the multimeter, and then compare those values (summed) to the battery's voltage.

PHYS 11 - Graphical methods in physics

Students complete a graph of their data using a computer program.

Different variable combinations to graph could include: (x independent variable vs y dependent variable)

- Pencil Length vs Current (shows how the increased length of graphite causes current to drop)
- Pencil Length vs Measured Resistance (shows if the resistance of graphite increases in a linear fashion as pencil length increases)
- Measured Resistance vs Current (shows how increased resistance causes current to drop – can also compare the shape of this graph to the form of the "pencil length vs current" chart)
- Suppose you have access to a variable DC power source. In that case, students could also collect data using one single pencil to make a current vs voltage graph (slope of the line is voltage / current, which gives them the resistance of the pencil, which can be compared to its measured resistance).

You may have them choose to graph one or all of these options, or you could provide them the opportunity to select which variables they are most curious about and wish to explore and graph.

Students provide analysis of their graphs, describe what the curve shape and intercepts indicate, and extrapolate to predict the results of the increased value of the variables.

Thermal equilibrium and specific heat capacity

Students could measure the temperature increase of the pencils/graphite with an infrared thermometer and develop ways to minimize the heat increase or temperature effects on resistance. You could have students research how temperature affects resistivity and different methods used in industry to maintain the temperature of valuable electrical circuitry. Have them research the role temperature plays in power distribution, at transformers, and in an overload situation. Do their pencils heat up? Why? Where is this energy coming from?

SCIENCE CHALLENGE OPPORTUNITY

LEDs are tricky to light up (and not damage) if students are unfamiliar with resistance, current, and voltage limits. Provide students with a limited supply (i.e., ten or so) of red LEDs, assorted batteries, graphite pencils, and alligator clips, and challenge them to light up as many LEDs as possible in series. To help them out, provide a link to an online LED resistance calculator so they can predict the batteries (voltage) and pencil lengths (resistance) needed to light up their LEDs without blowing them out. Remind them that LEDs work in one direction only, so try them in both orientations as a first-level troubleshooting tip.

Take it Further!

- **Add an appropriately-rated incandescent light bulb to your circuit – does the pencil length affect the brightness of the bulb?**
- **Using an appropriately rated resistor, connect a similar simple circuit to various low voltage batteries in series or a variable DC power supply. Test the current for each voltage amount. Graph voltage (x) vs current (y) and draw a best-fit line. Calculate the slope; this should be equal to the resistance rating (Ohm's law states that resistance = current / voltage, and in this case, resistance = rise/run!). Do you expect this to be a linear relationship? What might be some reasons why you don't see a straight line on your graph?**
- **Explore the difference between LEDs and incandescent light bulbs. Measure their resistance using a multimeter, insert them into a simple circuit and measure the current flow. Do they light up? Why or why not?**
- **Build a rheostat: use a mechanical pencil lead or split a pencil open to obtain the graphite cylinder. Build a circuit as you did in this activity, attaching one alligator clip to one end of the graphite. Instead of attaching the second alligator clip to the opposite end of the graphite, you can connect it anywhere along the length you choose. How much resistance do you think 1cm of graphite will provide? 2cm? 5 cm? Does the voltage drop across the graphite change depending on where you connect the circuit? Does the current in the circuit change? What kind of graph could you use to describe your results? What data do you need to collect to explain your findings?**

SIMPLE
ELECTRIC MOTOR

skills READY

SIMPLE ELECTRIC MOTOR

INSPIRATION

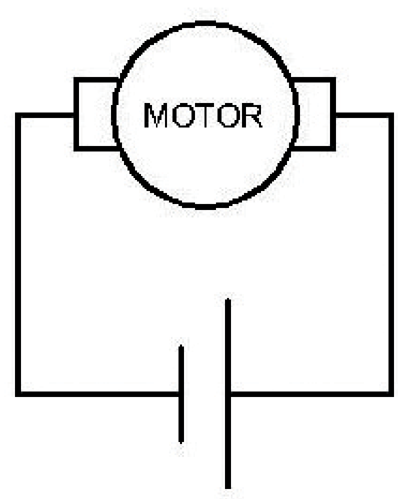
Electric motors work by applying electricity to a system of magnets and wires that results in a spinning motion. So long as the electricity comes from a sustainable source, electric motors don't produce the same environmentally damaging emissions as internal combustion engines. As such, it provides an increasingly viable alternative to our reliance on fossil fuels to power our engines. Does moving a magnet around a wire create a measurable difference in current in the wire? How can this phenomenon be harnessed to produce electricity?

OBJECTIVE

Students will explore the variables that affect the rate of spin of a simple electric motor through designing, assembling, and testing their own small motors.

TRADES CONNECTION - TOOLS

Electricians, millwrights, plumbers, carpenters.



SAFETY FIRST

Using too much voltage for a system with low resistance can cause overheating. Use small batteries (9V or less), and don't run your motor for longer than necessary to get your RPM reading. Tie long hair back to avoid it getting caught in the spinning motor.

MATERIALS

- ~25 cm of 18-22 AWG magnet wire (enamel wire)
- Assorted gauges and types of wire for experimentation
- One 9V battery
- Assorted batteries for experimentation
- Assorted magnets
  (i.e., neodymium magnets, rare earth magnets, etc.)
- 2 connector wires with alligator clips
- 1 mug or similar non-conductive container
- 2 medium-sized binder clips

VOCABULARY

Review the definitions with students at the beginning of the lesson and ensure that students have access to the glossary resource provided with this activity. Utilize these words often during the lessons to model how and where to use them.

- Ampere's Law
- RPM
- Frequency
- Pitch
- Hertz
- Independent variable
- Dependent variable

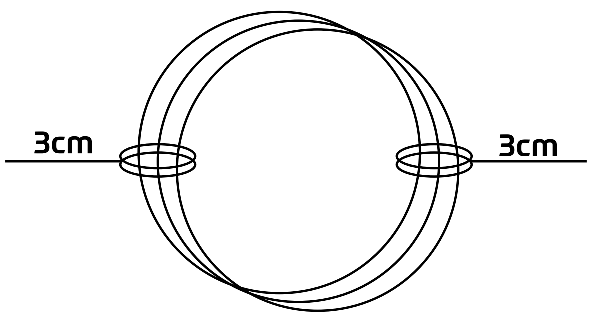
TOOLS

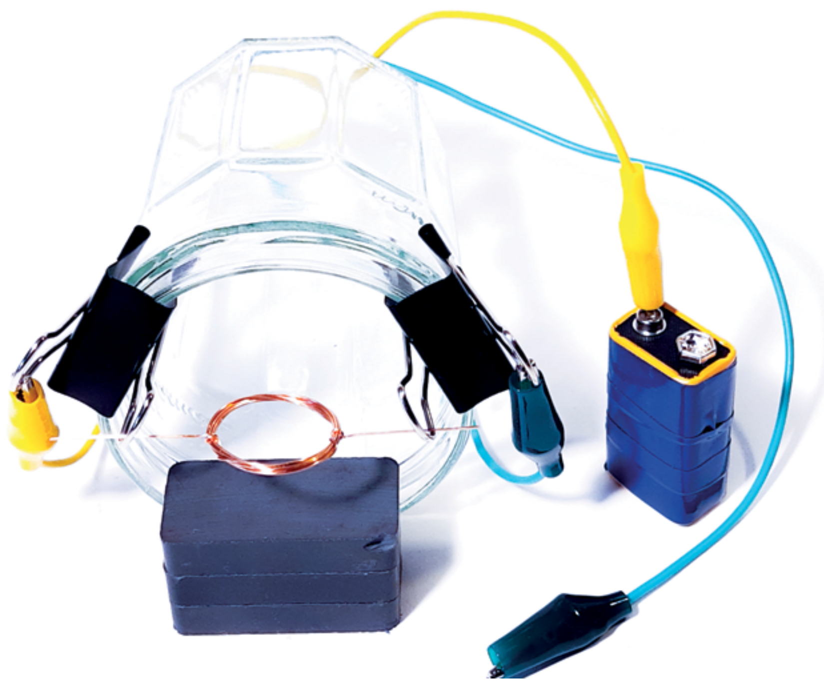
- Wire cutters
- Sandpaper
- Electrical tape
- Smart phone or microphone with a computer, with a sound-recording software that provides decibels vs time graph (free options are available such as Audacity)
- **Optional:** variable DC power source
- **Optional:** optical tachometer and reflective tape

PROCEDURE TO BUILD

Note: This procedure describes only ONE of the many designs that work – you may choose to offer students various wire, magnet, and battery options and let them experiment with which components work best for them, adapting the design as needed to accommodate different battery sizes, etc., including hooking their motors up to a variable DC power source.

1. Wrap the magnet wire tightly at least three or more times around a D battery or any found cylindrical object to create your coil. Pull the coil off carefully and secure the ends at the 3 o'clock and 9 o'clock positions by making a few tight wraps to bundle the coiled wire or by wrapping tightly with electrical tape. Make sure to leave about 3cm of wire extending from each side.
2. Make the wire ends poke directly away from the coil – this makes the axle for the coil spin around.





3. Use the sandpaper to scrape away the coating from ONE of the 3cm arms. Then, scrape the coating off ONLY the top of the second arm, leaving one long length of coating on the bottom of the arm. This will create an electrical barrier that stops the electrical current for a brief moment every time the coil spins around, allowing the coil to keep spinning on its momentum instead of getting stuck in one position.
4. Clip the binder clips to the top rim of the mug, then lay the mug on its side with the mouth facing you.
5. Place the coil arms into the inner binder clip wings, so the coil is suspended between them.
6. Place the magnet(s) under the coil, adjusting the binder clip height until the coil clearance is less than 0.5cm (or your desired height).
7. Use the connector wires to connect the outer binder clip wings to the battery terminals, then push the coil to help it start spinning.
8. Use a sound analyzing program or app, such as "Audacity," to record the sound of your motor. You may need to use a microphone if the sound peaks don't show up well on the graph. Look at the time vs decibels readout and highlight the time between peaks of noise; this is the time for one revolution (in "seconds per revolution"). 60 divided by this number will give you the RPM of your motor. Note: let's say you calculated your RPM to be 500. To get an idea of whether that value is at all accurate, you can search online "what does 500 BPM (beats per minute) sound like?", then use your ears to compare that beat to the sound of your simple motor.

TROUBLESHOOTING:

- Check your battery's voltage with the multimeter to make sure it is charged.
- Did you strip the enamel coating off the top of only one wire and entirely off the other?
- Is the coil well balanced and able to spin freely? (I.e., are the wires pointing perfectly straight out on opposite sides?)
- Is it not spinning? Try the following: a stronger magnet, a stack of magnets, turning your magnets upside down, raising the magnets or lowering your binger clip.
- Is it spinning too violently? Try increasing the distance between the coil and the magnet.
- Is the motor spinning too quietly to be analyzed by the sound app? Try adding an active buzzer to the circuit or a more sensitive mic. Is there any other way you can think of to make your motor noisier?
- Does the additional resistance of the buzzer stop the coil from spinning? Try adding more voltage or add your buzzer quickly and take your reading immediately before the motor loses momentum.

GUIDED EXPLORATION OF THE PROJECT (CURRICULAR COMPETENCIES):

Step 1: Demonstrate and Model

Discuss what students already know about the magnetic field that occurs around wire when electricity is flowing through it. Show the students the photo of the simple electric motor design or a DIY video of making a simple electric motor. Alternately, let them research “how to build a simple motor,” then have them draw up a plan with a materials list, which you ok before they go ahead with the build. As a quick intro, you could provide them with the materials to build an electric motor and let them experiment with making a prototype.

Questions to spark curiosity:

Do you think the orientation of the magnet’s pole makes a difference to the movement of the coil? What effect do you think a stronger magnet or an additional magnet will make on the RPM of your motor? How do you think that changing the position of the magnet will affect the RPM?

Step 2: Predict and define

Brainstorm as a class and discuss which variables in the design might affect the RPM of an electric motor (identify these as independent variables, indicated on the x-axis of a graph). Examples could include voltage (of battery or variable DC source), current, number of wire wraps, a diameter of wire loops, organization of wire wraps (i.e., number of crossed wires), strength/number/type of magnet, distance from magnet to wire coil, a gauge of wire, presence/absence/orientation/number of remaining insulation strips, etc.). Write these on the board and predict how manipulating each variable might increase or decrease RPM (your dependent variable, represented on the y-axis).

Questions to help clarify:

What approximate RPM do you predict your simple electric motor to produce - dozens of times per minute? Hundreds? Why might it be difficult to assess an independent variable’s effect on RPM if you change more than one variable at a time? What units will you use to quantify your independent variable?

Step 3: Plan and Conduct

Host a discussion on some ways students think they could quantify the RPM of their motors. An easy way to do this is to attach a small flag of tape to the coil then hold a pencil in the way of th eflag as the motor spins. Record the buzzing noise and analyze it with sound recording software on a computer that produces a decibel-time graph. Zoom into the sound graph until you can see individual sound peaks each time the tape hits the object. Students can use the time between sound peaks (the time of one revolution) to calculate revolutions per minute (this is a great opportunity to review how to convert units mathematically). If the peaks are difficult to read, students can try recording with a more sensitive microphone or experiment with making their motors louder.

Another way to determine RPM is to use an optical tachometer, which shoots a laser beam, and counts the number of times the laser is reflected onto itself (apply a small piece of reflective tape on the coil to reflect the laser beam).

Assign each group or student one independent variable from the brainstorm list from step 2 (if each experiment tests a different variable, then the entire class can learn from each other's results). RPM is their dependent variable. Students can use the Scientific Method Resource to write a hypothesis and design an experiment.

Assist students with developing their hypotheses, designing their motors, and conducting their experiments. If you want them to analyze their results statistically, make sure their data tables contain enough space for enough test results.

Questions for analyzing:

If something is moving faster than your eyes can follow, how can you quantify its movement? Think about other rates and frequencies that we encounter every day (i.e., heart rate, musical tempo, time) - how are these measured? Is there more than one way to quantify these frequencies? What units can frequency be measured in besides RPM? How many tests do you need to perform to ensure that your statistical analysis is relevant?

Step 4: Analyze and Solve

Students input their data into a computer graph-generating program (RPM on y-axis, independent variable on the x-axis). Have them analyze the shape of the graph. You can also have them perform statistical analysis on their data.

Students can also compare their simple motors to each other – can they tell by the sound of them whose motor has a higher or lower RPM?

Questions for analyzing:

Does the RPM change from the beginning of the testing to the end? Did you measure a difference between RPM readings of the same independent variable value? What are some suggestions for what might cause that difference?

Step 5: Evaluate and Reflect

Have students look back through their procedure to find possible sources of error with their experiment or analysis. Hold a class discussion about human error or the necessity of keeping all variables consistent except for the one being tested.

Questions to encourage reflection:

Are there any assumptions you made that might influence your results? (I.e., did you perform all the same tests on the same day? Did you measure the voltage of your battery before each test?) What variables were you not able to control for (i.e., room temperature, etc.)? Now that you know how one variable affects RPM, are there any other variables you'd be curious to test? How would you design the fastest-spinning motor you could with the materials available in the classroom?

Step 6: Communicating

Students get together as a class to present their findings. Refer to their predictions from the brainstorm about how each variable might affect RPM – did they confirm their hypotheses or disprove them? Get them to discuss any interesting points they may see now that they have done the testing.

Questions to consider:

How might you communicate your results differently in writing verses describing them to someone in person? What are some visual aids that might help to describe your experiment and effects to your classmates? How might you explain your results differently to a grade 7 student who is just learning about electromagnets versus your teacher who helped you with this project?

SUGGESTED ASSESSMENT STRATEGIES (STRUCTURE TO DESIGN ASSIGNMENTS)

PHYS 11 - Graphical methods in physics

Students use the Scientific Method Resource to design and complete their exploration into the variables that affect their simple electric motor RPM, including graphical analysis of their results. They could also include a print-out of their sound recording graph (zoomed in to show the frequency of volume spikes that indicate each revolution, from which they calculated the RPM).

FOM 11 - Applications of statistics

Have students calculate the average RPM for a specific (or for each) value of their independent variable. If they have performed enough tests for each value, they can look at a histogram of their data and decide if (for one specific value of their independent variable) their distribution is “normal”, and then calculate the standard deviation and z-scores. You can then have them answer questions such as “if you were going to test your simple motor again using [insert value] for your independent variable, what range of RPM values would you estimate that it would produce if you wanted to be 99% sure your estimation would be within that range?”

PHYS 11 - Characteristics of sounds

This assessment has students exploring the musical capacity of motors. Some supplies to get them started could be a variable DC power source, several small electric hobby motors of different kinds, a smart phone with a guitar tuner app and sound recording app, as well as access to other electric motors such as tools or kitchen gadgets

Ask students to explain how they think they could tell just by the sound if the RPM of a small hobby motor is changing. Can they identify RPM changes in the sounds of other motors, such as car motors or electric drills? (The concept you want to get across is that lower RPM have a lower-sounding pitch, and higher RPM have a higher-sounding pitch). Show students how to represent their RPM results in Hz (divide their RPM by 60). Give them a table of sound frequencies that represent different pitches or notes of the musical scale.

There are tons of songs that use only 5 notes – Journey's "Don't Stop Believing", Old MacDonald Had a Farm or Ode to Joy from Beethoven's 9th symphony are a few to get you started. Alternately, let students write their song. Research to find a written version of the song that indicates which note of the scale corresponds to which tone, or ask a musician to help by writing out the 5 notes (in whichever scale they choose, preferably one that matches the guitar tuner app that the students are using.

Challenge them to explore and test the pitch made by different electric motors to find and record the 5 different notes needed to play the melody of their song. They may choose to try to use one motor to achieve all 5 frequencies, or they may want to experiment with many different motors. Have them use the guitar tuning app to figure out which note the motors are playing. This is a great opportunity to teach them how each note of the chromatic scale has several different options depending on which octave it belongs in (i.e., if they can't get their motor running fast enough to play a high C, then a middle C will sound the same note from an alternate octave). Discuss how it's possible for the "same note" to have several different frequencies and help students recognize the similarities and differences between the same note in a different octave.

You can also encourage students to use found objects to increase the resonance of the sound of their motors, such as attaching the motors to wooden boxes, etc.

Have students perform their songs on their motors or create a video explaining how they made their instruments. They could use a song editing program to stitch together the recordings of their 5 frequencies to produce a cover of the original song.

PHYS 11 - Resonance and frequency of sound

Give students each a DC hobby motor and power source. Have them get their motors spinning at a constant RPM, then compare them to their classmates' motors. Have them listen for a beat frequency: When you spin the motors side by side, do you hear a "wowing" noise at all as the frequencies of the sounds overlap? Have them calculate the beat frequency of their motors running together, and then calculate the beat period (in seconds) so they can listen again for the "wowing" noise. It may be easier for them to hear the subtlety of the beat frequency if they are comparing the same type of motor running at only slightly different RPMs.

Get students to think about the difference between Hz, RPM, and decibels – what units do you measure each of these variables? What tools or instruments can you use to measure them? Is there a diagram or figure that you found that helps you visualize the similarities and differences between these concepts? Why might it be important to measure the decibel level of a motor?

FOM 11 - Graphical Analysis: linear inequalities, systems of equations, optimization

Use the following optimization scenario or customize your own with your students using some actual real-life constraints.

Imagine with your students that they have decided to make demo build kits for an Electrical Summer Camp for kids. They want to make two different types of kits that include all the supplies needed to build the project, as well as how-to instructions for making the following: electromagnets and simple electric motors. (Keep in mind that grade 7 students in BC learn about electromagnetism – your students might be interested in designing and making these kits for a younger class!)

Through a community drive, your students have amassed a collection of the materials needed. They have a surplus of most materials (such as tape, wood blocks, batteries, etc.). They have been donated 60 nails (to make electromagnetic kits) and 35 magnets (to make simple electric motor kits). A local electrician has even agreed to donate the shipping costs for a maximum of 80 kits to be sent. The only hitch is the wire: your students must buy the wire with their classroom budget, so they want to use as little wire in total to minimize the cost to the school.

Each electromagnetic kit uses 0.5 meters of wire, and each simple electric motor kit uses 0.75 meters of wire.

From this information, students determine the number of each type of kit they will make to minimize the amount of wire purchased to make all the kits.

SOLUTION:

Identify variables:

e = # electromagnet kits

s = # simple electric motor kits

W = amount of wire (in meters) to match "e" and "s" indents

Identify restrictions and restraints:

Electromagnet kits, $e \geq 0$, $e \leq 60$

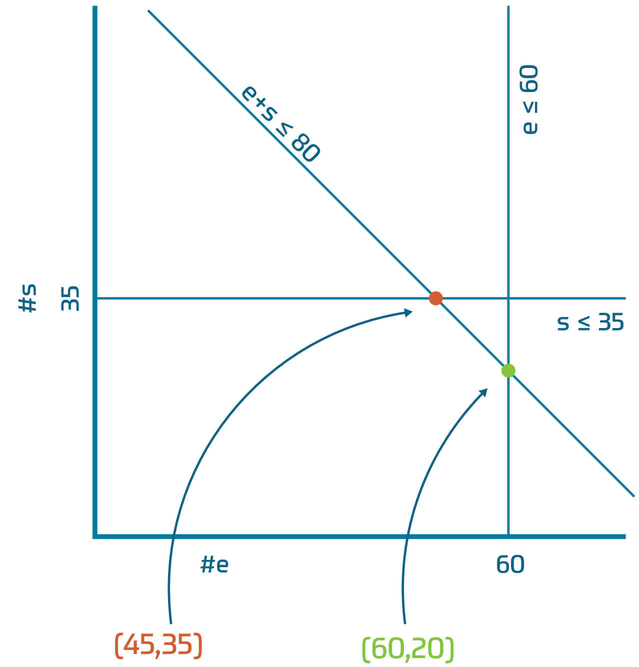
Simple electric motor kits, $s \geq 0$, $s \leq 35$

Maximum number of kits that can be shipped is 80, $e + s \leq 80$

Total length of wire: $0.5e + 0.75s = W$

Write a system of linear inequalities and graph the system (e on the horizontal axis, s on the vertical axis) to find the intersection points.

$e \leq 60$ $\quad s \leq 35$ $\quad e + s \leq 80$



$W = 0.5e + 0.75s$
$W = 0.5(45) + 0.75(35)$
$W = 22.5 + 26.25$
$W = 48.75$

$W = 0.5e + 0.75s$
$W = 0.5(60) + 0.75(20)$
$W = 30 + 15$
$W = 45$

Total wire used to <u>minimize</u> amount bought is 45 meters.

$e = 60, \quad s = 20$

∴ 60 electromagnet kits
20 simple motor kits

SCIENCE CHALLENGE OPPORTUNITY

Choose a small, light object, such as a paper clip, and challenge the students to build a device that incorporates a switch, a simple electric motor, and a 9V battery that can move the object 10cm (vertically or horizontally). Alternately, you could get them to build a device that can knock or push over the first domino in a line, etc.

TAKE IT FURTHER!

1. Design an alternative method to measure the RPM of the simple motor. Keep in mind that the electricity stops briefly every time the insulated (coated) section of the magnet wire touches the binder clip. Is there a device that could be inserted into this circuit that would indicate when electricity was and was not flowing? What tool can you use to detect the frequency this device is operating at?

2. Take apart an electric motor in a broken drill, printer, blender, laptop, etc. Pay close attention to the parts as you remove them to draw the pieces in an “exploded diagram” fashion. Label as many parts as possible by looking at a user manual for that (or a similar) motor.

3. Using the otimization example, design your own optimization problem and have your classmates solve it.

4. Research the history of electric motors. What source of energy did early inventors use to produce electricity? Build a demo of an early electric motor to present to the class.

5. Using a variable speed motor, such as a power drill, play with increasing and decreasing the RPM to make it “play” a song. See if your classmates can guess the song. What mechanism inside the motor allows the RPM to be varied with such precision?

6. Design, draw the plans for and build three attachments that could be built onto this motor that would do some sort of work (i.e., an air fan, or a small winch to pull something across a table, or a noise maker, etc.)

7. Draw a flip book that animates the construction process of this simple motor.

8. Hold a "Students teach students" class. Students or partners draw the following questions out of a hat, research the answer, and do a 3-minute presentation to the class to explain their findings:

- What are the three similarities and three differences between DC and AC electric motors?
- What are the function of "brushes" in some electric motors?
- What are two unique characteristics of "stepper" motors, and what kinds of applications are these motors used for?
- Are electric motors better for the environment than internal combustion engines? Give two reasons why you could argue "yes" and two reasons why you could argue "no."
- What is the limiting factor preventing electric motors from replacing all internal combustion engines? Find and summarize an article on recent research scientists are doing to overcome this challenge.

DOPPLER DEMONSTRATION

skills READY

DOPPLER DEMONSTRATION

INSPIRATION

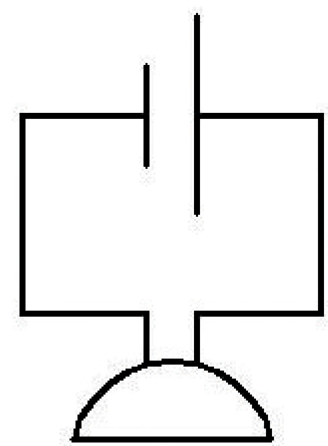
Part of the physics 11 curriculum requires students to "evaluate the validity and limitations of a model or analogy to the phenomenon modelled." The Doppler effect is an easily modelled phenomenon that applies to many different types of waves and has many applications. Why does a race car's pitch change as it drives past? Does the Doppler effect happen with water waves or light waves, too? Does the Doppler effect change the volume of a sound?

OBJECTIVE

Students will explore the Doppler effect and characteristics of sound waves by building and assessing the validity of a model: a tiny buzzer and battery assembly that swings at the end of a string.

TRADES CONNECTION

An ultrasound machine allows healthcare specialists a non-invasive way to see inside your body. An image is created by sending very high frequency sound waves into your body and then interpreting the reflected sound waves that bounce back to the machine. Ultrasound machines use the Doppler effect to determine how quickly your blood is flowing: the difference in frequency between the projected sound and the returning sound that is bouncing off moving blood cells allows the machine to quantify the speed of blood movement.



SAFETY FIRST

Make sure that the buzzer and battery are safely contained and attached tightly to the string. Double check your surroundings before swinging your project.

VOCABULARY

Review the definitions with students at the beginning of the lesson and ensure that students have access to the glossary resource provided with this activity. Utilize these words often during the lessons to model how and where to use them.

- Doppler effect
- Pitch
- Volume
- Longitudinal wave
- Transverse wave

MATERIALS

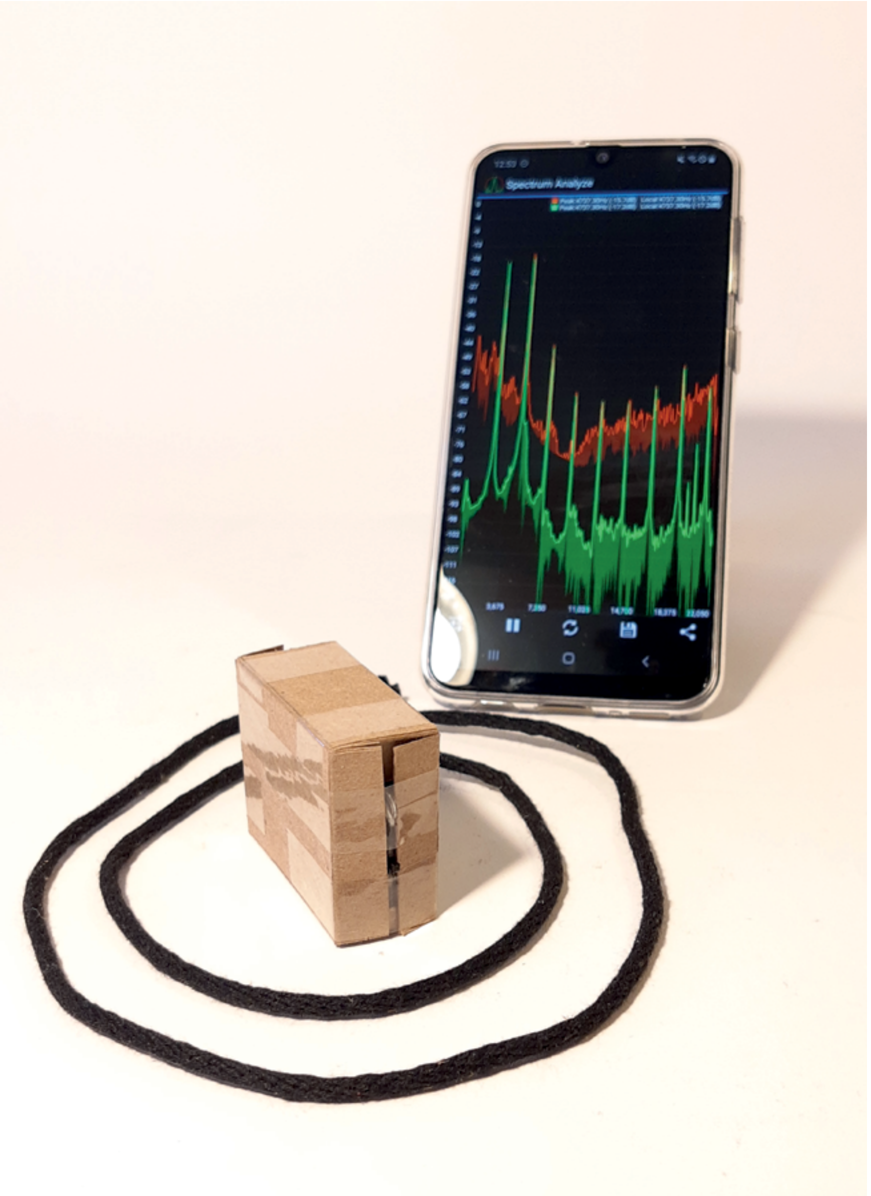
- Active buzzer (5V)
- 2-coin batteries (3V 2032 lithium)
- Coin battery holder with switch and lead wires attached
- 1 meter of strong string or yarn
- Cardboard to make a box, or a found matchbox or small container

TOOLS

- Scissors
- Electrical tape
- Clear tape
- Sound analyzing software or app that shows sound intensity (Db) vs frequency (Hz) with the ability to zoom in on the graph, such as "Spectrum Analyzer"
- **Optional:** video and sound recording device (i.e., a smart phone will suffice)
- **Optional:** solder iron and solder

PROCEDURE TO BUILD

1. Insert the batteries into the battery holder.
2. Turn the switch ON and touch the leads to the buzzer terminals. If no sound is emitted, reverse the leads.
3. Turn the switch OFF and secure the leads to the buzzer terminals. Twist the wire and fix it in place with electrical tape or solder the connection.
4. Close the buzzer and battery holder inside a small container, or wrap with padding and tape, or make a little box for it. Make sure to leave the switch exposed.
5. Secure your string to your buzzer assembly.
6. Check your surroundings before using to ensure you don't hit anything with your Doppler demonstration tool. Swing it in circles at the end of the string to produce sounds for analysis.
7. When recording, make sure to swing the buzzer towards and away from the microphone, not just in circles beside or around it.



GUIDED EXPLORATION OF THE PROJECT (CURRICULAR COMPETENCIES):

Step 1: Demonstrate and Model

Show students a model or demo about a concept they have learned already, such as using a slinky toy to demonstrate how longitudinal waves are generated. Host a class discussion about the validity of using the slinky as a demonstration tool; this discussion will act as a model for assessing analogies and demonstration tools which they will need for analyzing the efficacy of their buzzers as Doppler Effect demos.

Questions to spark curiosity:

Does the slinky demonstration help you visualize the difference between longitudinal waves and transverse waves? Do you think it is a good representation of how longitudinal sound waves travel through air molecules? What are some misconceptions that people might make by using a slinky as an example of demonstrating wave types? Is there a different tool or contraption you think would be better for explaining how waves are generated?

Step 2: Predict and define

Discuss as a class what they already know about the Doppler effect. Explain or show them a short video to help them visualize the phenomenon. Walk them through the schematic diagram for wiring a buzzer and ask them to come up with ways to utilize a buzzer to model the effect. Discuss as a class any risks or difficulties they expect to encounter and brainstorm possible solutions. For example, students may be concerned that the wire attachment points within the ball might come loose, and therefore they may need to make the connections more durable than in other projects they’ve made. They may be concerned that the buzzer will fall out, or that it might be difficult to turn on and off, or that it might not be loud enough

Questions to help clarify:

How is this device going to be used? Is there any part of the design you feel you could adapt to make sure it works well for the intended purpose and audience? Would an on/off switch would work well in this situation, and what could it look like? How will you illustrate or explain any design changes you make to the original prototype?

Step 3: Plan and Conduct

Assist students with the design and assembly of their own Doppler demonstration tools. Encourage them to take photos or write a journal as they proceed with the build. You may even choose to demonstrate their learning by handing in a "how to" video on building and using a buzzer demonstration tool.

Questions to help refine the experiment:

What parts of the build process are the most challenging? Are there any additional materials or tools you used to complete the build that weren't on the original list? How can you adapt the design to make it more functional? Is there a way to choose or set the buzzer frequency, and what initial pitch might be the best one to utilize?

Step 4: Analyze and Solve

Have students download a frequency-indicating sound app (such as Spectrum Analyzer or similar) and play with it until they are comfortable using the software. Get the students to test their Doppler demo tools in a place where there is little ambient noise. You may choose to have them screenshot their sound analysis app screen at specific moments or simply write detailed notes on the sound of the buzzer at rest and during different points along the circle, it is swung to assess pitch/volume/etc.

Questions for analyzing:

What do you expect the buzzer to sound like based on what you know already of the Doppler effect? What does the buzzer sound like when you swing it? What does it sound like when you observe someone else swinging it? Is there a difference in pitch if it is swung around at different speeds? What does it sound like when it is thrown straight up in the air and caught? What does it sound like if someone runs or rides a bike past you holding the buzzer?

Step 5: Evaluate and Reflect

Have students assess the validity of their buzzers as demonstration tools of the Doppler effect. You could even have them use their buzzers to teach a younger class the Doppler effect (for example, grade 10 science students learn about red and blue shift in their space units), and then get feedback from the younger class to assess how effective they were as Doppler demonstration tools. Work with students to develop a series of survey questions to ask the younger class to determine what they learned and how they liked the demo tool.

Students could analyze their sound recordings or sound analysis app screen shots, then draw diagrams of each throw scenario, including sketched concentric circles indicating sound waves and labelled frequencies.

Questions to encourage reflection:

Do you think the Doppler effect would have been more or less obvious had you started with a significantly lower or higher frequency? What are the limitations of your buzzer for showing the Doppler effect (are there facets of this phenomenon that the ball cannot explain)? Is there another version of this demonstration tool that you think would be more effective?

Step 6: Communicating

Host a class discussion about their findings from their reflective process. Students can share their ideas, their screen shots or graphs from their analysis, and even cooperatively design a Doppler effect demonstration tool that they feel would be even more effective than the buzzers.

You could also have the students refine their buzzer designs and bring the starting materials and tools to a grade 10 science classroom to help the younger students make their demonstration tools.

Questions to consider:

Who are some people in your family, school, or community that might enjoy learning about the Doppler effect? Can you think of any other applications for a buzzer toy other than a Doppler effect demonstration tool?

SUGGESTED ASSESSMENT STRATEGIES (STRUCTURE TO DESIGN ASSIGNMENTS)

PHYS 11 - Generation and propagation of waves
PHYS 11 - Properties and behaviours of waves
PHYS 11 - Characteristics of sound

Have students analyze screen shots from whichever frequency app they use (such as Spectrum Analyzer) or their detailed notes from testing. They can zoom in on a sound intensity (Db) vs frequency (Hz) read-out and observe the location of the buzzer's main sound peak when the buzzer is at rest. When they start swinging the buzzer towards and away from the microphone, the sound peak will appear to widen, and they can take a screen shot to capture the width of the peak (the app will often save a maximum line that you can read afterwards).

Help students understand and visualize how the lower frequency is that of the buzzer flying away from the microphone and the higher frequency when the buzzer is moving towards the microphone. Have them describe how they interpret the sounds changing by listening vs by looking at the sound analysis. Can they hear the difference in the sound (pitch) as the buzzer swings around? Are there any misconceptions around volume vs pitch?

Students can draw diagrams of the buzzer being swung to indicate its motion and position for each frequency noted, matching up the app screen shot frequencies with the buzzer at different places: i.e., if swinging horizontally, the 3, 6, 9, and 12 o'clock positions. For each position, you could have them draw the concentric circles that represent sound waves emerging from the buzzer, showing areas of maximum compression, and labelled with the sound frequencies recorded at each position. Have them explain to you in writing or verbally how the frequency differences affect how the buzzer sounds at each position (relative to the microphone), and how there are frequency differences despite the buzzer only sounding at one frequency.

PHYS 11 - Graphical methods in physics
PHYS 11 - Graphical analysis

Students may have some misconceptions about how waves are represented graphically (i.e., how a longitudinal wave is represented on an amplitude vs time GRAPH of seems visually like an actual transverse wave SHAPE, like an ocean wave). Having students compare different graphs with different axes values may help their understanding.

Students can record their buzzers from different reference points and analyze a sound intensity vs frequency read-out available by using free phone apps like "Spectrum Analyze", or frequency vs time (or sound intensity vs time) available with free software for computers such as "Audacity". If you think they might enjoy a challenge, you could have them figure out how to move the buzzer in a direct line towards or away from the microphone, then take the observed and actual frequency measurements from their graphs and calculate the speed of the buzzer using Doppler effect formula.

Alternately, have students make a theoretical sketch of a frequency vs time graph of what was heard by an observer at a specific position relative to the swinging buzzer. Get them carefully consider four sections of the graph: When the buzzer is at 3, 6, 9, and 12 o'clock around the head of the person swinging it. Make sure they understand that the time-frequency graph is NOT what a sound wave looks like, but a visual representation of the characteristics of a sound wave.

You may also choose to show them a corresponding diagram or video of the molecules in a sound wave illustrating compression and rarefaction of particles.

Ask them:

What does the y-axis represent (and what units is it measuring) in a frequency vs time graph? In a sound intensity vs frequency graph?

What do the sound waves (and air molecules) LOOK like as the waves pass? Have students find a time vs pressure graph that overlays an air molecule sketch to illustrate compression and rarefaction. Have them use this to help draw the sound waves coming in circles out of their buzzer, indicating that the pencil lines indicate the maximum compression.

SCIENCE CHALLENGE OPPORTUNITY

Starting with buzzers that buzz at the same frequency, which group or individual can design a catapult that launches a tennis ball at the greatest velocity? Measure the speed of the buzzer by analyzing sound recordings at the time of launch.

TAKE IT FURTHER!

- **Wire your buzzer into a circuit for another purpose, such as a high-water alarm, a "fridge door open" alarm, a "cap flap open" buzz indicator to hear if your pet is coming or going, etc... How will you design a switch to complete the circuit to indicate what is happening?**

- **Make an instructional video for the use of the buzzer ball as a demonstration tool. Video a buzzer thrown from several different reference points (thrower, catcher, mid-point observer, an observer from the side, etc.) Explain what is causing the pitch changes in each scenario. Upload your video and share it online as an educational resource.**

- **Make a class set of 25 buzzer demonstration tools (including instructions) and donate them to a local middle school as classroom tools for teachers.**

SOLENOID LAUNCHER

skills READY

SOLENOID LAUNCHER

INSPIRATION

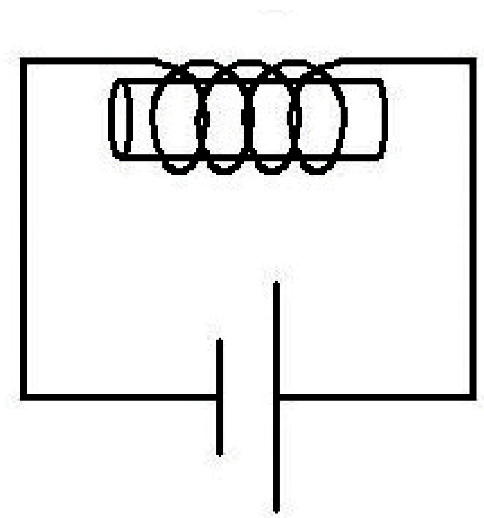
Catapults and slingshots have been used for thousands of years to fling objects with greater distance than a human's ability to throw them. Modern versions using electrical technology can even shoot jets into flight from aircraft carriers. How far and fast can an object be launched using a simple electric launch system? How do solenoids work, and could they produce enough kinetic energy to fling an object? How can mathematics help us describe the path of a launched object?

OBJECTIVE

Students will experiment and build their solenoid launcher to fling a tiny magnet, then use its resulting motion to explore how quadratic functions describe parabolic flight.

TRADES CONNECTION - TOOLS

Auto-mechanics, heavy duty mechanics, and plumbers are trades people that work to install and use solenoids as tools every day. For example, in heavy duty equipment, solenoids are used to control the flow of hydraulic fluid through hollow lines to control the articulation of machinery. Using hydraulics, tiny solenoids in combination with fluid lines and simple machines can control enormous systems.



SAFETY FIRST

Keep your electronics and debit cards away from the neodymium magnets, as the strength of the magnetism can damage them. Only connect the circuit on your solenoid long enough to launch the magnet: the solenoid is a short circuit, and the battery will get hot very quickly if left connected.

VOCABULARY

Review the definitions with students at the beginning of the lesson and ensure that students have access to the glossary resource provided with this activity. Utilize these words often during the lessons to model how and where to use them.

- Coil
- Helix
- Parabola
- Trajectory
- Catapult
- Ballistics
- Angle of launch
- Range
- Vertex
- Quadratic equation
- Quadratic function
- Quadratic root or “zero”
- X and Y intercepts
- Instantaneous velocity

MATERIALS

- Magnet Wire, 18-30AWG, up to approx. 12m
- 9V battery
- 2 insulated connector wires with alligator clip ends
- One ¼” neodymium disc magnet, or a similar strong tiny magnet
- Scrap paper or cardboard, approx. 3cm x 10cm

TOOLS

- Scissors
- Pencil or pen permanent marker or found cylindrical object slightly larger than magnet’s diameter
- Jar or mug
- Clear tape
- Electrical tape
- Wire cutters
- Sandpaper
- Measuring tape, meter sticks, sewing tape, etc.
- A digital camera or smartphone capable of recording slow motion footage
- Stopwatch
- Protractor
- **Optional:** demo tools (batteries, assorted wires, resistors, magnets, and a class set of magnetic compasses)
- **Optional:** multimeter
- **Optional:** variable DC power supply
- **Optional:** Laptops or desktops to view video footage on a large screen

PROCEDURE TO BUILD

1. Place your spool of magnet wire on a pencil and balance it over the rim of a mug or jar to help it pay out.
2. Leaving a 10 cm tail, use a small piece of clear tape to fix your wire to the side of the permanent marker/found cylindrical object. Make tidy wraps coiling up the marker in a tight helix, periodically pushing the coils down to sit tightly together.
3. When you have about 3 or 4cm of coil wraps, lay a small strip of clear tape over the wire wraps to secure them, and wind another layer of wraps down over the first layer.
4. Lay another small piece of clear tape down to secure the second layer of wraps and begin coiling the wire again in the opposite direction.
5. After you have used approximately 12 metres of wire, or have done 4 layers, wrap the coil completely in one layer of clear or electrical tape to keep its cylindrical shape.
6. Snip the wire, leaving another 10cm tail.
7. Use sandpaper to strip the insulation off the last 2cm or so of each wire end, then remove your coil (solenoid) from the marker. You may need to peel up the clear tape and snip it away with scissors to free the solenoid.
8. Make a small triangular prism using some scrap paper or cardboard and tape. Affix your solenoid to the prism, so one solenoid end touches the table and the other rises at an angle. Secure this assembly to the tabletop with tape.
9. Clip one connector wire to the 9V battery and the other to one wire end of the solenoid.
10. Clip a second connector wire to the free wire end of the solenoid.
11. Place the neodymium magnet on the table at the base of the solenoid. To launch the magnet, briefly touch the free alligator clip to the free 9V battery terminal. Do not leave the clip in place, just touch the terminal quickly and remove it again.
12. Play with the magnet's position and orientation (as well as the lenth of time you connect the circuit) to get the magnet to launch through the solenoid.

TROUBLESHOOTING:

- Is the magnet getting stuck in the solenoid instead of launching? Try touching the battery terminal for a shorter length of time. (If the electricity remains on, the magnet is held in the center of the solenoid and does not shoot out with the momentum it gained in the first half of the solenoid).
- Experiment with which side of the battery faces up before launching. You may want to indicate one side by sticking a tiny piece of electrical tape to one side.
- Is the solenoid too wide? Try rewrapping the solenoid on an object with a smaller diameter.
- Do you want to power up the launcher? You could try adding more voltage, or more wraps, etc.

GUIDED EXPLORATION OF THE PROJECT (CURRICULAR COMPETENCIES):

Step 1: Demonstrate and Model

Brainstorm with the class to see how much they already know about solenoids and/or electromagnets. Introduce and/or discuss the concept of the magnetic field that exists around a live wire. Get students to play with simple circuits, magnets, and compasses to develop an idea of the forces that exist when electricity flows through the wire.

Questions to spark curiosity:

How could you draw a diagram to illustrate the invisible lines of magnetic force around a live wire? What might the lines of force look like around a straight wire? Around a wire loop? Around a helix (electrical coil)?

Step 2: Predict and define

Show the class how a solenoid works (i.e., hotel room door locks), and ask them if they think they could use that technology to build a device that would launch a magnet across the classroom. Have them come up with a list of variables they think might affect the distance the magnet is flung (i.e., the diameter of a helix, a gauge of wire, number of wraps, angle of launch, the voltage applied, magnet strength, magnet diameter, etc.). Draw a quick diagram of the launcher on the board and brainstorm the importance of the launch angle in getting the magnet projectile to fly and/or land where they want it to.

Questions to help clarify:

Do you think that the angle of launch will affect the time that the magnet flies in the air before landing? How does the angle of launch affect the horizontal distance the magnet flies? Does it affect the maximum height the magnet will achieve? If all other variables are kept constant, is there only one launch angle to send your magnet to the same target?

Step 3: Plan and Conduct

Show students the design for the solenoid launcher. Assist students in the design, construction, prototyping, and testing of their solenoid launchers. Encourage them to experiment with some of the variables from step 2 to get their magnets to fly as far and high as they can. Encourage them to add some flair by customizing the housing for their launcher, designing a unique "launch" switch or button, designing a fancy holder, etc.

Questions to help refine the experiment:

How will you be able to read the launch angle of your solenoid launcher? Will your launcher include an adjustable "angle of launch" mechanism? What variables can you adjust if your magnet doesn't fly as far as you want it to? What mechanism or switch could you use to connect your circuit?

Step 4: Analyze and Solve

Assist students in the planning and set-up of digital cameras, measuring tape, graph paper background, etc., to capture four quantities:

A) A side view video of the full parabolic flight of the magnet from launch (0,0) to the point at which it falls back down to launch level (the height at which it left the top of the solenoid).

B) The horizontal range of the magnet's flight (the distance from launch to the point where it falls to the launch level).

C) The maximum height of the magnet's arc.

D) The time of flight: launch being zero seconds, to the moment it falls to launch level (this can also be measured by reviewing the footage and looking at the number of frames the magnet is in flight).

Questions for analyzing:

What effect does the placement of the video camera have on the recorded shape of the magnet's trajectory? What camera position and angle would result in the most accurate and useful footage? What are some ways you could quantify the maximum height the magnets achieve? Are you familiar with any video editing software that could be useful in quantifying the flight path and time of your magnet? How far along with the horizontal range of the magnet's flight do you expect it to reach maximum height? Do you think it might be easier to determine the moment the magnet reaches launch level by setting the solenoid's top edge at table level and watching for when the magnet lands?

Step 5: Evaluate and Reflect

Help students review their video footage and analyze using quadratic functions. Follow the "suggested assessments" below to help them determine the quadratic function that describes the parabolic arc that their magnet flies, as well as the quadratic function that describes the projectile motion (height vs time). Compare the two graphs for similarities and differences. Use their customized quadratic function to predict things, like will their magnet clear an obstacle? Can they hit a certain target of a specific size at a determined distance or height?

Questions to encourage reflection:

Which component of the quadratic function do you think describes the height the magnet flies? Which component describes the arc shape? What real-world scenarios can you imagine where being able to predict a projectile's trajectory is important?

Step 6: Communicating

Students could present their trajectory and quadratic functions with the class, and then discuss each launcher's differences using mathematical vocabulary.

Students could invite other science classes in for a demo of their launchers and to share their findings, which could be a valuable virtual or in-person field trip for any grade 4s learning about energy types and transformations, grade 6s in BC who are learning about gravity and Newton's laws, or grade 7s learning about electromagnetism, for example. Students may want to share their world-relevant quadratic functions with other math 11 classes.

Questions to consider:

Did all the launchers send the magnets in a similar arc? Which launchers gave the most unique flight paths? How did the quadratic functions differ between launchers?

How does your launcher demonstrate simple scientific or physics concepts? How could it be used to teach about gravity, energy transformations, electromagnets, etc.?

For the grade 4s: What different forms of energy do you see in the launcher system? What energy transformations do you observe?

For the grade 6s: Why does the magnet fly in an arc shape? What happens if you shoot it straight up?

For the grade 7s: How does the magnet get launched? What happens when the electricity is connected?

SUGGESTED ASSESSMENT STRATEGIES (STRUCTURE TO DESIGN ASSIGNMENTS)

FOM 11 - Graphical analysis: quadratic functions – characteristics of graphs, including end behaviour, maximum/minimum, vertex, symmetry, intercepts

Graphical methods in Physics

TWO DIFFERENT QUADRATIC FUNCTIONS can be analyzed with the data obtained from the video recordings. Students can film in slow motion to obtain more frames per second, then analyze the projectile flight using the stills from the recording (find a program that allows them to edit or view the recording frame by frame)

1) First Quadratic Function (height vs distance):

Students discover the quadratic function of the parabola that their magnet flies using the following steps, taking measurements from stills or screen shots of the slow-motion frames from their video capture (Note- the dimensions need not be to scale, they can be taken directly off the screen shots at whatever zoom is easiest for them. It is the ratio of height to the distance that is important, not the actual values):

A) Designate the launch point where the magnet is released as (0,0). Find the second root or x-intercept by measuring the range (r) of the magnet's flight- the point at which it falls back to the height it left the solenoid (r,0). The third coordinate they need is the vertex of the parabola (h,k). The y-value of this point (k) is the maximum height they measured. The x-value is the axis of symmetry of the parabola, (h) - with no air resistance, this number would be half the range the magnet flies (r/2). (If you want to include the concept of air resistance with your students, have them include a horizontal tape measure in the video shot as well).

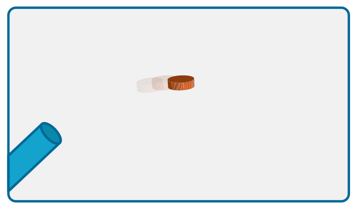
B) Use these points to determine the coefficients for their very own quadratic function:

Use the vertex form of the quadratic function: $y=a(x-h)^2 + k$, where h and k describe the coordinates of the vertex (h,k). Insert their values for h and k, insert their known (x,y) at launch (0,0), and then solve for a. Note: make sure students understand that "h" in this case is an x value and does not stand for "height".

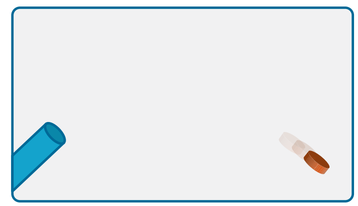
C) Rewrite the vertex form of the quadratic function $y=a(x-h)^2+ k$. Next, insert their own values of a, h, and k, and expand this mathematically to get their formula into the classic quadratic formula format of $y=ax^2 + bx +c$.

D) Have students graph their equation digitally (there are many online quadratic function graphing programs where they can insert their a, b, and c coordinates to view their graph). They can then compare this graph to the video of their entire launch and list all differences they observe (and include some possible explanations for each). Is the x-value of the second root the same as your range (r?). Is the x-value "h" half your range "r"? What might explain any discrepancies here?

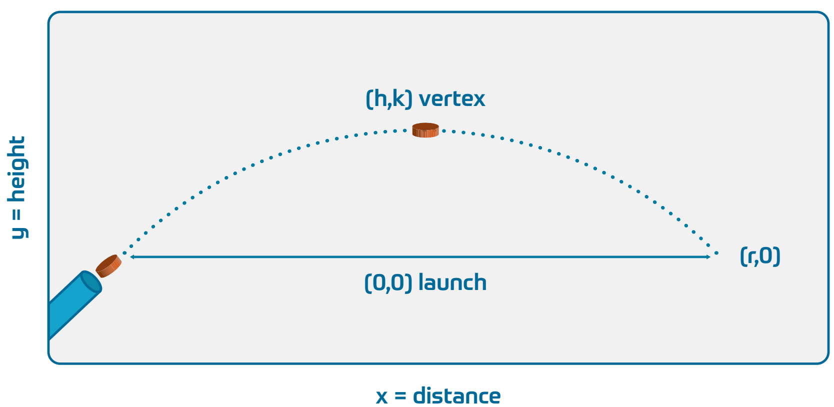
At launch moment.



At max height.



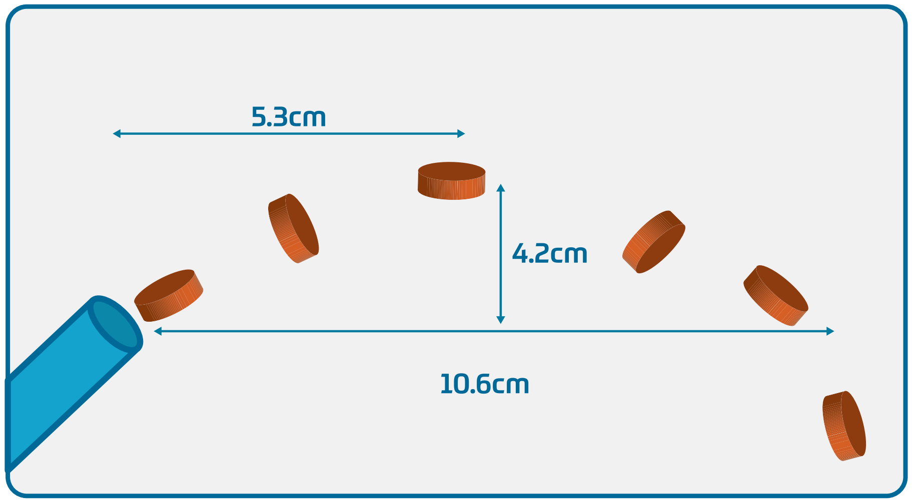
At return to launch height.



Using launch point as (0,0), measure on your screen shots to determine (h,k) and (r,0).

You won't need to convert the measurements from your screenshots to actual scale measurements, as it's the ratio between height and distance that matters, not the actual valves.

Example: (camera horizontal)



Launch point	(x,y)	x=0	y=0
Vertex	(h,k)	h=5.3	k=4.2

Find your own unique value of "a" by using your values for x, y, h and k in the vertex form of the quadratic equation:

$y = a(x-h)^2+k$

$0 = a(0-5.3)^2+4.2$

$0 = a(-5.3)^2+4.2$

$0 = 28a+4.2$

$\frac{-4.2}{28} = \frac{28a}{28}$

$a = -0.15$

Next, use your "a" to discover the magnet flight's very own quadratic function in the classic form $y=ax^2-bx+c$

First, insert your “a” value, as well as your “h” and “k” into the vertex form of the quadratic function:

$$y = a\,(x-h)^2 + k$$

$$y = -0.15\,(x-5.3)^2 + 4.2$$

Next, expand to turn it into the classic quadratic function format:

$$y = -0.15\,(x-5.3)^2 + 4.2$$

$$y = -0.15\,(x-5.3)(x-5.3) + 4.2$$

$$y = -0.15\,(x^2-5.3x - 5.3x+28) + 4.2$$

$$y = -0.15\,(x^2-10.6x+28) + 4.2$$

$$y = -0.15x^2-1.59x-4.2+4.2$$

$$y = -0.15x^2+1.59x$$

$$\boxed{f(x) = -0.15x^2+1.59x}$$

Your magnet trajectory’s very own quadratic function. You can check by graphing it and comparing the shape to the arc the magnet flew in your video.

You can use it to figure out the magnet’s height if you know the distance (horizontal) from the launcher, and vice versa.

24 frames from launch to when magnet returns to launch height.
Video (slo-mo) captured in 240 frames/second.

$$\frac{240 \text{ frames}}{1\text{s}} = \frac{24 \text{ frames}}{X\text{s}}$$

x = 24 x 1 ÷ 240 = 0.10s = time from launch to end of arc

$$y = \tfrac{1}{2} at^2 + V_0 t + y_0$$

What is the initial vertical velocity of the magnet?

Use: y = height @ end of arc (magnet at 0m, back to launch height)
t = time it took to get to end of arc
a = acceleration due to gravity = $-9.8 m/s^2$
y_0 = initial height at launch (set it to 0m)

$$y = \tfrac{1}{2} at^2 + V_0 t + y_0$$

$$0 = \tfrac{1}{2} (-9.8) (0.1)^2 + V_0 (0.1) + 0$$

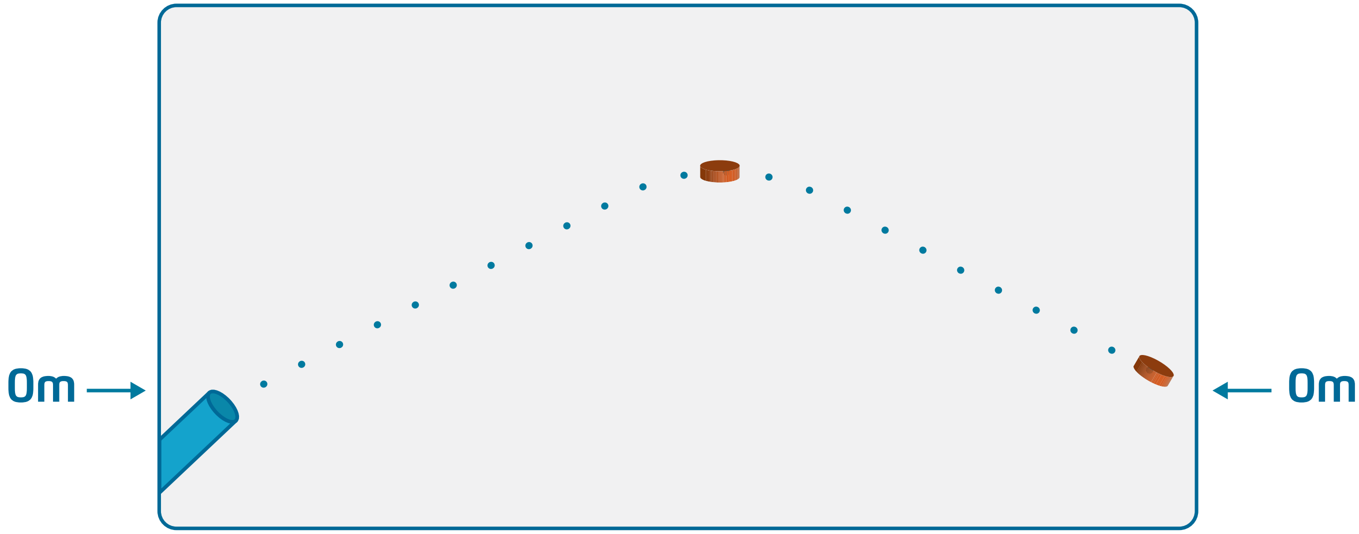
$$0 = \tfrac{1}{2} (-9.8) (0.01) + 0.1V_0$$

$$0 = -0.049 + 0.1V_0$$

$$\frac{0.049}{0.1} = \frac{0.1V_0}{0.1}$$

$$V_0 = 0.49 m/s$$

This is how fast the magnet is moving vertically at launch (vertical component of velocity vector).



2) Second Quadratic Function (height vs time):

BALLISTICS FORMULA FOR HEIGHT:

$$y = \frac{1}{2}at^2 + v_0 t + y_0$$

Students calculate the initial vertical velocity of the magnet by using the information for the moment. The magnet returns to launch height:

v_0 = unknown, initial (starting) velocity

y = height (0m as magnet returns to launch height at the end of arc)

t = time in seconds (from launch to returning down to launch height. Students find how many frames per second their recording is showing, then count how many frames until the magnet has returned to launch height)

a = acceleration due to gravity (–9.8m/s/s)

y_0 = initial (starting) height (0m at launch height)

A) Students can use this equation to calculate the initial VERTICAL velocity of the magnet. They can change the units from meters per second into kilometers per hour. What objects move at this approximate speed? Can students jump this fast vertically? =

B) Students can compare this quadratic function to the one they developed in part 1. What do the x and y represent in each function, and what units are they measured in? Is “a” similar in both functions?

C) Once they have calculated their y0 (initial velocity), which is the “b” coefficient, students can use the same program as they used for their first function to graph their own magnet’s height vs time curve.

Have students analyze the similarities and differences between the two quadratic functions and associated graphs. Are the graphs a similar shape? Which one represents the exact shape of the magnet’s trajectory? Why are both graphs parabolic? What circumstances might make the two graphs look different? (I.e., a head or tail wind? A magnet with a different shape or density?)

PHYS 11 - Vector and scalar quantities:
addition and subtraction, right-angle triangle trigonometry

FOM 11 - Angle relationships

FOM 11 - Graphical analysis: quadratic functions – characteristics of graphs, including end behaviour, maximum/minimum, vertex, symmetry, intercepts

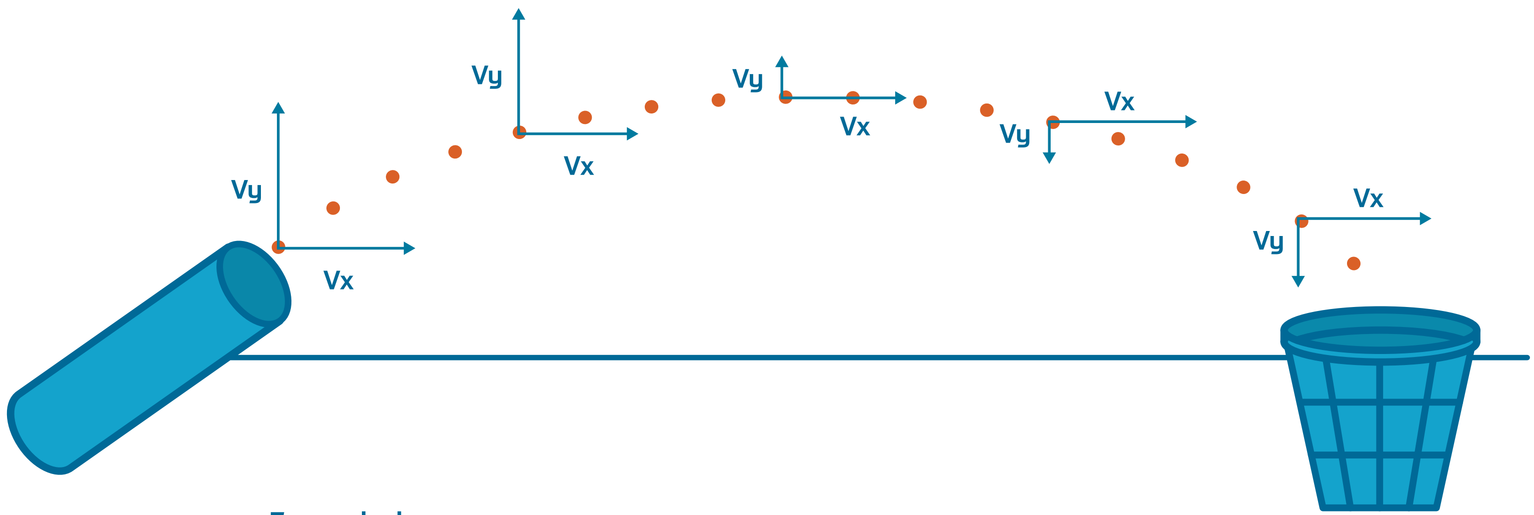
Students can sketch the trajectory of their magnet or use a print-out of the graph of their height vs distance graph to draw on. Show them how to sketch a vector diagram of the horizontal and vertical components of the magnet's velocity, and then have them do it for every hundredth of a second (or whatever fraction of a second that gets them drawing a fair number of diagrams).

For each vector diagram, they can find the horizontal velocity (which is constant throughout the flight, assuming no air resistance). Have students measure on their frame stills the magnet diameter and the horizontal displacement of the magnet at the point it returns to launch height. Then, using the magnet's REAL diameter, use that scale to find the actual displacement value. Divide this number by the time (using the number of frames the magnet took to fly to that point and the frames per second rate of their camera).

They can then find the value for each vertical velocity component by using their personalized ballistics equation (first, they must determine their initial vertical velocity by using the time and height at the moment the magnet returns to launch height)

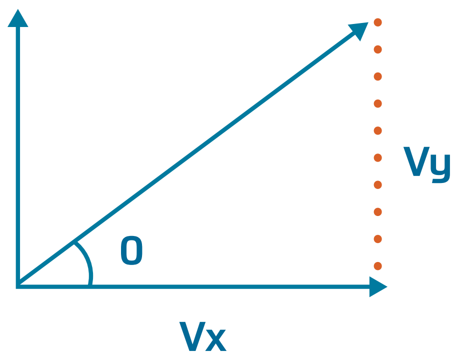
$$y = \frac{1}{2}at^2 + v_0 t + y_0$$

At each point, use the vertical and horizontal components to calculate (using trigonometry) the instantaneous velocity of the magnet, as well as the exact angle relative to the horizontal that the magnet is flying at.



For each chosen moment (ie, every 0.25s)

Calculate the instantaneous velocity vector value as well as 0 the angle of flight



The important point here is that students see that horizontal motion is constant but the vertical component changes. You could have them analyze the rate change of vertical velocity to see if they can explore finding “g.” How close to –9.8m/s^2 they can get, and can they come up with some reasons why they DON’T calculate their acceleration to be exactly that value.

Students can use their initial vertical velocity, as well as their horizontal velocity and time value, to play with their kinematics formulae and answer questions about whether or not the magnet would clear an obstacle, etc.

PHYS 11 - Newton's laws of motion and free-body diagrams
Balanced and unbalanced forces in systems

Have students draw and label free-body diagrams for their magnets at different stages of the flight trajectory: before launch, at launch, at the vertex, at the moment it returns back to launch height, etc. What are the forces acting on the magnet? Where are the forces balanced? Where are they unbalanced? How does this affect the motion of the magnet?

PHYS 11 - Projectile motion, 1D and 2D, including: vertical launch, horizontal launch, angled launch

FOM 11 - Forms of mathematical reasoning

1) Students can use the ballistics equation (using their known initial vertical velocity), as well as d=vt with their known horizontal velocity, to make predictions about whether their magnet will clear an obstacle placed in front of the launcher. E.g., "Do you predict that your magnet will clear a 3cm tall obstacle placed 2cm in front of your catapult?" Students can make the prediction, calculate it, then test it. "Was your prediction accurate? Was your calculation accurate? Did anything unexpected happen? Why might your magnet hit the obstacle during testing even though mathematically you predicted that it would clear it, or vice-versa?"

2) Student's video their catapult from three different angles: side-on, oblique, and end-on. For the side-on and oblique recordings, analyze the film and take the vertex and x-axis range measurements directly off the screens, then determine the quadratic function for each parabolic arc drawn on the screen. What are the similarities and differences between these two quadratic functions? Why is there a difference between the functions if they both describing the exact same magnet's flight? Analyze the end-on footage (magnet should appear to fly in 2 dimensions only, up and down). Can you make a height vs distance quadratic function for this perspective? Why or why not? What would the height vs time graphs look like for each of these three scenarios?

3) Students can set their launcher up to shoot the magnet vertically or horizontally to analyze the motion for each set-up. Students can also apply any math in this project to any type of launching device they build.

PHYS 11 - Evaluate the validity and limitations of a model or analogy in relation to the phenomenon modelled

Students assess their launchers as demonstration models for teaching purposes. Give them a phenomenon, such as gravity, energy types and transformations, simple machines, electromagnetism, quadratic functions, etc. Have them write a paragraph or do a short oral presentation analyzing the efficacy of the launcher as a model of the phenomenon. This could easily be tied into a solenoid launcher presentation to another grade or class, where students plan a short explanation of their demo for the audience and then reflect on their presentation and how well they think the audience understood the phenomenon being demonstrated.

FOM 11 - Scale models

Have students draw to-scale, detailed diagrams of their solenoid launcher design.

PHYS 11 - Electric circuits (dc), Ohm's law, and Kirchoff's laws

On a sketch of their solenoid launcher, include a circuit schematic and description of the voltage and current of the launcher circuit when electrified, as well as the resistance of their solenoid. Have students research the forces that occur around a solenoid when electrified and include an explanation of how the launcher works.

SCIENCE CHALLENGE OPPORTUNITY

Split the class into two and have them design a system with two solenoid launchers that plays "catch" with itself (OR, have multiple solenoids pass the magnet forward through a system of launchers that take it all over a tabletop!). Can the students design a funnel system that catches the magnet from the opposing or previous team's launch and directs it towards their own launcher?

TAKE IT FURTHER!

- Challenge students to design a launcher that shoots a ping pong ball and utilizes a hobby motor.

- Give students some independent variables to play with, such as magnet diameter, strength, etc., and predict how the trajectory path would be affected. Students develop a hypothesis regarding the flight path of the magnet and design a scientific procedure to explore their idea. Get them to analyze their quantifying data using statistical calculations (central tendency, standard deviation, confidence intervals, z-scores, and distributions).

- Discuss with the class the phenomenon of achieving the greatest horizontal distance of the magnet with a 45-degree launch angle from the launcher. To hit a target any closer, you have TWO different launch angle options: sends the magnet low and more directly into the target and one that sends the magnet higher in the air first. See if students can determine the two angles of launch and then explore the phenomenon of those two angles adding up to 90 degrees every time!

ULTRASONIC SENSOR

ULTRASONIC SENSOR

INSPIRATION

The ticker timer has been an essential fixture of physics classrooms for studying motion and acceleration. The new BC curriculum (for physics 11, specifically) requires that students “use appropriate ... equipment, including digital technologies, to systematically and accurately collect and record data”. For teachers hoping to update their “acceleration due to gravity” lessons from ticker timer to digital technology, here are the step-by-step instructions, pre-written code (.ino file), an excel spreadsheet template (.xlsx file) needed to make a stress-free introduction to microcontrollers for first-time users - no coding necessary!

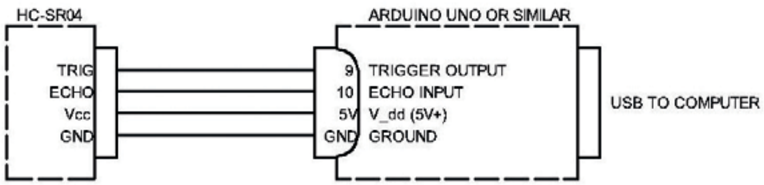
How do you think a sensor that sends out ultrasonic pulses might be able to determine the velocity of an object? What patterns in the data would you expect to see if you track an object that moves at a constant rate or an object accelerating or decelerating? Can you think of similar speed-detecting tools that are useful in your daily life?

OBJECTIVE

Students will use the instructions and associated files to assemble an ultrasonic speed sensor that outputs a distance-time graph for motion analysis. Using the sensor, students will explore motion, acceleration due to gravity, and frequency and sound characteristics.

TRADES CONNECTIONS

Ultrasonic sensors can be used to monitor the level of liquids and materials in containers remotely. By sending ultrasonic pulses down from the top of the container, then measuring how long it takes the sound to reflect off the surface of the liquid below, the sensor can communicate where the top of the liquid is. This can be very useful in situations where the liquid monitored is toxic, such as in industrial acid facilities, or when access to a holding tank is difficult. Ultrasonic sensors can also measure the speed and acceleration of liquid rising or falling.



SAFETY FIRST

The ultrasonic pulse that the sensor emits is above the human hearing range but can still be capable of causing damage. Don't place the sensor right up to your ear. Be mindful of which objects you choose to test and design a safe landing place so that objects don't break or fall on someone's foot.

VOCABULARY

Review the definitions with students at the beginning of the lesson and ensure that students have access to the glossary resource provided with this activity. Utilize these words often during the lessons to model how and where to use them.

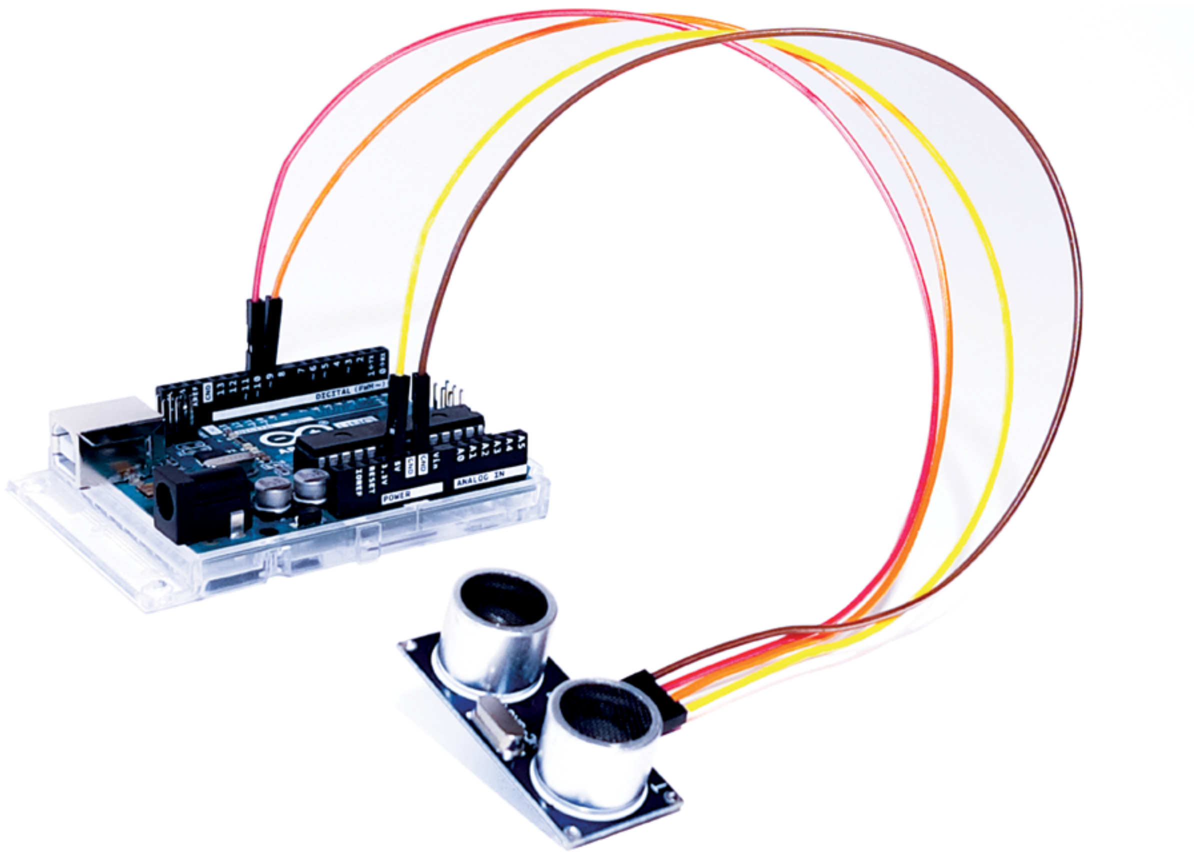
- Ultrasonic
- Arduino UNO
- Pin-socket cables
- Acceleration
- Negative acceleration
- Gravity
- Frequency (wave)
- Compression
- Rarefaction

MATERIALS

- 1 x USB A-B cable (like you use on a printer. Standard USB on one end and the square one on the other)
- 1 x Arduino UNO (or similar)
- 1 x HC-SR04 ultrasonic sensor
- 4 x pin-socket cables (formerly "male-female jumpers")
- Assorted objects for dropping to discover "g"
- **Optional:** toy car

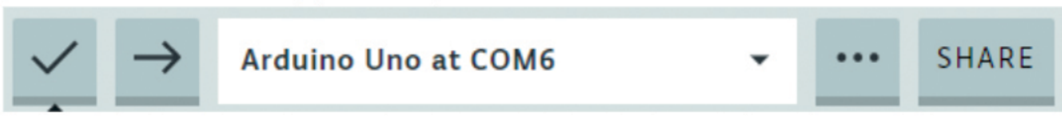
TOOLS

- Desktop or laptop computer for analyzing excel spreadsheet data
- Scale (to measure the mass of objects)
- **Optional:** air track
- **Optional:** ticker timer and ticker tape for demonstration purposes

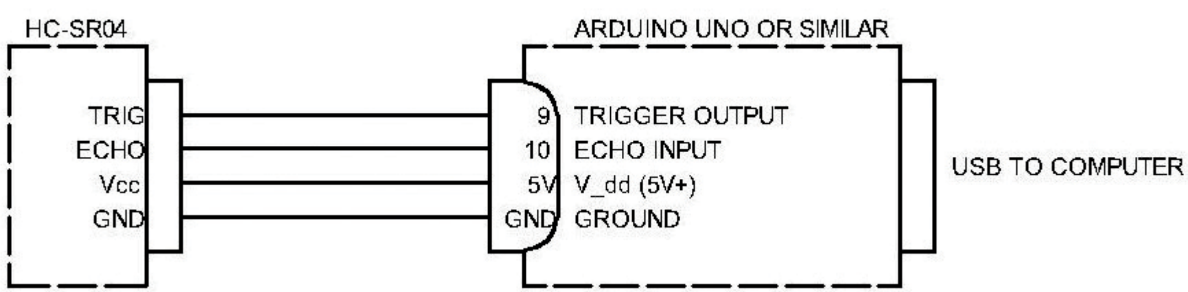

DIGITAL (PWM~)
POWER
ANALOG IN

PROCEDURE TO BUILD

1. Go to Arduino Create: https://create.arduino.cc/
2. Click on “Web Editor” from the top right 9-squares icon. You need to make a login and agree to the privacy policy.
3. If this is the first time you are using the Arduino with your computer, you will need to download the web editor plug-in (“Arduino Create Agent”) by finishing the “Getting Started” process at: https://create.arduino.cc/getting-started/plugin/welcome
4. Download the 7Ultrasonic_Data_Acquisition.ino file from the online resources associated with this lesson. Go back to Arduino Create web editor “sketchbook” page from step 2, and click the import button image.png, to import the .ino file you just downloaded.
5. Plug in your Arduino to the computer with the USB cable.
6. The Arduino should appear on your screen and look like this:



7. Click the arrow that points to the right; this will send your code to the Arduino. It will save it inside and start running the code. You only have to do this once each time you change the code.
8. When the code has finished loading, unplug the Arduino. Use the following connections to connect the Arduino to the sensor with the pin-socket cables:



9. Download and open the **7Data_Plotting.xlsx** file from the online resources associated with this lesson. Next, open another new excel spreadsheet and name it **"TEST.xlsx"**
10. Perform a drop test with your sensor: hold your sensor with the cylinders pointing down and hold an object up to the sensor. Go back to Arduino Create web editor and click "Monitor" on the left side of the screen. Plug in your printer cable to start the test. You should see numbers flying down the screen.
11. Drop your object, then press **"DISCONNECT"** in the web editor to stop the data collection.
12. To graph your data, click the copy button and paste the data into your TEST spreadsheet. Fix the data here, if necessary, by deleting any cells that contain any characters other than numbers (the number on the left is the number of milliseconds that your Arduino had been alive. The number on the right is the distance in cm to the object from your sensor).
13. Copy and paste your data into the **7Data_Plotting.xlsx** spreadsheet and view your graph!
14. **Note:** the data you need will likely be less than half a second's worth or approximately 40 cells' worth of data. If you started your Arduino early and stopped it late, you will have to look at your graph, determine the section that shows the acceleration from the object's drop, then copy and paste ONLY those data cells into your raw data column.

GUIDED EXPLORATION OF THE PROJECT (CURRICULAR COMPETENCIES):

Step 1: Demonstrate and Model

Show the students a traditional ticker timer or a video of how they were (can be) used to record data of motion and acceleration.

Questions to spark curiosity:

How do you think the electrical circuitry inside the ticker timer works to make the dots on the ticker tape? How does the pattern of dots on the paper strip represent movement? How does knowing the frequency of the buzzer help finds the velocity of the moving object?

Step 2: Predict and define

Brainstorm with students to determine how they think a machine that emits ultrasonic pulses might be able to determine the velocity or acceleration of an object in a similar way to a ticker timer. See if you can get them to come up with the idea that the pulses should happen at a regular frequency and that the machine needs a sensor to receive and record the return of the ultrasonic pulses. Show them a video on how radar guns work or how bats and orcas sense the environment around them using echolocation.

Questions to help clarify:

How do bats and whales use echolocation to “see”? Do you think they can sense if an object is moving towards or away from them? How does what they “hear” change depending on the movement of the object? What might the frequency of “ultrasonic” pulses be?

Step 3: Plan and Conduct

Play students the video tutorial of building the ultrasonic sensor or demonstrate how to build their own ultrasonic sensors, using an Arduino.

Assist them with their builds and help them test a few objects as they learn how their sensors work.

Any classic ticker timer experimental set-ups can be adapted for use with the ultrasonic sensor – see the “suggested assessment” section for ideas on how to get students experimenting with their machines and recording data to analyze.

Questions to help refine the experiment:

What parts of this process will be a new experience for you? What different objects are you curious to know the velocity and acceleration of while they are falling? If you want to know “g”, the acceleration due to gravity, what kind of object do you think might give the best or most accurate data, and why?

Step 4: Analyze and Solve

Display an example excel spreadsheet showing data from one of the sensors and walk the students through how to read it. Point out the headings and the different types of data, and the shape of the height vs time graph. Keep in mind that the "height" in this case is the "distance away from the sensor", so if the sensor is facing downward, then the actual height of the object is decreasing as it falls toward the floor.

Questions for analyzing:

What units are the "x" and "y" values measured in? Does the equation give to remind you of any other types of equations you've seen in math 11 yet? Does the equation give to remind you of any formula you've seen in physics 11 yet? What shape does the graph have? What does a height vs time graph look like for an object at constant motion? For an object that has acceleration in a positive direction. A negative direction?

Step 5: Evaluate and Reflect

Encourage students to reflect on the process of building and using their sensors. You may choose to have them complete a journal of the process, including explaining how they overcame difficulties in building, coding, and using their sensors, as well as interpreting the data.

Questions to encourage reflection:

What did you find was the most challenging part of this project? Can you think of some practical uses for your ultrasonic sensor? What do you need to know about the nature of sound to understand how the sensor works?

Step 6: Communicating

Students could film a video of using an ultrasonic sensor and demonstrate their ideas of its practical uses. Keep in mind that grade 6s learn about Newton's laws and gravity and that your students might enjoy showing off their sensors and explaining to younger students how acceleration works.

Questions to consider:

Could you use your sensor to help dispel any misconceptions about how objects fall? How can you use what you know about your sensor to help explain to someone how a radar gun works? Could you design an interface for your sensor that would give a real-time read-out of velocity?

SUGGESTED ASSESSMENT STRATEGIES (STRUCTURE TO DESIGN ASSIGNMENTS)

Applications of statistics

Have students repeat the testing of the same falling object enough times to achieve significant data for statistical analysis. Teach them how to find acceleration from their data:

The excel equation given for each graphical analysis will be in the format $y=mx^2 + bx + c$. Keep in mind that this is a position vs time graph. In this case, they value gives the object's position (distance from the sensor) "x", and the x-value is time "t", which matches the motion formula $x= 1/2at^2 + v(initial) + x(initial)$. The excel sheet gives them the "m" value, which is equal to 1/2a, and from there, they can multiply each "m" value by 2 to find their acceleration for each data set).

Have students use the data from several tests to calculate central tendency, then their z-scores and confidence intervals. Does your data show a normal distribution? If acceleration due to gravity is constant, what are some things that could account for a discrepancy between values? What minimum and maximum value of acceleration could you give for a guess as to how fast an unknown object will accelerate while falling, given that you want to be 95% sure of your answer?

Remind them that if they are trying to find the acceleration due to gravity, "g", and are confused because "g" is negative, but their data is showing a positive acceleration, that their sensor is facing downward, so the data given for "x" is showing positive acceleration AWAY from the sensor.

PHYS 11 - Graphical methods in physics
PHYS 11 - Horizontal uniform and accelerated motion

Utilize the students' ultrasonic sensors to perform classic "ticker timer"-style experiments about motion and acceleration. You could design investigations for students to explore some of the following:

- Uniform motion – Have students orient their sensors horizontally and test the speed of toy cars or balls or other objects rolling across a table. Get them to predict which objects will roll the fastest or get them to each build a small car to race against each other to see whose is fastest (then analyze why). Dig out the air track from the prep room and let students measure and play with low-friction horizontal motion.

- Acceleration due to gravity (g) - Challenge the students to find an object that accelerates most closely to –9.8m/s^2. Have them brainstorm which objects they could test, then order them in what they predict to be "slowest to fastest to accelerate" objects, and then test their hypotheses (Use the Scientific Method Resource to get them to design an experiment around their sensor). Have them print and hand in their graphs for each object, complete with calculations to find acceleration (see "applications of statistics" section above for calculation example).

- Ask them why objects fall at different rates if "g" is constant for all objects. Assess whether a heavy weight falls faster than a lighter one – help students design a hypothesis and scientific experiment based on this query. Assess the data after two test runs, one with a 5-gram weight and one with a 20-gram weight, for example. Calculate acceleration and compare between weights. What might account for any difference in acceleration between the two objects?

NEWTON'S LAWS OF MOTION AND FREE-BODY DIAGRAMS
CONTACT FORCES AND THE FACTORS THAT AFFECT MAGNITUDE AND DIRECTION
MASS, THE FORCE OF GRAVITY, AND APPARENT WEIGHT
BALANCED AND UNBALANCED FORCES IN SYSTEMS

As part of the graphical analysis, the students can draw free-body diagrams for their objects at different moments in time across their graphs. When the height is 0, the object is momentarily still at the top of the fall. Consider such forces as gravity, air resistance, etc. Repeat for "uniform" motion of a toy car being pushed across a desk, or a cart along an air track, to include forces like normal force, friction, etc.

What type of motion indicates that the forces are balanced, and where does this occur in each of your test runs? What type of motion indicates that forces are unbalanced, where this occurs, and which force is more significant? How do these forces affect the direction and velocity of the object?

PROPERTIES AND BEHAVIOURS OF WAVES

Have students research the speed of sound/ultrasonic waves in different materials or media. If you could waterproof your sensor, do you think it would work the same underwater as it does in the air? Do you think you would get better data to determine "g" if you could operate your ultrasonic machine in a vacuum? Why or why not? Do you think your sensor accounts for the Doppler shift? Why or why not?

GENERATION AND PROPAGATION OF WAVES

Scale models

Students draw a to-scale diagram of their sensor in the centre of a large piece of paper and determine (by researching about their sensor) what frequency of sound their ultrasonic sensor is making. Have students use a compass to draw the sound waves emanating from the sensor at the appropriate distance apart (i.e., an ultrasonic pulse of 40 000 Hz has a wavelength of 0.858cm) and label the distance between them as "wavelength." You could also have them label these lines as "maximum compression." and then use a different colour to draw concentric arcs between these and label them as "maximum rarefaction" to help them visualize the longitudinal propagation of sound pressure waves.

FOM 11 - Graphical Analysis: Quadratic functions

Have students measure the acceleration and deceleration of a toy car on a horizontal surface or have them gently lob an object up vertically toward the sensor to read the motion of the object until it falls and is caught again. Is the resulting graph showing a quadratic function? How do you know? What are the “a, b and c” values?

See Suggested Assessment Strategies of “Solenoid Launcher” project for detailed quadratic function analysis suggestions.

SCIENCE CHALLENGE OPPORTUNITY

Which group or individual can make a 5-gram weight fall with the LOWEST value of acceleration that they can? Provide the groups with the same initial starting materials, for example, 1 sheet of newsprint, 1m of masking tape, 3m of thread, 5 paperclips, etc... Quantify the data using ultrasonic sensors to find the results.

TAKE IT FURTHER!

- **Make a tool out of your ultrasonic sensor to solve a problem or answer a question about your daily life. I.e., How fast does a slug move? How much does the helicopter motion of a maple seed slow its descent?**

- **Now that you know a bit about how an ultrasonic sensor works, can you use what you know about the Doppler Effect to make your velocity sensor using sound waves within the human sensing range? Where would you put the noise-making component? Where would you put the noise-receiving component? What would you want to measure (and in what units), and how could you derive velocity from the data?**

ELECTRIC ACCELERATION

skills READY

ELECTRIC ACCELERATION

INSPIRATION

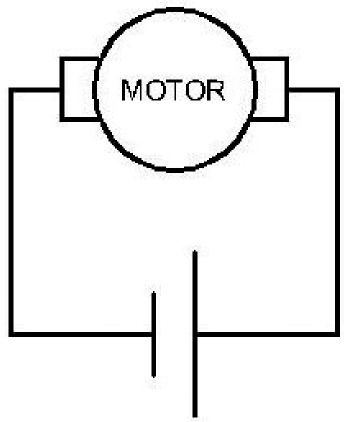
Electricity can be used to transport humans and objects and materials all over! It can be used to power electric cars, to energize electromagnetic tracks for maglev trains, and even to fly planes. Can you design an electrical system to accelerate a toy car? What variables affect acceleration and velocity? How can you measure the rate at which a toy car speeds up?

OBJECTIVE

Students will explore the options of using electricity to accelerate a toy car, design and build an accelerator, then quantify and describe the horizontal motion of their car using mathematical language.

TRADES CONNECTION(S)

The classic acceleration gauge of "0 to 60" miles per hour is a benchmark for automobile and engine developers competing against each other for the top place in car design. The initial acceleration achievable with electric engines is superior to what internal combustion engines can produce, with the added benefit of lower emissions.



SAFETY FIRST

Ensure that you only test your accelerator when there is no danger of hurting or damaging anything or anyone by an accelerated toy car.

VOCABULARY

Review the definitions with students at the beginning of the lesson and ensure that students have access to the glossary resource provided with this activity. Utilize these words often during the lessons to model how and where to use them.

- Velocity
- Accelerate / acceleration
- Quantify
- Friction
- Applied force
- Normal force

MATERIALS

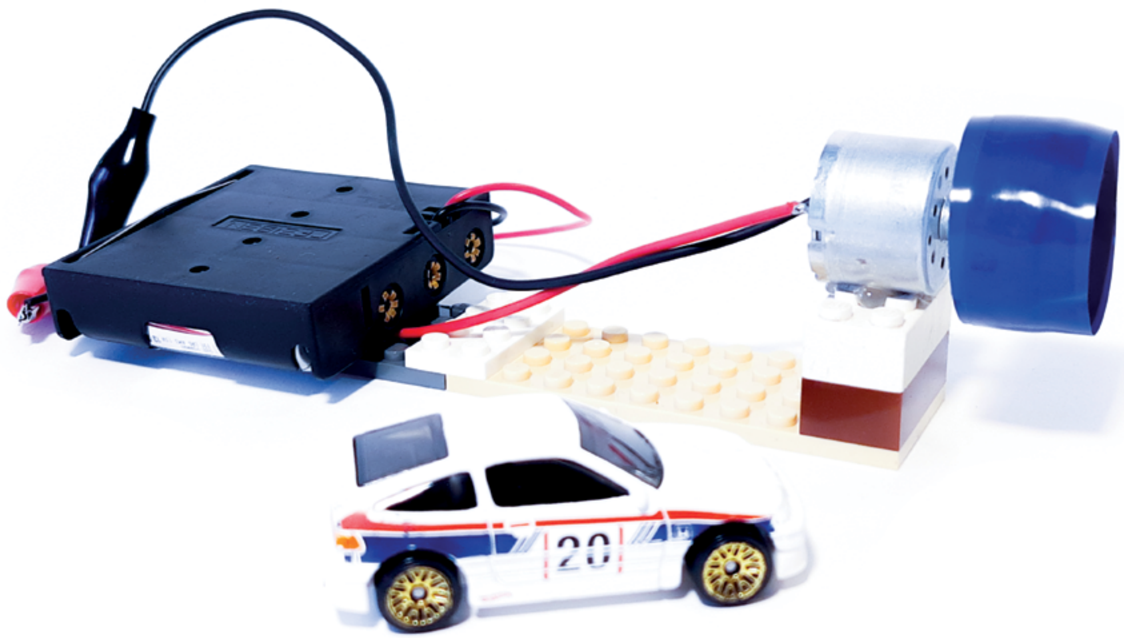
- Toy car (1 or more)
- Plastic pop bottle cap, or similar
- A small strip of thick fabric felt, or similar
- Hobby motor (6~V) with lead wires (and alligator clips)
- 4xAA battery holder
- 4 AA batteries
- Found materials to make a base for hobby motor (i.e., snap blocks, cardboard, etc.)
- **Optional:** switch

TOOLS

- Small nail or awl
- Hot glue gun and glue sticks
- 2 x meter sticks (or one-meter stick and one straight edge of similar length)
- Electrical tape
- **Optional:** variable DC power supply
- **Optional:** wood working tools to make a base, i.e., saw, drill, hammer, etc.

PROCEDURE TO BUILD

1. Make a tiny hole in the center of the pop bottle lid with a nail or awl.
2. Drop a bead of hot glue on the tip of the hobby motor axle, then push the pop bottle cap over it so that the open part of the cap is facing AWAY from the motor case. Make sure not to glue the axle to the motor case. Apply more glue inside the cap to secure it to the axle.
3. Hot glue a strip of felt around the perimeter of the cap, then cover it with a few layers of electrical tape.
4. Hot glue your motor onto a solid block or base, ensuring that the pop bottle cap sticks out and can spin freely.
5. Build up the base for your hobby motor, testing the height of it with your toy car. You want the pop bottle lid edge to spin about 1mm lower than the height of your toy car, so you can squeeze the car underneath to be accelerated.
6. Place your meter sticks side by side along a smooth surface, making sure there is enough space between them for your toy car to freewheel.
7. Insert the batteries into the battery holder. If your motor leads have alligator clips attached, clip the red wire to the red wire and black to black. If you are using a switch, wire this in between one of the battery **holders'** wires and the hobby motor wire.
8. Turn the motor off and position it at "0 cm" on the meter stick. Turn your motor on and play with pushing your car under the cap to send it racing along the meter stick track. If necessary, you can reverse the motor leads to make your motor turn spin in the opposite direction.



GUIDED EXPLORATION OF THE PROJECT (CURRICULAR COMPETENCIES):

Step 1: Demonstrate and Model

Bring many toy cars to class (or have students build their own small toy cars!). Brainstorm different ways they can think of to use electricity to accelerate their toy car (encourage them to come up with as many contraptions as they can think of that might push or fling their car. Show students some videos of toy car accelerators online, and then go through the above procedure for building the accelerator project.

Questions to spark curiosity:

What are some different vehicles you know of that accelerate using electricity only? Can you think of any electric tools, kitchen appliances, etc., that you could use to accelerate a toy car? What is the difference between velocity and acceleration? What are some ways you could quantify the velocity of the toy car? Is there a way to quantify the acceleration of the toy car?

Step 2: Predict and define

Brainstorm as a class or in pairs to think about which variables in the system could be altered to maximize the velocity of the toy cars (ex, electrical variables such as voltage and current. And others are like such as the placement and orientation of the electric motor, shape and size of the toy car, wheel and axle size, track material, etc.). Remind them that this experiment is to study horizontal motion, so the car must stay on a flat surface for its entire run.

Students could make their cars for use in the experiment. Otherwise, they can choose a toy car to use for their testing.

Use the Scientific Method Resource to help students turn their prototyping into a scientific experiment: tell them that first they will build the standard accelerator described in the procedure and run several tests to quantify the motion of their car, and then choose ONE variable to adjust (which may involve a re-build) to see if/how it affects acceleration and velocity.

Questions to help clarify:

How fast (in m/s) do you predict a toy car could be moving by the time it gets to the end of the track? What variables do you think might affect the velocity and acceleration of the car? Do you think you will observe the acceleration of your car? If so, which part of the track and in what direction will you observe acceleration? If you measure the velocity of two different toy cars to be 1 m/s when they reach the end of the track, does this mean that they also shared a similar velocity value at the beginning of the track? (And can you explain or justify your answer by demonstrating with the toy cars and using mathematical vocabulary?)

Step 3: Plan and Conduct

Students make their electric accelerators according to the procedure. Students test and video (or use the ultrasonic sensor) their setups at the track as they finish their builds. You may choose to have them perform several tests so they can apply statistical analysis to their data.

Questions to help refine the experiment:

What variables need to stay the same for all the tests, and how will you ensure they stay constant? Do you think it is important to test run your car more than once? What are some reasons why you might find you measure a different velocity and acceleration from one test to another (despite controlling all the variables you can for each test?). How will you indicate which test run you are filming each time so that you can see during the analyzing stage which test run you are watching? Which procedureal steps are imported essential in the correct order? does this make sense?

Step 4: Analyze and Solve

Students analyze their ultrasonic sensor data, or alternately, their video footage using a software editing program. If using video footage, determine the frequency of each frame or still shot of the video, and read the displacement of the front of the car by looking at a meterstick alongside – from this, you can determine the displacement (and from that, the velocity and acceleration) of the car at several points along the track. (See sample data table in the “suggested assessments” section)

Questions for analyzing:

Why might it be important to have several different tests to analyze? What would it mean if you calculated your acceleration rate to be a negative number?

Step 5: Evaluate and Reflect

Facilitate a class discussion about any difficulties they overcame during the design, build, and analysis steps. As a class, theorize a new, even faster design incorporating adaptations suggested by each groups' results.

Questions to encourage reflection:

Were there any variables that you could not easily control for in this experiment? Why might other groups get different values for velocity than you did? If you wanted to make your car accelerate faster next time, what variable would you change and why? Could you, as a group, take what you've all independently learned and design an accelerator that propels toy cars even faster than any already built in the classroom?

Step 6: Communicating

Students share their results with the class. You could have them give a short presentation explaining their graph to their peers and then explaining three variables they would like to test further that they think would increase the velocity and acceleration of their car.

You could also invite an elementary school class to come and view (or play with!) the accelerators (Science 4s learn about devices that transform energy, science 6s learn about Newton's laws of motion, etc.)

Questions to consider:

What is the value of sharing your results with your classmates? Were there any suggestions or ideas that your classmates came up with for making their car go faster that you hadn't thought of? Can you think of any practical applications for your acceleration setup? How could you explain how your accelerator works to a younger student?

SUGGESTED ASSESSMENT STRATEGIES (STRUCTURE TO DESIGN ASSIGNMENTS)

PHYS 11 - Horizontal uniform and accelerated motion
PHYS 11 - Graphical methods in physics

1) If using the ultrasonic sensors, students could analyze the data from their graphs to study acceleration and associated equations (i.e., is this a quadratic function? Part of a quadratic function? How do you know?).

2) If using video recording, students could fill out the following data table while analyzing their video (use the "frames per second" feature of the recording to calculate the time between frames – usually 24 frames per second, so 0.042 seconds between each frame).

Frame or time	Distance from 0 (m)	Displacement (m) (relative to previous frame)	Velocity (m/s) (displacement divided by time)
First frame	0		
Second frame	0.21	0.21-0= 0.21	0.21 / 0.042 = 5
Third frame	0.45	0.45-0.21= 0.24	0.24 / 0.042 = 5.7

2) You could have the students draw up and analyze the shape of a Distance vs Time graph (slope gives you velocity of the car). Is the graph shape linear? Curved? What does this tell you about the car's motion?

3) Next, they could draw up and analyze the shape of their Velocity vs Time graph. Explore how the slope indicates the acceleration of the car and describe what is happening to the car during each stage of the graph (positive slope means acceleration, negative slope means deceleration, 0 slope means constant velocity). At what time is acceleration greatest? Is acceleration ever 0?

4) Students can calculate the slope (acceleration) at points along with their velocity vs time graph. Take two arbitrary x values (x1 and x2) that are close together along their timeline (i.e., 0.5s and 0.6s) and calculate the (velocity) of each (y1 and y2). Next, plug the values they found into the following formula and calculate acceleration:

m= change in y / change in x

m = y2-y1 / x2-x1

Students can then use this method to calculate the maximum acceleration of their system (do students expect it will be positive or negative?). Compare the acceleration values that each group calculated and discuss reasons why some cars and groups had different values. (Note: this could be acceleration OR deceleration, and you may choose to discuss the difference with the class at this point).

FOM 11 - Scale models

Students use rulers and grid paper to draw a scale model of their "new and improved" accelerator design and/or toy car track setup, including a scale or ratio for reference. You may choose to add energy labels to indicate the different types of energy observed and the energy transformations.

FOM 11 - Application of statistics

Students can calculate central tendency for their velocity/maximum acceleration results at any or all the values of the independent variables. They could also utilize the entire class's acceleration results (from the control data of the original build before changing any variables) to calculate the average acceleration of the cars, and then find the z-scores and standard deviation and establish confidence intervals. "If someone wants to make a car accelerator by using the procedure for this lesson, and you were going to try to predict what the acceleration of the car would be, what would be the upper and lower values of acceleration you would guess if you wanted to be 90% sure you'd be correct?" Why might the z-scores and standard deviation be different for your data vs using the data from the entire class?

PHYS 11 -Contact forces and the factors that affect magnitude and direction
PHYS 11 - Newton's laws of motion and free-body diagrams
PHYS 11 - Balanced and unbalanced forces in systems

Students can measure the mass of their toy car using a spring scale and draw free-body diagrams (or print still shots of the video) of the car at 3 different points along the track: at time 0, at the peak velocity, and the car as it comes to rest. Label all forces: normal force, frictional force, applied force, gravity force, air resistance force. For each drawing, describe what is happening regarding motion (uniform? accelerating? decelerating?) and discuss how unbalanced forces can help explain the car's motion.

PHYS 11 - Vector and scalar quantities

You may choose to have students draw velocity vectors for the car's instantaneous velocity at different points along a track or force vector diagrams describing the motion of the car. Students could change the grade or steepness of their car tracks, make the cars run uphill or downhill or along a varied track, and analyze when (and why) the car is accelerating, decelerating, or moving at a constant velocity.

PHYS 11 - Simple machines and mechanical advantage

Students could calculate the ideal mechanical advantage of the toy car wheels and the hub on the electric motor in their accelerator.

Financial literacy: compound interest, investments, and loans

Students imagine they are putting their “toy car accelerator and track” into production as a toy or a science lab demonstration device. Have them list each material and cost individually and tally up the total cost to make 500 items. As a class, you could have a brainstorm to come up with the overhead costs they can think of, such as rent at a production facility, wages necessary for assembly, power and utility costs for a month, etc. From this information, students can calculate what they would have to sell each toy to make a profit. You could also use these details to estimate a business loan amount they would need and show them how compound interest would affect their loan amount and how long it would take to pay the amount back.

Further to this, students could do some “market research” in an elementary school classroom to see how their accelerators hold up to use by younger children and how universal their designs are for accelerating different brands and toy car dimensions. Your students could take notes and redesign their prototypes according to the new information.

SCIENCE CHALLENGE OPPORTUNITY

• As a team, designing a multi-section car track that uses electric accelerators to move one single car the entire length of a school hall. Each group or student designs a section of track with an accelerator that sends the toy car back up to speed after it slows down from the previous run. Write a bunch of “track challenges” on small bits of paper that each group pulls out of a hat and must design their section too, such as “loop-de-loop,” “jump - no wheels touching!”, “car passing starts a sound effect,” “car passing causes lights to come on,” etc. You could even challenge the students further by requiring that everything they use to build their track must be a found material, or from a recycling bin, etc.

TAKE IT FURTHER!

1. Write a paragraph or make a poster outlining a real-life application of this type of propulsion system in their community (i.e., in place of the T-bar at the local ski hill). Next, address three safety concerns that would need to be considered in the design of this machine. Finally, students predict and address potential community concerns over whether their invention is environmentally “friendly”, sustainable or not.

2. Redesign the accelerator to incorporate two hobby motors to increase the acceleration on the toy cars.

3. Design and build an automatic launching device that pushes the car through the accelerator.

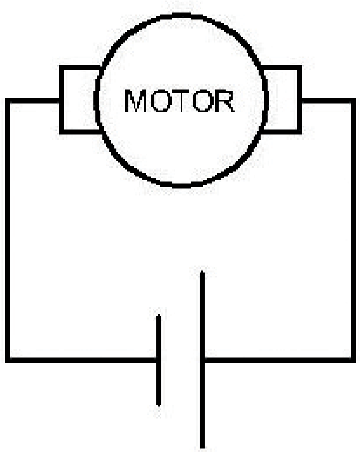
WINCH
ROLLER COASTER

skills READY

WINCH ROLLER COASTER

INSPIRATION

Roller coasters provide a playful way to visualize the motors' power, work, and efficiency that raise the cars to the top of the first hill. The energy transformations are relatively easy to track and quantify if the mass of the roller coaster car is known and the height it is raised to. What energy transformations can we identify happening in a roller coaster? Can we build a mechanism utilizing a small motor to lift a ball bearing and send it on an adventure along a homemade roller coaster track? How much electrical energy does it take to lift the ball bearing 1m high? Can we make it easier for the motor to do the lifting?



OBJECTIVE

Students will independently (or in pairs) design and build a roller coaster unit consisting of a gear motor winch that lifts a ball bearing to a height of about 1m and a track that the ball rolls down to the starting height. To add a collaborative element, students' roller coaster units can all be connected "in series," where the track from one system deposits the ball bearing to the winch component of the neighbouring student's unit, etc., sending the ball bearing all over the classroom. Students will then explore their winch mechanism's power, work, and efficiency through multimeter measurements or Arduino analysis.

TRADES CONNECTION - TOOLS

Cranes on construction sites need to lift extremely heavy loads safely and efficiently. A lifting plan is drawn up before an oversized load is moved and includes calculating the volume and mass of the load and determining the proper chains, slings, shackles, and anchor points needed to lift it safely. Solid working knowledge of forces and simple machines such as levers and pulleys is also essential to learning how to operate a crane.

SAFETY FIRST

The motor can heat up if it is overused. Make sure not to overload the motor with heavy weights and to only run it for as long as it takes to lift the ball bearing to the desired height. Tie your hair back and avoid loose clothing that can get caught in moving parts. Make sure to use electrical tape on connections to prevent short circuits.

VOCABULARY

Review the definitions with students at the beginning of the lesson and ensure that students have access to the glossary resource provided with this activity. Utilize these words often during the lessons to model how and where to use them.

- Gear motor
- Efficiency
- Work
(measured in Joules or Newton-meters)
- Power
(measured in Watts, or one Joule per second)
- Gravitational potential energy
- Kinetic energy

MATERIALS

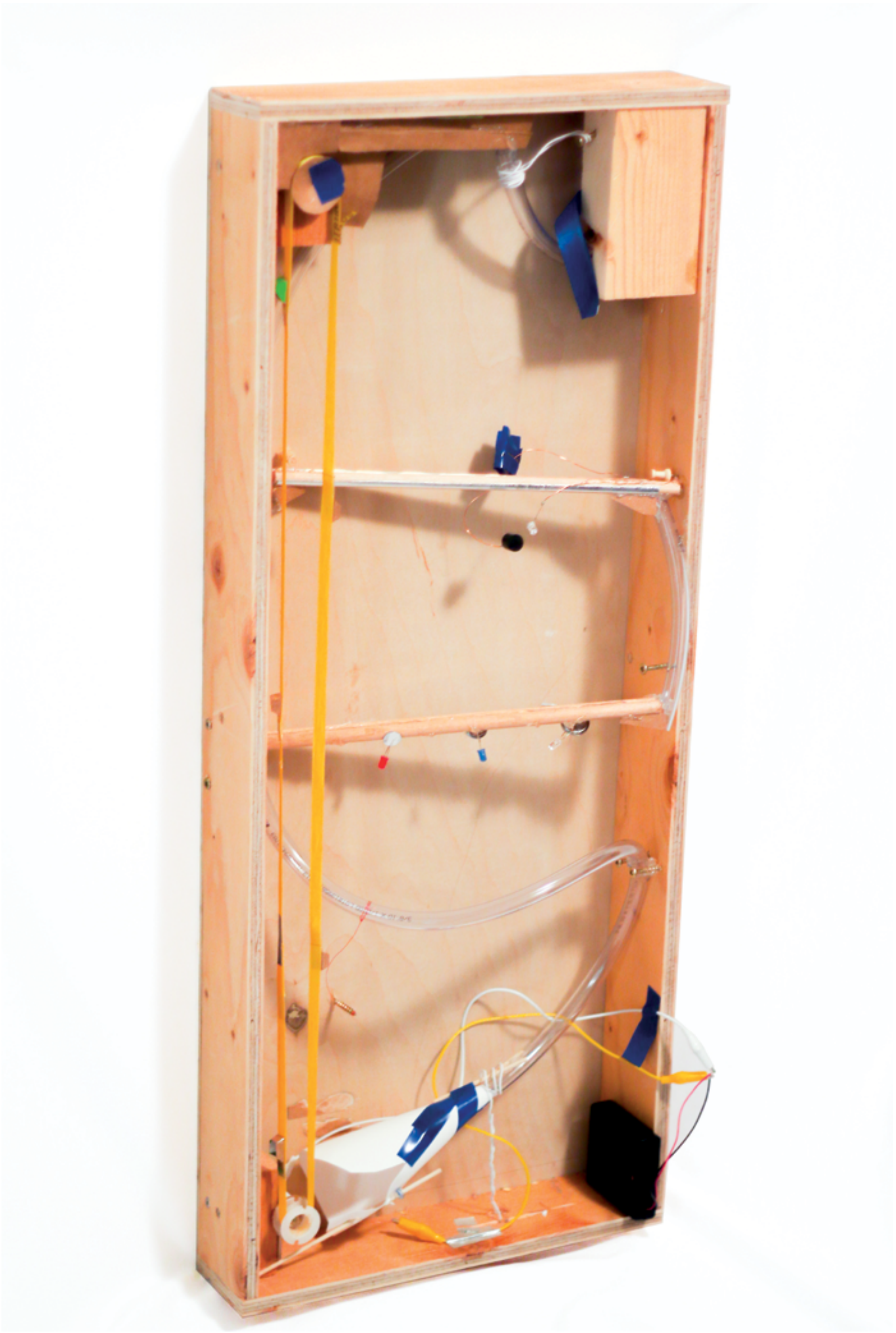
- Steel ball bearings: any size, (¼" used in example) approx. 5 per group
- Gear motor (6V, ~30 RPM)
- **Optional:** Gear motor bracket (matching size to your motor)
- Doorskin or thin plywood, ~4"x4."
- Large pieces of scrap wood and plywood for building support structure (~up to 4' long)
- Plastic lids, caps, spools, small found cylindrical objects for hubs
- Corrugated cardboard (approx. 1 box or more)
- Ribbon or string (~2m)
- 4 x AA batteries (or whatever batteries needed to power gear motor)
- AA battery holder (4-cell) #3905 (with switch)
- Assorted connecting wires with alligator clips
- Magnet wire (~32AWG) 1m
- Clear tape
- Various glue (wood glue, super glue, hot glue sticks, etc.)
- Various fasteners (nails, screws, etc.)
- **Optional:** solder
- Various found objects: plastic, wood, plywood, cardboard, dowels, metal, etc. bits to build the structure, track, and winch assembly
- **Optional:** assorted LEDs, coin batteries, resistors, magnet wire, active buzzers, etc., to embellish roller coaster run

- **The following materials are optional if you choose to use an Arduino to analyze the power output of the gear motor:**

- Potentiometer (# 3386F-1-103TLF)
- LED (# SLR-56VR3F)
- Transistor – NPN (# 2N3904)
- Capacitor – 1mF (# ECA-0JHG102)
- Resistor – 100ohm 1/8 watt (# CFM18JT100R)
- Resistor – 1ohm 1 watt (# FMP100JR-52-1R)
- Breadboard Jumper Wire Kit (# WK-2)
- 10x 300mm M-M Jumper wires (# BC-32670)
- 20x 6" M-M Jumper wires (# PRT-12795)
- Breadboard (# BB-32656)
- Arduino Uno (# A000066)

TOOLS

- Wire strippers and cutters
- Hammer or drill, depending on your fasteners of choice
- Wood saw (or access to a shop setting)
- Scissors
- Electrical tape
- Utility knife
- Hot glue gun and glue sticks
- Compass or found round objects
- Scale
- Multimeter
- Meterstick
- Ruler
- Sandpaper
- **Optional:** soldering iron
- **Optional for Arduino analysis:**
    - Desktop or laptop with internet and spreadsheet capabilities



PROCEDURE TO BUILD

Making the Winch

Decide what kind of lifting winch system you want to use (or come up with your own!). Two options might include: a pulley that lifts one ball bearing at a time or a rotating escalator system:

To make the escalator system:

1. Make or find a solid frame to build the system on, such as a large piece of wood or crate. Secure the gear motor to the top of the crate using glue or the motor bracket, making sure the shaft is set proud of the edge.
2. Glue a hub to the gear motor shaft, such as a bottle cap or empty spool.
3. Secure another hub to a nail or screw at the bottom of the crate directly below the gear motor. Ensure it spins freely and stably (not wobbling or pulling quickly out of the plane).
4. Lay a strip of hot glue in the middle of each hub and let cool (to create grip).
5. Imagine a loop of ribbon running between the two hubs how a bike chain connects the bike gears: run a strip of ribbon around both hubs and use electrical tape to secure it into a loop, keeping tension on the ribbon.
6. Wire up your gear motor to the battery holder (using the connecting wires with alligator clips or soldering to magnet wire extenders), insert the batteries and test your system.
7. Design a small attachment to affix to the ribbon that scoops up a ball bearing and then releases it at the top.
8. You may need to include a guiding system that helps the ribbon track properly.

To make the pulley system:

1. Use a compass (or found round objects) to draw 3 circles on corrugated cardboard, dimensions of your choice (e.g., 2 at 5” diameter, and 1 at 3” diameter). Cut them out.
2. Poke a small hole in the middle of each of the three disks, then glue them together with the small piece sandwiched between the larger ones.
3. Enlarge the center hole, if needed, and glue your pulley to the gear motor shaft.
4. Poke another small hole in the side of one of the larger disks and tie on a piece of string, so it lays close to the middle disk.
5. Secure the gear motor to a piece of door skin or plywood, which can then be fixed to a solid object at whatever height you need.
6. Design a small attachment for the string that can scoop up a ball bearing and release it at the top.
7. Wire up your gear motor to the battery holder (using the connecting wires or by soldering to magnet wire extenders), insert the batteries and test your system.

two larger and one smaller dimension of your choice (e.g., two 5” diameter and one 3”)

Making the Track:

Let students’ creativity dictate what the track for the ball bearing roller coaster looks like and is made of and the attachment on the gear motor winch assembly that lifts the ball bearing up approximately 1m. Spherical objects roll well down V-shaped tracks; get them to help you brainstorm a materials list and let them have fun with it! As steel ball bearings are conductive, students can design and incorporate small electrical components along the track, such as lighting up LEDs or buzzers, etc., as the ball rolls past.

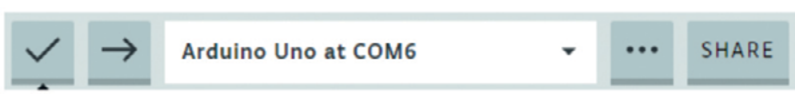
To make a simple LED circuit that lights as the ball passes:

1. Cut and strip two 2” pieces of thin wire.
2. Solder or tape the end of one wire to the LED cathode (short leg).
3. With a small square of tape, secure one end of the OTHER piece of wire to the negative side of a coin battery (3V). NOTE: do not use solder on the battery itself.

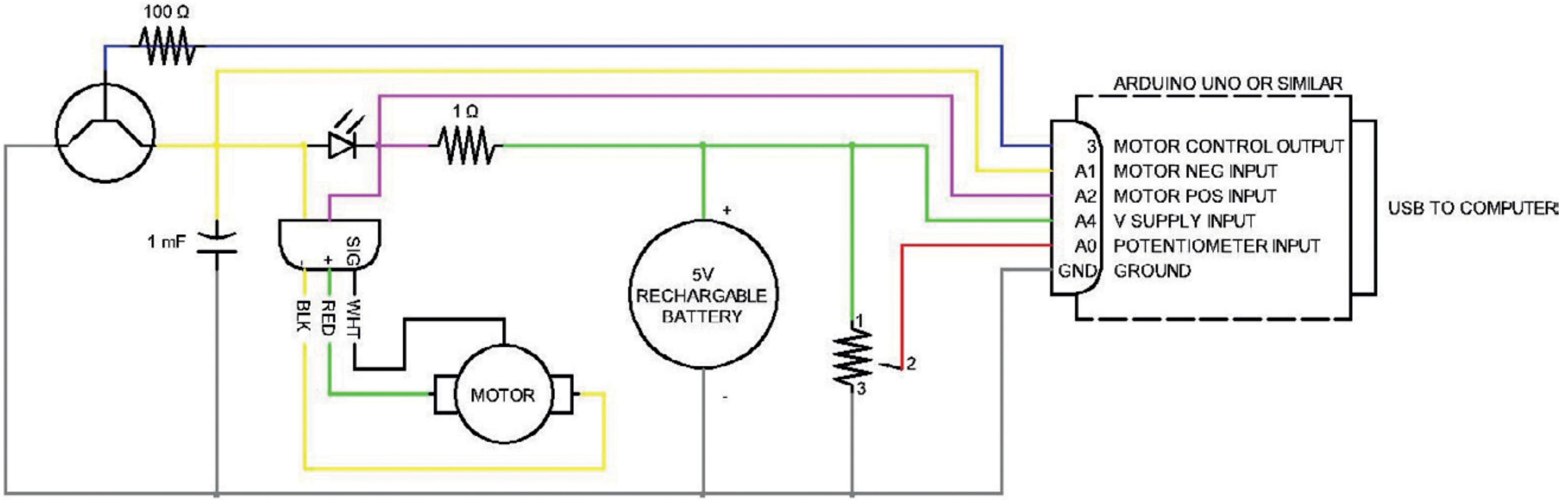
4. With another piece of tape, secure the LED anode (long leg) to the positive side of the coin battery. Connect the two wire pieces to test your circuit.
5. Hot glue the two wires along your track so that when the ball bearing rolls past (and under the LED), it connects the two wires and completes the circuit. See the videos section for a visual description.
6. Inspect your circuit to make sure a short circuit is not possible, as wires can accidentally rest on both terminals of the battery.

OPTIONAL: ELECTRICAL AND ARDUINO SETUP PROCEDURE

1. Wire up the circuit as shown in the schematic.
2. Go to Arduino Create: **https://create.arduino.cc/**
3. Click on "Web Editor" from the top right 9-squares icon. You need to make a login and agree to the privacy policy.
4. If this is the first time you are using the Arduino with your computer, you will need to download the web editor plug-in ("Arduino Create Agent") by finishing the "Getting Started" process at: **https://create.arduino.cc/getting-started/plugin/welcom**e
5. Download the **9_Arduino_Code.in** file from the online resources associated with this lesson. Go back to Arduino Create web editor "sketchbook" page from step 2, click the import button image.png, and import the .into file you just downloaded.
6. Plugin your Arduino into the computer with the USB cable.
7. The Arduino should appear on your screen and look like this:



8. Click the arrow that points to the right; this will send your code to the Arduino. It will save it inside and start running the code. You only have to do this once each time you change the code.
9. Go back to Arduino Create web editor and click "Monitor" on the left side of the screen. You should see numbers flying down the screen. To start a test, connect the battery to the winch. To stop the test, unplug the Arduino.
10. Copy the test data you want from the monitor (Ctrl+C, Ctrl+V) into the raw data column of the **9_Data_Plotting.xlsx** file, which you can download from the online resources section of this lesson. The program will plot your motor current, voltage, and power for you.
11. Turn the potentiometer clockwise to make the motor turn faster or to adjust speed as needed.


100 Ω
1 Ω
1 mF
SIG
WHT
RED
BLK
MOTOR
5V
RECHARGABLE
BATTERY
ARDUINO UNO OR SIMILAR
3 MOTOR CONTROL OUTPUT
A1 MOTOR NEG INPUT
A2 MOTOR POS INPUT
A4 V SUPPLY INPUT
A0 POTENTIOMETER INPUT
GND GROUND
USB TO COMPUTER

GUIDED EXPLORATION OF THE PROJECT (CURRICULAR COMPETENCIES):

Step 1: Demonstrate and Model

Ask students about their experiences on roller coasters. Have any of them been on an old-fashioned roller coaster ride or one that uses power only on the first uphill? Lead a class discussion on how roller coasters work or give them a 5-minute research window before sharing their findings with the class and show them a video on the physics of roller coasters (better yet, take them on a field trip to the local amusement park!).

Introduce the idea of a ball bearing or marble roller coaster system around the classroom: each student or group creates a mini roller coaster for the ball: In the first part of their section, the ball is raised by a gear motor winch, and then it is deposited onto a roller coaster-like track to roll down, landing in the winch mechanism for the next group's section to begin.

Questions to spark curiosity:

Have you ever taken a ride on an old-fashioned roller coaster? What are some mechanisms that you think could pull or push a roller coaster on its first ascent up the big hill?

Step 2: Predict and define

The challenge for the class is to co-create a giant roller coaster system to move a ball bearing around the classroom. Each group's roller coaster consists of a gear motor winch system that raises the ball bearing to a height of approximately 1m. At this point, it rolls free and along a track or series of pathways until dropping at the start of the neighbouring group's winch system. Each group's section can connect to the next group's so that the ball bearing is constantly in motion. You may choose to give each group a limited floor area to work in, i.e., each group uses 1 cubic meter or one tabletop, or you may choose to challenge them to move the ball bearing all the way around the classroom wall perimeter, etc. Make it fun and encourage buy-in by getting student input on the challenge parameters.

Brainstorm as a class what kinds of materials would be useful to build the tracks. Decide as a group if they want to restrict the starting materials in any way: if they wish to let individual groups utilize any and every material they can get their hands on (Is buying new materials allowed? Will there be a budget limit?), or if they want each group to start with a standardized type and number of materials. They may also want to consider if they will allow the use of new materials or require that all materials be scavenged from waste or recycling bins, etc. This is a key place to discuss the physics 11 curricular competency of “assess risks and address ethical, cultural, and environmental issues associated with their proposed methods.”

Questions to help clarify:

What are some mechanisms you could attach to your winch to hold the ball bearing during the lift? How will the ball bearing be released and directed onto your track? How will you turn your gear motor on and off? Do you think your ball bearing might be moving fast enough to incorporate an upside-down loop section? What kinds of materials do you think you could use to guide the ball’s path?

Step 3: Plan and Conduct

Students amass the materials they need to make their roller coaster track sections. Have them sketch out prototype design ideas and run them past you before building. Encourage them to experiment and play with the gear motors to find the best setup for their purpose.

Questions to help refine the experiment:

Will you use your winch to pull your ball bearing straight up? Will you pull or push it up a ramp? Will you remove it or push it up a ramp? How might the track design of the groups before and after you affect the way you design your section of track? What information do you need to exchange with the group passing the ball bearing off to you? Does the group that gets the ball from your track need you to incorporate anything specific into the design of your section? Who will be responsible for designing and building the track where the ball is passed from one group to the next? How can you slow the ball bearing down to a stop for the next group?

Step 4: Analyze and Solve

Have students use multimeters or Arduinos to measure the current and voltage while their winch is operating. For efficiency calculations, they will be comparing the potential energy gained by the ball bearing to the electrical power used by the winch. They will need to measure the following: current, voltage, time of lift, the mass of ball bearing, and the height it is lifted. For statistical purposes, have them run and quantify several tests. See "suggested assessment strategies" below for calculation examples.

Questions for analyzing:

What formula (and what information) do you need to calculate how much potential energy the ball bearing gains when the motor lifts it at the beginning of your roller coaster section? Do you think that this potential energy is the exact amount of electrical energy that your motor uses to lift the ball? How can you compare the amounts of different energies if they are measured and calculated in different units? Can you measure how much energy your motor uses to lift the ball? If these two energy values are different, what could be going on?

Step 5: Evaluate and Reflect

Hold another class-wide discussion or brainstorm about the discrepancies they find between the potential energy gained by the ball bearing and the power their motor exerts. Encourage students to name (and diagram) all the energy transformations they observe and categorize them as either "intended" or "lost."

Questions to encourage reflection:

Where is energy "lost" in your systems? Can that type of energy ever be helpful? What are some ways you can utilize the power "wasted" by this system? What are some modifications you could make that you think might increase the efficiency of your system? Do you think that your motor is running at its most efficient speed or voltage?

Step 6: Communicating

Consider letting students choose from a list of methods of communicating their exploration and learning. Some students could (from the beginning) design and perform a scientific experiment using the Scientific Method Resource to explore variables that affect power. In contrast, others present their findings in a class presentation. Students could keep a journal or log of their design process from initial sketch ideas through to prototyping, testing and revising, noting any problems they face and the solutions that resolved them.

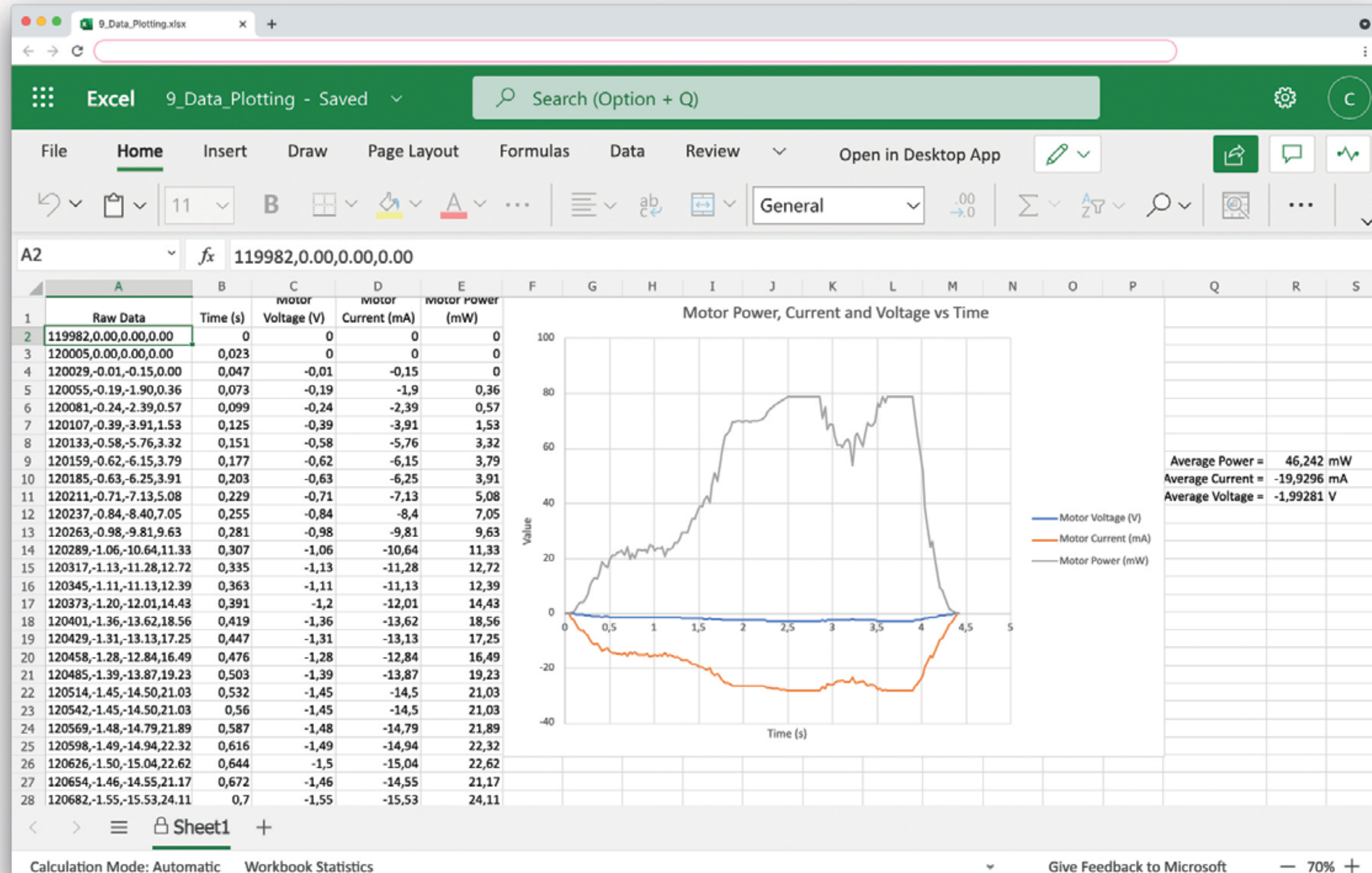
Questions to consider:

What aspects of what I experienced in this activity do I think other students might be interested in hearing about? Can the concepts I learned in this activity be relevant to other subjects I'm learning about? What are some other electric motors I use in my daily life? What is the efficiency of the motors used in the machines that are used in the metal shop? How might I quantify the efficiency of the kitchen appliances in the home economics classroom?

SUGGESTED ASSESSMENT STRATEGIES (STRUCTURE TO DESIGN ASSIGNMENTS)

PHYS 11 - Power and efficiency

PHYS 11 - Principle of work and energy



	A	B	C	D	E
1	Raw Data	Time (s)	Motor Voltage (V)	Motor Current (mA)	Motor Power (mW)
2	119982,0.00,0.00,0.00	0	0	0	0
3	120005,0.00,0.00,0.00	0,023	0	0	0
4	120029,-0.01,-0.15,0.00	0,047	-0,01	-0,15	0
5	120055,-0.19,-1.90,0.36	0,073	-0,19	-1,9	0,36
6	120081,-0.24,-2.39,0.57	0,099	-0,24	-2,39	0,57
7	120107,-0.39,-3.91,1.53	0,125	-0,39	-3,91	1,53
8	120133,-0.58,-5.76,3.32	0,151	-0,58	-5,76	3,32
9	120159,-0.62,-6.15,3.79	0,177	-0,62	-6,15	3,79
10	120185,-0.63,-6.25,3.91	0,203	-0,63	-6,25	3,91
11	120211,-0.71,-7.13,5.08	0,229	-0,71	-7,13	5,08
12	120237,-0.84,-8.40,7.05	0,255	-0,84	-8,4	7,05
13	120263,-0.98,-9.81,9.63	0,281	-0,98	-9,81	9,63
14	120289,-1.06,-10.64,11.33	0,307	-1,06	-10,64	11,33
15	120317,-1.13,-11.28,12.72	0,335	-1,13	-11,28	12,72
16	120345,-1.11,-11.13,12.39	0,363	-1,11	-11,13	12,39
17	120373,-1.20,-12.01,14.43	0,391	-1,2	-12,01	14,43
18	120401,-1.36,-13.62,18.56	0,419	-1,36	-13,62	18,56
19	120429,-1.31,-13.13,17.25	0,447	-1,31	-13,13	17,25
20	120458,-1.28,-12.84,16.49	0,476	-1,28	-12,84	16,49
21	120485,-1.39,-13.87,19.23	0,503	-1,39	-13,87	19,23
22	120514,-1.45,-14.50,21.03	0,532	-1,45	-14,5	21,03
23	120542,-1.45,-14.50,21.03	0,56	-1,45	-14,5	21,03
24	120569,-1.48,-14.79,21.89	0,587	-1,48	-14,79	21,89
25	120598,-1.49,-14.94,22.32	0,616	-1,49	-14,94	22,32
26	120626,-1.50,-15.04,22.62	0,644	-1,5	-15,04	22,62
27	120654,-1.46,-14.55,21.17	0,672	-1,46	-14,55	21,17
28	120682,-1.55,-15.53,24.11	0,7	-1,55	-15,53	24,11

Students can make simple calculations using multimeter measurements of the winch system or use an Arduino assessment of the gear motor.

They will need the following information:

1) Voltage (Volts) while the motor is pulling the weight (multimeter or Arduino readout)

2) Current (amps) while the motor is pulling the weight (multimeter or Arduino readout)

3) Time (seconds) it takes to lift the weight from 0m to height (stopwatch) (convert to hours for calculations)

4) m = mass (Kg) of marble or ball bearing (scale)

5) h = height (m) the marble is raised by the servo motor (meterstick)

Note: consider having students do several trials measuring each value to calculate an average for each with which to do the efficiency calculation.

Energy out = potential energy gained by marble (J)= mgh (in kg, m/s^2, and m)

Energy in = electrical work done (Wh)= power x time = current x voltage x time (in A, V, and hours) (students can also calculate the average power from the Arduino data read-out)

1Wh = 3600J

Efficiency = (energy out / energy in) x 100%

Efficiency Calculations for Winch System:
(from electrical energy IN to potential energy OUT)

$E_p = mgh$

$= (0.00105)\,(9.8)\,(0.735)$

$E_p = 0.0076J$

$m = 1.050g \times \dfrac{1kg}{1000g} = 0.001050kg$

$g = 9.8m/s^2 = 9.8\ N/kg$

$h = 73.5cm \times \dfrac{1m}{100cm} = 0.735m$

$E_{elec} = \text{Power} \cdot \text{time}$

$= V\,I\,t$

$= (6.08)\,(0.047)\,(0.01271)$

$= 0.0036Wh$

$V = 6.08V$

$I = 47mA \times \dfrac{1A}{1000mA} = 0.047A$

$t = 45.75s \times \dfrac{1hr}{3600s} = 0.01271h$

1 Wh = 3600J

$0.0036wh \times \dfrac{3600s}{1wh} =$ **$13J = E_{elec}$**

$\text{Efficiency} = \dfrac{E_{out}}{E_{in}} \times 100\% = \dfrac{E_p}{E_{elec}} \times 100\%$

$= \dfrac{0.0076J}{13J} \times 100\%$

Efficiency of winch System = 0.058%

Questions to ask: How can we compare these two energy values if they're in different units? What unit conversions need to happen? What are some reasons you think your efficiency calculation result might be less than 100%? What are the energy transformations you observe in this system? (i.e., electrical, kinetic, gravitational potential, sound, heat). What energy is considered "lost" in your system (i.e., left out of the efficiency calculation)? Can you think of any practical uses for this "waste" energy? How could you quantify or measure these lost energy amounts? Are there any ways to re-engineer the system to make it more efficient? Under what conditions do DC motors work at their highest efficiency?

FOM 11 - Applications of statistics

Students can look at data read-out from Arduino and calculate average voltage, current, and power.

Students could also (controlling the variables like the size of ball bearing, voltage, current, etc., in every scenario) test their winches a certain number of times (e.g., 15) and note down the time in seconds that it takes to lift the ball bearing to height. Using their data (and data from the entire class if you choose to have them raise all their ball bearings to the same height), they could calculate the average time. It takes to lift the ball bearing with a motor, then find the variance and standard deviation, and have them assess which times are outliers (why did these two tests take so long? Should they be included in the data? Why or why not?). From there, you can get them to graph their data and make a histogram and ask them questions about distributions (Do you think this data shows a normal distribution? Why or why not?). If the data shows a normal distribution, you can ask them questions about the z-values and confidence intervals (i.e., "if you want to make a guess as to how long it will take your motor to lift the ball bearing 1m, and you want to be 95% sure that your guess will be correct, what would be the slowest time you would guess, and the fastest time you would guess? Find the 95% confidence interval for the sample for the time it takes a gear motor to lift a ball bearing 1m").

FOM 11 - Scale models

Students draw a scale diagram of their gear motor system that raises the ball bearing and the track the ball runs down. You could have them draw plan views as well as from other perspectives.

PHYS 11 - Conservation of energy

Students make a sketch of their gear motor system and the track in its entirety. Have them label the diagram with every energy transformation they observe. (Reminder: the energy types are kinetic, light, sound, thermal, elastic, nuclear, chemical, magnetic, gravitational, electrical.) Have them discuss which energy forms are intended and which are "waste." Can they come up with any ways to reduce the waste energy? Is there any way to utilize the energy that is considered waste?

PHYS 11 - Balanced and unbalanced forces in systems
PHYS 11 - Newton's laws of motion and free-body diagrams
PHYS 11 - Contact forces and the factors that affect magnitude and direction
PHYS 11 - Graphical methods in physics

Students can analyze their ball bearing's path through their gravity-fed track system, drawing free-body diagrams of the ball at critical points along the track. What forces are acting on the ball, and in which direction? Where does the ball bearing accelerate? Where does it decelerate? What do these changes in speed and velocity tell you about the balanced or unbalanced forces acting on the ball? Are there any parts of the track where the forces on the ball are balanced? What kind of evidence would you need to prove that? What kinds of details are present when the ball turns a corner or does a loop-de-loop?

Students can draw free-body diagrams of forces acting on the ball bearing in three positions along its gear motor winch ride - at the bottom of their system, during mid-rise, and the moment it reaches the final height (before descending the track).

If they're interested, they could also use their ultrasonic sensor (from lesson 7) to measure the movement of the ball bearing or use a digital camera to video record the winch lifting the load. Use a meter stick behind the ball bearing to read its displacement or height, analyze the video using software to deduce the time elapsed, and fill in a data table with displacement and time. Make a graph of this data and describe the shape of the graph. Does the shape of the graph indicate that the ball bearing is lifted at a constant velocity, or does it accelerate and decelerate? What does this tell you about the RPM of your gear motor? Do you think it would lift objects with different masses at different rates?

PHYS 11 - Vector and scalar quantities

Have students set up a video analysis of the gear motor raising the ball bearing alongside a meterstick? This would work especially well for scenarios where the ball is being dragged up an inclined plane instead of vertically upward. Students can then analyze the video, noting where the ball is every few frames (or whatever segment of time is appropriate), and draw up a displacement vs time data table and graph. From that, they can determine the velocity of the ball at different points along with the rise and draw vector diagrams for each.

Vector diagrams can also be drawn for the ball at multiple points along the gravity-fed track describing the vertical and horizontal components of velocity and acceleration. You could have students set up their ultrasonic sensor to measure the motion of their ball at specific points along their tracks and use that data for analysis.

SCIENCE CHALLENGE OPPORTUNITY

Provide the students with connector wires with alligator clips, a gear motor and power source, a ball bearing, and some other random materials such as thread, string, recycled paper, twist ties, magnets, nails, wire, etc. The challenge is to build a self-perpetuating machine that moves the ball bearing up to a height (say 50cm) and then releases it down a track and back to the beginning of the system. The catch is that students design the servo circuit switches, so the conductive ball bearing ITSELF switches the motor on and off as it moves through the system, creating a self-reliant loop. The system must work to move the ball bearing around 5 laps.

Take it Further!

- Invite another class to come and observe the ball bearing system in action (Keep in mind, grade 4s in BC learn about energy types and transformations – this could be a great excuse for an educational field trip!)
- Design a version of the track that can be taken into other classrooms or into the school hallway to demonstrate electric motors for other students. Make the ball bearing perform a task at the end of the track that somehow benefits the observer, such as raising a sign with an inspirational quote to read, displaying a funny picture, playing a song, etc.
- Obtain permission to build a ball bearing track in a display case in the school. Design it so that the ball bearing returns to a start position and provide an electric “play” button that observers can push outside the case to start the ball bearing moving and watch it run the track and return to start.
- Ask students how they might design their setup differently if they were using a spherical magnet instead of a ball bearing in the initial ascent. Could an electromagnet be used in this system?
- Remind students of the many types of energy they learned in grade 4. Challenge them to incorporate as many energy types as possible and transformations they can through their roller coaster track (adding to it with a Rube-Goldberg-style sense of play).
- Have students video record the entire roller coaster track from start to finish, then edit in music and credits to everyone who helped build it. Upload it to the school’s website to show off their class’s skills.
- Can students change the angle or grade of the incline that the ball bearing takes during its ascent? Challenge the students to design a scientific experiment to determine whether the angle of the ramp affects the efficiency of the motor. (For several different angles, repeat the measurements and calculate the efficiency of the motor. The ramp angle is the independent variable on the x-axis, and motor efficiency depends on the y-axis).
- Challenge the students to try and determine if they could power their motor using a lemon battery. What predictions and observations can they make about this? What are some possible explanations for their observations?

MINI GENERATOR

MINI GENERATOR

INSPIRATION

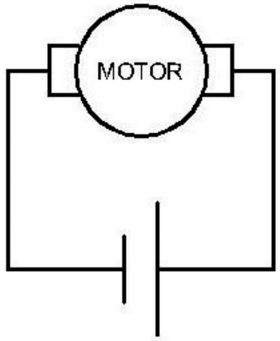
Generating electricity requires facilitating the transformation of another type of energy into electrical energy. It can be accomplished in a few different and fascinating ways, including trapping light with photovoltaic cells, trapping infrared radiation with thermophotovoltaic cells, etc. One way to transform kinetic energy into electrical energy is to move a magnet relative to a wire, which induces an electrical current within the wire. There are many different sources of kinetic energy that can be harnessed to do this. Encouraging students to observe energy types and possible energy transformations will help them understand and appreciate how electricity is produced and even get interested in harvesting and transforming energy from unexpected sources.

OBJECTIVE

Students will illustrate the transformation of gravitational potential energy into kinetic energy into electrical energy by building a demonstration tool: reversing a gear motor to make a small generator powered by a falling weight. They will then quantify the energy transformations by measuring their generator with a multimeter or by Arduino analysis.

TRADES CONNECTION: THEORY

Winder electricians have an in-depth and up-close understanding of the transformation of electrical energy to kinetic energy and vice versa. Moving coils of wire relative to magnets produces electricity. A winder electrician needs to visualize and quantify this process to troubleshoot and fix problems with equipment to get electricity flowing again.



SAFETY FIRST

Secure loose clothing or hair to ensure nothing gets caught in the moving parts of the generator. Prepare a soft landing for your mass to protect the floor.

VOCABULARY

Review the definitions with students at the beginning of the lesson and ensure that students have access to the glossary resource provided with this activity. Utilize these words often during the lessons to model how and where to use them.

- Dynamo
- Gear motor
- Generator
- Power
- Efficiency

MATERIALS

- A gear motor (6V, ~30 RPM)
- **Optional:** mounting bracket (matched to gear motor, if available)
- Hub that fits the gear motor shaft securely, such as a robot wheel, or shaft coupler
- Connector wires with alligator clip end (3+)
- Doorskin or thin plywood, approx. 5: x 10”
- Cardboard, approx. 20 x 30cm
- Ribbon ~2m
- Assorted objects for use as weights, i.e., a handful of large metal nuts
- Metal mug or another robust container, if weights cannot be easily tied to ribbon/string
- **Optional:** if the motor needs terminal leads, you will need solder and two small, insulated connector wires approx. 10cm in length (22 AWG or whatever gauge is appropriate for the gear motor size)
- **Optional:** for Arduino analysis:
    - Capacitor – 1mF (# ECA-0JHG102)
    - Resistor – 100ohm 1/8 watt (# CFM18JT100R)
    - Breadboard Jumper Wire Kit (# WK-2)
    - 10x 300mm M-M Jumper wires (# BC-32670)
    - 20x 6” M-M Jumper wires (# PRT-12795)
    - Breadboard (# BB-32656)
    - Arduino Uno (# A000066)

TOOLS

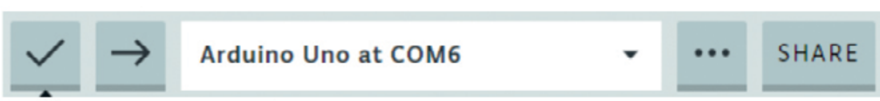
- 2 x multimeters
- Scissors
- Hot glue gun and glue sticks
- Spring clamp
- Meter stick
- Scale
- If using mounting bracket, a drill and small bit may be needed
- **Optional:** Soldering iron, wire strippers and cutters
- **Optional:** For Arduino analysis:

◊ Desktop or laptop for analyzing excel spreadsheet data

PROCEDURE TO BUILD

1. Using a bracket or hot glue, secure the gear motor to the edge of the piece of doorskin or plywood, making sure the shaft hangs over the edge. Use a spring clamp to fix it to the edge of a table.
2. Draw and cut out two circles of cardboard, approx. 2" larger in diameter than your hub diameter.
3. Punch a shaft-sized hole in one of the cardboards disks and push it onto the gear motor shaft.
4. Press the hub onto the shaft, ensuring that you leave enough clearance with the motor's body for the cardboard disk and hub to rotate freely.
5. Tie one end of your ribbon tightly to the hub, securing it in place with hot glue.
6. Glue the second cardboard disk to the exposed side of the hub, creating a spool shape to wind the ribbon in.
7. If the gear motor does not come with terminal wires, and it is difficult to attach the alligator clips to the terminals, strip the ends of two ~4" lengths of insulated wire and solder them to the terminals.
8. Test your generator: use the connector wires and attach the motor terminals to the probes of a multimeter set to measure current. Tie several nuts to the ribbon as weights (or tie on a small container to hold the objects), then wind your ribbon onto the spool. Release the weight to rotate the motor shaft and create electricity. Perform the test several times and record your readings. See "Suggested Assessment Strategies" below for further analysis ideas using multimeters.

1. **Optional:** Electrical and Arduino Setup ProcedureWire up the circuit as shown in the schematic.
2. Go to Arduino Create: **https://create.arduino.cc/**
3. Click on "Web Editor" from the tip right 9-squares icon. You need to make a login and agree to the privacy policy.
4. **If this is the first time you are using the Arduino with your computer, you will need to download the web editor plug-in ("Arduino Create Agent") by finishing the "Getting Started" process at: https://create.arduino.cc/getting-started/plugin/welcome**
5. Download the **10_Arduino_Code.in** file from the online resources associated with this lesson. **Go back to Arduino Create web editor "sketchbook" page from step 2, click the import button , and import the .ino file you just downloaded.**
6. Plug in your new Arduino to the computer with the USB cable.
7. The Arduino should appear on your screen and look like this:

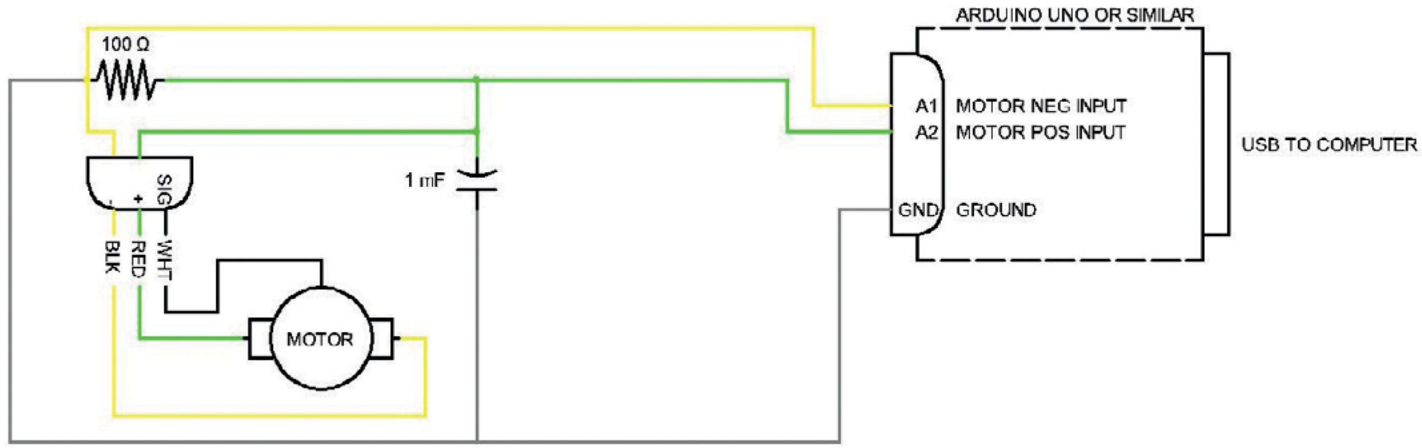


8. Click the arrow that points to the right; this will send your code to the Arduino. It will save it inside and start running the code. You only have to do this once each time you change the code.
9. **Go back to Arduino Create web editor and click "Monitor" on the left side of the screen. You should see numbers flying down the screen.**

10. Perform a test with your weights: attach the weight to the string, wind the string onto the pulley (make sure it is still hanging free of the cardboard), then let go so the falling weight pulls the string and turns the pulley / hub.

11. To stop the test, unplug the Arduino.

12. Copy the relevant test data from the monitor (Ctrl+C, Ctrl+V) into the raw data column of the **10_Data_Plotting.xlsx** file, which you can download from the online resources section of this lesson. The program will graph the power, current, and voltage that your mini generator produced.



GUIDED EXPLORATION OF THE PROJECT (CURRICULAR COMPETENCIES):

Step 1: Demonstrate and Model

Give students 10 minutes (and some internet) to research the difference between a motor and a generator so they can collaborate and draw a big Venn diagram on the board comparing the two. The basic idea you want to get across is that the two are essentially physically the same thing. They transform energy in different ways depending on what energy you put into them (i.e., electrical to kinetic or kinetic to electrical).

Questions to spark curiosity:

What is the purpose of a motor/generator? What parts do they have in common? What are some examples of motors/generators that you use in your daily life? Can every motor be used in reverse as a generator and vice versa?

Step 2: Predict and define

Introduce the idea of developing a demonstration tool for use in a grade 4 class where students are learning about energy types and transformations. This will get them thinking about the physics 11 curricular competency that asks them to "evaluate the validity and limitations of a model or analogy in relation to the phenomenon modelled."

Questions to help clarify:

How does the gear move when electricity is applied to it? How must it move to produce electrical energy? How might you test or measure the amount of electricity or electrical energy generated to see if your machine is working? What additional components will your mechanism need to support the gear motor physically? Is there a fun way to display the electrical energy produced by the generator that a grade 4 student might find more interesting than a read-out on an Arduino or multimeter?

Step 3: Plan and Conduct

Show the students how to construct the gearmotor mini generator set-up and assess it with multimeters, or hook it into the Arduino system, if you choose to use it. Help them build their mini generators and collect their data (to satisfy their physics 11 level analysis of the generator). See "Suggested Assessment Strategies" below for ideas of what students can measure and observe. Brainstorm to see if students would like to add anything to the circuit other than the multimeter or Arduino that would help illustrate the electrical energy being produced.

Questions to help refine the experiment:

Are there any other ways to determine if electricity is being produced other than connecting your generator to a multimeter or Arduino? Could younger students use a magnetic compass to detect electricity in a circuit? What types of energy are observable by human senses? Does the mini generator create enough voltage and current to run a small buzzer, like the one used in the Doppler Demonstration project? A tiny vibrating motor? How about a LED? What measurements or calculations would you need to do to check if the LED will need a resistor?

Step 4: Analyze and Solve

Students can analyze the multimeter measurements or the Arduino read-out data from their mini generator systems. See below in "suggested assessment strategies" to see some different examples of calculations they could do with their data.

You could also have students analyze the efficacy of their mini generators as demonstration tools for the transformations of gravitational potential energy to kinetic and kinetic to electric energy.

Questions for analyzing:

How many tests will you need to run to give you a statistically relevant sample size? How relevant do you think it would be to analyze data from the entire class? (I.e., did everyone builds a similar enough generator to make the data relevant? Or are the generators dissimilar enough that you can compare the differences in data between them?).

What possible misconceptions could young students have while observing your mini generator demonstration tool? What could you do to make your demonstration tool more entertaining or instructive?

Step 5: Evaluate and Reflect

Have students play with the power calculations and analysis. Get them to research and make a list of 5 different electrical mechanisms available on a robotics website and then predict and explain whether their mini generators would power the mechanism or not based on their measurements and the information available on the website.

Questions to encourage reflection:

What kinds of mechanisms could you add to your system to make it an interesting and relevant demonstration tool to show energy transformations to grade 4 students? Can you and your classmates come up with an idea to raise enough money to purchase some of the mechanisms to experiment with? Could your mini generator power a simple electrical game that younger students could play? Is there another application you can think of to utilize the electrical energy given off by your mini generator? For example, how much energy does it take to charge a smart phone battery? How many times do you think you would have to lift your weight and rewind the ribbon to produce the power necessary to charge a phone, and can you try calculating this?

Step 6: Communicating

Students can complete their demonstration tools by wiring in their LED or buzzer, etc., and then either take them to a grade 4 classroom or film a video that a grade 4 teacher could play for their class. Your students could develop a short explanation of their demonstration tool to read out for the grade 4s, explaining the energy transformations illustrated by their mini generator circuit.

Questions to consider:

What could be an effective way to engage the younger students? Do you think that getting THEM to name out all the types of energy that they observe in your demonstration tool would be a good way to help them practice their new vocabulary and concepts? How can you make your video or presentation interactive to help the younger kids learn about energy?

SUGGESTED ASSESSMENT STRATEGIES (STRUCTURE TO DESIGN ASSIGNMENTS)

PHYS 11 - Contact forces and the factors that affect magnitude and direction
PHYS 11 - Balanced and unbalanced forces in systems
PHYS 11 - Newton's laws of motion and free-body diagrams

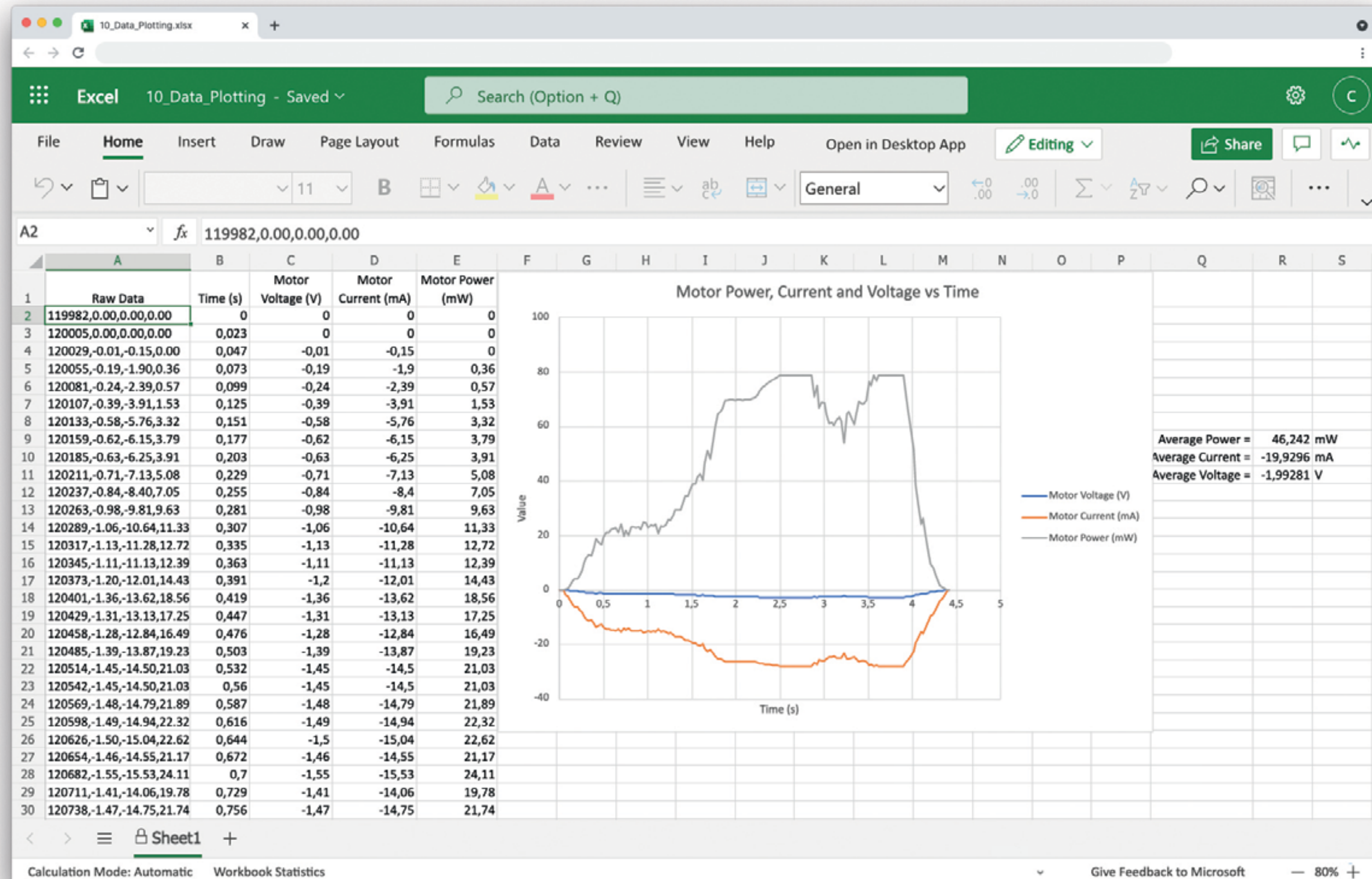
Students can draw free-body diagrams of forces acting on the weight in three positions along its generator ride - at the top of their system, mid-fall, and the moment it maxes out on the ~1m string and reaches the bottom. Do they observe their weight accelerate, decelerate, or move in uniform motion anywhere along with the system? How does the movement differ from what they expected? Could they use their ultrasonic sensors to measure the velocity of the weight? What does the motion indicate about the balance of forces acting on the system? What does the motion indicate about the RPM of their generator? You could have students give a written or oral explanation of their free body diagrams and explain the movement of the weight through the mechanism.

Have students research how a gear motor works – which force do they think produces the electrical energy in their generator? Encourage them to use the vocabulary they already have to describe forces and energy transformations to explain how they think the electrical energy is being produced.

PHYS 11 - Power and efficiency

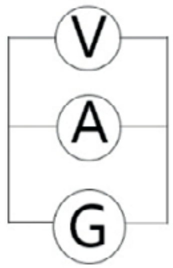
PHYS 11 - Conservation of energy; the principle of work and energy

Students can make simple calculations using their multimeter measurements as well as the read-out from the Arduino assessment of the gear motor mini generator:



	Raw Data	Time (s)	Motor Voltage (V)	Motor Current (mA)	Motor Power (mW)
2	119982,0.00,0.00,0.00	0	0	0	0
3	120005,0.00,0.00,0.00	0,023	0	0	0
4	120029,-0.01,-0.15,0.00	0,047	-0,01	-0,15	0
5	120055,-0.19,-1.90,0.36	0,073	-0,19	-1,9	0,36
6	120081,-0.24,-2.39,0.57	0,099	-0,24	-2,39	0,57
7	120107,-0.39,-3.91,1.53	0,125	-0,39	-3,91	1,53
8	120133,-0.58,-5.76,3.32	0,151	-0,58	-5,76	3,32
9	120159,-0.62,-6.15,3.79	0,177	-0,62	-6,15	3,79
10	120185,-0.63,-6.25,3.91	0,203	-0,63	-6,25	3,91
11	120211,-0.71,-7.13,5.08	0,229	-0,71	-7,13	5,08
12	120237,-0.84,-8.40,7.05	0,255	-0,84	-8,4	7,05
13	120263,-0.98,-9.81,9.63	0,281	-0,98	-9,81	9,63
14	120289,-1.06,-10.64,11.33	0,307	-1,06	-10,64	11,33
15	120317,-1.13,-11.28,12.72	0,335	-1,13	-11,28	12,72
16	120345,-1.11,-11.13,12.39	0,363	-1,11	-11,13	12,39
17	120373,-1.20,-12.01,14.43	0,391	-1,2	-12,01	14,43
18	120401,-1.36,-13.62,18.56	0,419	-1,36	-13,62	18,56
19	120429,-1.31,-13.13,17.25	0,447	-1,31	-13,13	17,25
20	120458,-1.28,-12.84,16.49	0,476	-1,28	-12,84	16,49
21	120485,-1.39,-13.87,19.23	0,503	-1,39	-13,87	19,23
22	120514,-1.45,-14.50,21.03	0,532	-1,45	-14,5	21,03
23	120542,-1.45,-14.50,21.03	0,56	-1,45	-14,5	21,03
24	120569,-1.48,-14.79,21.89	0,587	-1,48	-14,79	21,89
25	120598,-1.49,-14.94,22.32	0,616	-1,49	-14,94	22,32
26	120626,-1.50,-15.04,22.62	0,644	-1,5	-15,04	22,62
27	120654,-1.46,-14.55,21.17	0,672	-1,46	-14,55	21,17
28	120682,-1.55,-15.53,24.11	0,7	-1,55	-15,53	24,11
29	120711,-1.41,-14.06,19.78	0,729	-1,41	-14,06	19,78
30	120738,-1.47,-14.75,21.74	0,756	-1,47	-14,75	21,74

If not using the Arduino analysis, students can measure voltage and current simultaneously by using two multimeters (one set to read amps, one set to read volts) in the following setup:



To do energy and efficiency calculations, they will need to measure the following information:

1) Average voltage (Volts) produced while the weight is dropping (multimeter or Arduino read-out)
2) Average current (amps) produced while the weight is dropping (multimeter or Arduino read-out)
(OR, instead of 1 and 2, simply calculate the average power from the Arduino read-out)
3) Time (seconds) it takes for the weight to drop from height to 0m (stopwatch)
4) m = mass (Newtons) of weight (scale)
5) h = distance the weight falls vertically (meterstick)

Questions to ask: Is the power consistent over the whole time the weight is dropping? Why do you think that is? What do you think it would mean if the efficiency of the generator was 100%?
Energy in = gravitational potential energy of weight at start time = mgh (at start height)
Energy out = electrical work produced = power x time = current x voltage x time
Efficiency = (energy out / energy in) x 100%

Questions to ask: What are some reasons you think your efficiency calculation result might be less than 100%? What are the energy transformations you observe in this system? (Using: electrical, kinetic, gravitational potential, sound, heat, etc.). What energy is considered “lost” in your system (i.e., left out of the efficiency calculation)? Can you think of any practical uses for this “waste” energy? Are there any changes you could make to your mini generator set-up that you think you could make that would increase its efficiency?

PHYS 11 - Graphical methods in physics

Students can analyze the graphical readout from the Arduino data and explore or research possible reasons why their voltage and current (and therefore power) are constant over time. Students could also design an experiment using the “Scientific Method Resource” to maximize the voltage, current, or power produced by their gear motor and graph their results.

Students may be interested to explore the relationship between RPM and voltage or torque and current. You could introduce them to motor curves and use them to draw up some understanding of (or hypotheses for) their gear motor system (running as a motor or running as a generator).

FOM 11 - Application of Statistics

Have the students perform the weight drop test several times and then calculate the average current, voltage, or power produced over each test using either multimeter or Arduino data. Next, they could use these power values to find an average power for the tests as a set. Students could compile their data as a class, find the average power produced for the whole data set, and then calculate the standard deviation. From there, they could answer questions such as, “if you were to build another mini generator using the same materials and procedure, how much power would you estimate that it could generate? If you wanted to be 95% sure that it would produce the power you say it will, what would be the lower and upper power amounts that you would guess it could produce?”.

SCIENCE CHALLENGE OPPORTUNITY

Give students a hobby motor and a standardized kit of starting materials (paper, cardboard, plastic, glue, tape, string, etc.) and see who can make a water wheel that produces the highest voltage. Test the mini generators by filling a 4L milk jug with a hole poked in the bottom. Keeping the hole plugged, let students put their generators in place (a standardized distance away from the jug) and then start the water flowing. Hook up a multimeter to test each generator, record the highest voltage reading throughout each test, and brainstorm real-world applications for such a generator.

TAKE IT FURTHER!

- Design and build a gravity-powered night light that you turn "on" by lifting a mass off the floor.

- Are there any other input energy sources that you could transform into electrical energy using a hobby motor or gear motor mini generator? What attachments would you need to build on the shaft to harness the input energy? Could you make a hand-cranked dynamo? What would you need to measure or quantify about that set-up to calculate the efficiency of the generator? Can you take an energy source considered "waste" energy or "lost" energy in another process and utilize it to produce energy?

- Can you use efficiency calculations to approximate how many grams of almonds you would need to eat to charge your cell phone using your mini generator as the electrical source? Start by quantifying the amount of electrical energy it takes to charge your phone (look at the charger to see how many watts it provides, and test how long your phone takes to charge). Sketch out a diagram of the different energy transformations that would happen along the way. Can you look up the approximate efficiency of energy transformations at each stage? (I.e., what is the efficiency of the human body in transforming the chemical energy of food into kinetic energy of muscles?) What kinds of unit conversions will you need to make to get from the energetic value of food to the electrical energy of charging your cell phone? How many times will you need to lift the weight and reset the mini generator? How does this change the way you think about the electricity available from an outlet in your home?

- List all the types of energy you can think of. Which ones are often used to produce electricity (and how?) Which ones have you never heard of being used to produce electricity? Research to see if anyone has come up with a way to do it – what mechanism is used? How much electricity is produced? Is it sustainable? Are there any new electrical production methods that you first learned of during this research? Which one do you find most intriguing, and why?

SIMPLE MACHINES MECHANISM

skills READY

SIMPLE MACHINES MECHANISM

INSPIRATION

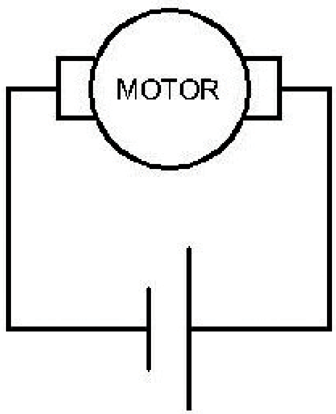
Simple machines are all around us! Even the largest mechanical machines can be broken down into smaller components made of six simple machines. How exactly do simple machines make big jobs easier to do? What are some different ways to link up to other simple machines together to accomplish a goal?

OBJECTIVE

In the spirit of the Physics 11 curricular competencies "contribute to care for self, others, community," and "contribute to finding solutions to problems at a local... level through inquiry", students will ideate to come up with a simple mechanical action that solves a problem or performs a difficult task. Then build a mechanism that utilizes both a DC motor and at least one simple machine to complete the task.

TRADES CONNECTION: TOOLS

Lifting and moving heavy objects safely is an important workplace skill. Knowing how a lever, a wheel and axle, a pulley system, etc., can lessen the force needed to move or lift loads enables people to design ways to complete an action without risking harm to their body, the surroundings, or the load itself. Simple machines are in use everywhere on job sites: choosing a longer wrench handle, pulling nails with the claw of a hammer, using a turnbuckle to tie down a load tightly. These are all examples of how simple machines make work feel easier by allowing you to apply less force (albeit over a longer distance) to complete your task.



SAFETY FIRST

When soldering, make sure you have long hair tied back and don't wear loose-fitted clothing that can accidentally come in contact with the heated soldering iron tip. Use heat shrink or electrical tape to cover and insulate any wires or connections that could cause a short circuit.

VOCABULARY

Review the definitions with students at the beginning of the lesson and ensure that students have access to the glossary resource provided with this activity. Utilize these words often during the lessons to model how and where to use them.

- Mechanical advantage (actual and ideal)
- Force
- Simple machine
- Servo motor
- Soldering iron

MATERIALS

- A gear motor (6V 30 RPM)
- Mounting bracket for gear motor, if needed
- Hub that matches the gear motor shaft (i.e., robot wheel or shaft coupler)
- String or ribbon (1.5m)
- 4 x AA batteries and holder (or whatever power source needed for gear motor)
- Switch
- Assorted connecting wires with alligator clips
- Super glue
- Assorted found materials for building simple machines and mechanism structures (cardboard, plastic, wood, etc.)
- Various fasteners (nails, screws, etc.)
- **Optional:** if the motor needs terminal leads, you will need solder and two small, insulated connector wires approx. 10cm in length (22 AWG or whatever gauge is appropriate for the gear motor size)

TOOLS

- Wire strippers/cutters
- Scissors
- Electrical tape
- Hot glue gun and glue sticks
- **Optional:** Soldering iron
- Spring scales, assorted sizes
- Assorted gram weights, or a collection of small weights such as dried peas or similar
- Multimeter
- Rulers, calipers, assorted measuring devices
- Assorted wood working tools (if working in a shop setting), hammer, drill, saw, etc.

PROCEDURE TO BUILD

1. After deciding what kind of simple machine mechanism you want to build, it is time to set up your power.
2. Use your mini generator set-up from project #10 as your motor, or follow the steps below to make one:
3. Solder some extending wires onto the gear motor terminals, if needed. Strip both ends of two 6" lengths of insulated wire (22AWG or whatever gauge required) and solder them to the motor terminals.
4. Insert your batteries into the holder. Using connector wires with alligator clips, connect the motor's wire extenders to the battery holder wires to make a circuit, and test your motor.
5. Insert a switch into your circuit if your battery holder did not come with one installed.
6. Keep in mind that the direction you want your motor to turn may change as you design your mechanism. Hold off soldering any more of your connections until you are sure you want them to be hard-wired.
7. Attach your hub to the gear motor shaft, then tie or glue your string or ribbon onto the hub.
8. If the string or ribbon keeps falling off the end of the hub, construct a spool by gluing cardboard disks to both ends of the hub. This will help guide the string or ribbon to wind correctly.
9. The string of the pulley you have made can be attached to a simple machine in many ways: have it pull one end of a lever mechanism, or get it to shorten a block and tackle assembly, or have it pull the thin edge of a wedge between blocks or into a material - your design options are limitless!

Building the rest of the mechanism

1. The rest of the mechanical design is up to you!
2. Decide on the following:
    a. The purpose of your mechanism
    b. The intended use of your mechanism
    c. Which simple machine(s) you want to incorporate
3. Use found materials and different types of glues and fasteners to put together your mechanism.
4. Connect your simple machine to your gear motor.

GUIDED EXPLORATION OF THE PROJECT (CURRICULAR COMPETENCIES):

Step 1: Demonstrate and Model

Play a video of a Rube Goldberg machine for the students (one good one to try is "This Too Shall Pass" by the band, OK Go, or "The Lemonade Machine" video by Sprice Machines). After they watch, host a class discussion about simple machines – see how many of the 6 types they can name (lever, wedge, inclined plane, wheel and axle, pulley, and screw), and list them on the board as headings. Next, see how many examples of each that they can recall from the video. You could even play the video a second time and have them call them out to you as you list or tally them on the board.

Questions to spark curiosity:

What are some different tasks each simple machine performed? How might the task have been completed had a simple machine not been used? Did any of the simple machines act as switches to complete an electrical circuit? Can you think of any practical uses for some of the machines you saw in the video?

Step 2: Predict and define

Brainstorm with the class to develop ideas of simple, useful tasks that simple machines in their daily lives could perform. There are many avenues of exploration and design you could present to the students:

- You could encourage them to think of tasks that they might find easily accomplishable, but those other people might find difficult. Many people have careers in designing and building mechanisms to assist people, such as installing chair lifts for the elderly, creating wheelchair ramps, developing prosthetics, etc.

- You could ask them to walk back through their memories of their day to remember the tasks they did - the things they lifted, the buttons they pushed, etc. - and encourage them to come up with a list of at least 5 things they did that they think they might be able to design a machine to do for them. For example, measuring out a specific amount of pet food into a bowl, dispensing a snack, picking up a pencil from the floor, taking a photograph, etc.

- You could propose a challenge that involves animals – can they build a mechanism to train a house pet to operate, like a mechanically opening cat door or a treat dispenser?

- You could host an ideating brainstorm about issues or problems that they notice in their community at large, such as a public building with no wheelchair accessibility, a stream with garbage or waste near the edge, etc. Students could build a small-scale mock-up of the area and design a model mechanism using a simple machine mechanism that would help "fix" the problem. Students could then use the model as a demonstration tool to bring community attention to the issue and as an impetus for finding a real-life solution.

Questions to help clarify:

What do you do every day that you think would be fun to build a mechanism to do for you? Is there a way to fulfill a need in your home, your school, your community, or the larger world with a machine you design? Can you help anyone out by creating a machine that performs a task they cannot do by themselves?

Step 3: Plan and Conduct

Tell students that their simple machine mechanism must include the three following components:

1) a DC gear motor (or servo motor) (note: the hub attachment, if used, will be considered part of the motor mechanism, and not a "wheel" simple machine component)
2) one of the 6 simple machines (or two, if they need a challenge) to lower the input force applied by your motor, or to change the direction that the motor applies force in
3) a switch to complete a circuit that starts the motor's action

Assist the students in designing and building their simple machine mechanism. You may choose to have them submit design sketches and explain the purpose of their mechanism before giving them the ok to move ahead with their project.

Questions to help refine the experiment:

How does your simple machine interact with your motor? Based on what you already know about simple machines, what are some ways you could amplify the effect of the motor? How much mass do you think the motor can move on its own? What are some materials and tools you will need to put your machine together?

Step 4: Analyze and Solve

Show students how to calculate the ideal mechanical advantage (IMA) of the 6 different simple machines (see "suggested assessment strategies" below for formulae). Have them do the relevant measurements on their simple machine to calculate its IMA.

Next, have the students compare the IMA to the actual mechanical advantage (AMA).

AMA = output force / input force

If possible, students can try to measure the output and input forces in a few different ways, e.g., using spring scales (depending on their mechanism, it may be difficult, but still have them ideate a way that they COULD quantify the forces if they had the tools or time).

Students then compare the two numbers and hypothesize reasons for any discrepancy (such as friction, loss of energy, etc.). It may help them draw free-body diagrams of their mass to visualize the forces acting on the load.

If students are successful in measuring the forces and calculating both the ideal and actual mechanical advantage, they can then explore efficiency:

Efficiency = AMA / IMA x 100%

Questions for analyzing:

What might cause a discrepancy between your ideal mechanical advantage and your actual mechanical advantage? What is “work,” and does your simple machine allow the motor to do less work? How do you know? Is your simple machine 100% efficient? Is there anything you can do to increase the efficiency of your mechanism?

Step 5: Evaluate and Reflect

Have students assess the efficacy of their simple machines and describe what changes they would like to make to improve the efficiency or other characteristics of their mechanism. You may choose to have them research similar applications of their simple machine choice to compare efficiency ratings and tips for increasing efficiency (for example, use rollers or a cart to increase the efficiency of an inclined plane).

Questions to encourage reflection:

How could your mechanism be improved by including another simple machine in the design? What was the biggest challenge you faced in designing and building your simple machine mechanism, and how did you overcome it? What part of your mechanism do you think works well?

Step 6: Communicating

Students could provide peer evaluations for each other's simple machine mechanisms through watching presentations, live demonstrations, gallery tours, video demonstrations, etc., of their classmates' final products. Keep in mind that grade 5 science students in BC are introduced to the concept of simple machines and might be excited to be invited into your workshop for a demonstration or to watch a video specially made for them by your physics 11 students showing off their mechanisms.

Questions to consider:

How might you explain to a grade 5 student how your simple machine makes it easier for the motor to perform the task you require? Is there a way to demonstrate this that would help illustrate it for the kids? What criteria were in place for building the simple machines mechanisms, and what do you think are some fair and effective ways to evaluate your peers' projects?

SUGGESTED ASSESSMENT STRATEGIES (STRUCTURE TO DESIGN ASSIGNMENTS)

PHYS 11 - Applications of simple machines by First Peoples

Invite a guest speaker into your classroom, such as a local elder or historian, who could help your students design their simple machine mechanisms and draw parallels to traditional simple machines utilized by First Peoples in your area. Speak to your school's indigenous support staff if you need assistance in contacting and inviting someone.

Have your students choose an example of a traditional simple machine (used locally) and write a comparison to their simple machine mechanism. What purpose does each machine serve? Is it possible to approximate the ideal mechanical advantage of the traditional simple machine, and how does it compare to the IMA of your simple machine? What are some modern-day tools that utilize the same simple machine as the traditional one? Can you find examples of similar simple machines used by indigenous people elsewhere in the world?

PHYS 11 - Simple machines and mechanical advantage
PHYS 11 - Mass, force of gravity, and apparent weight

Forms of mathematical reasoning

As students design their simple machine mechanisms, get them to consider the ideal mechanical advantage their simple machine will apply to the motor.

Levers: IMA = input distance / output distance

Wheel and axles: IMA = radius of large wheel/radius of small wheel

Inclined planes: IMA = length / height

Wedge: IMA = depth of wedge insertion/separation of wedged surfaces at the point of entry

Screw: IMA = 2π x diameter of screw shaft/distance of spacing between two consecutive threads

Pulley: IMA = Number of rope segments pulling UP on a load

Research simple machines and draw a diagram to illustrate each of the 6 formulae above. Can you explain how the formulae for a screw, an inclined plane, and a wedge are similar in mathematical terms?

Have students research how to measure and calculate the actual mechanical advantage of their simple machine. Provide them with a set of spring scales (Newton scales).

AMA = output force / input force

What are a few possible explanations for any discrepancy in IMA vs AMA? Are there any additional forces that need to be considered other than tension force on string and force of gravity? What was the most challenging aspect of measuring input and output forces? What is the difference between measuring the mass of the load with a scale and measuring the gravitational force acting on it using a spring scale?

Efficiency = AMA / IMA x 100%

You could have students measure and calculate their efficiency and then develop a hypothesis about their modifications to their mechanism that would increase efficiency. Use the “Scientific Method Resource” to help them design an experiment.

PHYS 11 - Contact forces and the factors that affect magnitude and direction
PHYS 11 - Newton’s laws of motion and free-body diagrams

Have students draw a free-body diagram of the load on their simple machine mechanism, labelling all the forces they can identify in the scenario.

Can your simple machine mechanism be used as a demonstration tool to illustrate any of Newton’s 3 Laws?vWhat part of the movement of the load helps explain the laws?

PHYS 11 - Balanced and unbalanced forces in systems

Students can analyze the load’s motion – is there anywhere along with the distance of action where the load is exhibiting acceleration, deceleration, or uniform motion? Students could measure this using their ultrasonic sensors or simply rely on observations. Does the load move in a straight line, or does it change direction? Draw a free-body diagram for each scenario, then describe the differences and similarities between them. In which scenario is the forced balanced? Unbalanced? How might you quantify the forces shown in your diagrams?

FOM 11 - SCALE MODELS

Students could draw a diagram of their simple machine mechanism – either larger or smaller – and include a ratio indicating scale. Make it entertaining by presenting it as a poster ad for their machine “for sale,” having them describe its purpose alongside the scale.

FOM 11 -Conservation of energy; the principle of work and energy
FOM 11 -Power and efficiency

Suppose students are able to measure the input and output forces and distances acting on their simple machine. In that case, they will be able to calculate the efficiency of their simple machine mechanism:

W = F x d   Efficiency = Work (output) / Work (input) x 100

Have students draw a diagram of their simple machine, then label all the energy transformations they observe (e.g., electrical energy --> kinetic energy, kinetic energy --> sound energy). Have them indicate all the “waste” energy transformations. Ask them which specific energy transformation their efficiency calculation describes. Can students explain the connection between the waste energy transformations and the % efficiency they calculated? For each “waste” energy they label, have them list two changes they could make to their simple machine mechanism that would help avoid the transformation into waste energy, and increase the transformation into output energy (and consequently, increase the efficiency of their machine). Hint: what forces are acting on the system to resist the motion in the desired direction? What are some reasons why designing optimally efficient systems might be important?

SCIENCE CHALLENGE OPPORTUNITY

Challenge students to see who can build a machine that can lift a 200-gram mass the highest distance off the floor. Give them each the same kind of DC motor and power source. Challenge students to use ONLY the materials found in the recycling bins in the school (or a similarly limiting requirement) and provide some essentials such as hot glue, string, tape, scissors, etc. Their machines can utilize as many components as they choose, and compound machines made from multiple simple machines.

TAKE IT FURTHER!

- Design an on/off switch for your motor that someone with limited mobility or coordination could operate.
- Describe a task your simple machine mechanism could complete if you were able to scale it up in size by 20 times.
- How could you include more than one simple machine in your mechanism? Research and explain how this would affect the efficiency calculations for your mechanism.
- As a class, build a simple machine mechanism that is strong and safe enough to lift a student or a similarly sized mass.
- Incorporate a microcontroller, such as an Arduino, and research about how to write some code that will turn your simple machine mechanism on and off according to your instructions. For example, you could design a plant watering system that waters your plants once a day, or a mechanism that turns a light on at a specific time of day, etc.
- Add lights or noises to your circuit or any other additional electronic component that might be relevant. Does it need to buzz to warn people that it is moving? Would it help to light your mechanism if it's being used at night?

HEAT IT UP!

skills READY

HEAT IT UP!

INSPIRATION

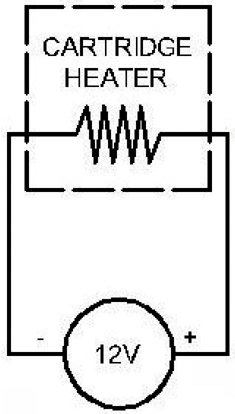
Students likely use electricity every day but may not have quantified and valued the actual amount of energy easily available from a power outlet. Exploring the specific heat capacity of water via electrical input gives students the opportunity to quantify energy amounts and transformations by studying a transformation they observe daily and giving them a relevant context to conceptualize efficiency.

OBJECTIVE

Students will explore the conservation of energy and the specific heat capacity of water by making a DC water heater, then experimenting with different water vessel designs and insulations to make their water heater more efficient.

TRADES CONNECTION: THEORY

Steam, water in its gas phase, has many modern applications, including acting as an energy transporter. For example, it can take the heat given off by combustion or nuclear fission and deliver that energy to a turbine, where it is then transformed into electrical energy. A steam fitter has the skills needed to build the systems that safely contain and transport the steam. Ensuring that the system is insulated and closed is important for keeping the efficiency of the energy transformations high and protecting the surroundings from the steam, which is under pressure and very hot.



SAFETY FIRST

Be careful when using the heating element; if it is not submerged in water, it will get hot quickly. Monitor the water temperature carefully and be aware of spilling hot water. Also, make sure that no water gets splashed on the electrical wall socket.

VOCABULARY

Review the definitions with students at the beginning of the lesson and ensure that students have access to the glossary resource provided with this activity. Utilize these words often during the lessons to model how and where to use them.

- Conservation of energy
- Efficiency
- Specific heat capacity
- Independent variable
- Dependent variable

MATERIALS

- One 12V 2A AC Adapter Power Supply
- 24V 40W Ceramic Cartridge Heater (one per power supply)
- Water containers (various materials – minimum volume ~ 500mL)
- Insulating materials (various – have students collect and bring in)
- Tape, glue, etc., for attaching insulation

TOOLS

- Wire stripper
- Hot glue gun and glue sticks
- Thermometer
- Graduated cylinder (~500mL) or scale
- Stopwatch
- Spoon or glass stirring rod

PROCEDURE TO BUILD

Water Heater Setup

1. In the box for the power supply, there is a female connector with a green end. Strip and insert the two cartridge heater lead and tighten the screws. Plug connector with cartridge heater attachments into the adaptor cord
2. Fill a container with water, insert your thermometer, and let it come to room temperature.
3. Submerge the cartridge heater element (metal end on the wires).
4. Plug the power supply adaptor into the wall.
5. Make sure to stir the water while monitoring the temperature.
6. Do not remove the cartridge heater from the water while it is still powered. The cartridge heater will get extremely hot very quickly.

GUIDED EXPLORATION OF THE PROJECT (CURRICULAR COMPETENCIES):

Step 1: Demonstrate and Model

See how many of the different forms of energy students can name (kinetic, light, sound, thermal, elastic, nuclear, chemical, magnetic, gravitational, electrical). Now, hold a brainstorm about heating water: name as many daily uses of hot water as they can, and then make a separate list of the different ways that water can be heated (i.e., electric kettle, a pot of water on the gas range, the pot of water on the open fire, solar heating, etc.). For each example, have the students think back through the energy transformations that happened to make the water come up to temperature (e.g., water heating for tea on an electrical stove element: heat energy of water, heat energy of coil, electrical energy of stove, kinetic energy of turbine, the gravitational potential energy of water in a hydroelectric dam, etc.).

You may choose to run through a few example calculations using the specific heat capacity of water and energy conservation at this point.

Questions to spark curiosity:

If you back up the energy transformations as far as you can go, do they all lead to a similar energy source? What is this energy source? Do you think any energy is lost through all these transformations? What efficiency do you think occurs at each step, and what form(s) of energy is (are) lost? What are the efficiencies of different water heating methods? Do other water heating methods result in more or fewer emissions or by-products released into the air or environment? Which method seems to be the most efficient and environmentally “clean”?

Step 2: Predict and define

Show students the plan for how to make their own wall-plug DC water heating element. Discuss the conservation of energy and how the specific heat capacity of water can help with calculating and quantifying the amounts of energy that move through the system and its efficiency. Remind students of the specific heat capacity formula: $Q = mc\Delta T$. If they know the mass of the water and the temperature change, they can calculate the “output” energy for their water heating contraption (the number they want to maximize). Give them the formula $E = Pt$. If they know the power (wattage) of their cartridge heater and the time it takes to heat the water, they can calculate the “input” energy. Using their input and output energy values, they can calculate the efficiency of their water heaters (efficiency = energy out / energy in x 100).

Have students explore the efficiency of their water heating systems by using the Scientific Method Resource handout as a guide to design experiments. They should all use temperature as the dependent variable. Host a class brainstorm to help them think of independent variables they are interested in testing (without modifying the heating element or power source) such as: water container size (is heating a large amount of water at once more efficient than heating a small amount?), container shape, container material, insulation type/thickness, etc.

Encourage students to visualize what graphs they will use to illustrate their data to plan what they want to measure and quantify. For example, do they want a “temperature vs time” graph that shows the temperature climbing every minute (each line/curve representing a test and depicting a different value for their independent variable)? Every 5 minutes? Or a bar graph that shows the temperature after 10 minutes as a standard one-off measurement? Which will give more data for statistical analysis?

Students may also benefit from a “how to write a testable hypothesis” group session where they help each other refine their hypotheses before further designing their experiment.

Help them refine their data collection tables and procedural steps.

Questions to help clarify:

What data do you need to collect to do the calculations for efficiency (and what measuring instruments do you need to collect this information with)? How does using water temperature (after a specific amount of time) as your dependent variable give you an indication of the efficiency of your water heater? Do you expect your water heater to convert 100% of the electrical energy into heat energy for your water? Where might you expect energy to be lost in this system, and in what form? If the goal is to heat water most efficiently, What other variables will be important to consider and keep constant?

Step 3: Plan and Conduct

Help students build and test their own DC water heating element and water container; this is their “control”. If students want to use data from the control tests to compare across the class, make sure they all build the same set-up and test them in the same manner, keeping all other variables consistent (eg, initial water temperature, volume, etc.). Next, they will change their independent variable (rebuild the water heating system if necessary), then perform a second set of tests to collect data. For example, they could build their system, test it, then add a layer of insulation to the water container and re-test.

Questions to help refine the experiment:

Had you made any assumptions about the DC water heating element before you made it? What were those assumptions, and what observations did you make that showed your assumption correct or incorrect? How many test runs do you need to make to provide adequate data for statistical analysis? What are some variables that might be difficult to keep constant during testing, and what can you do to mitigate this?

Step 4: Analyze and Solve

Help students analyze their data, develop their graphs, and write their conclusions. Assist them with any calculations and statistical analysis they can do with their data.

Questions for analyzing:

What were the central tendencies of your data, and what does that tell you about your experiment? Do your results support your hypothesis?

Step 5: Evaluate and Reflect

Encourage students to look back over their procedure and articulate which changes they would make if they were to try the experiment again and WHY.

Questions to encourage reflection:

What worked well about your experiment? Would you recommend making any changes to your original set-up? What was one of the biggest challenges you faced during testing, and how did you overcome it?

Step 6: Communicating

Provide students with several different possible ways to communicate their results or their redesigned experiement ideas from step 5. You may choose to: have them hand in a completed lab report, share their results with the rest of the class in presentation format, hand in an amended set of scientific procedure steps, make a short video explaining and illustrating what went wrong the first time and what they would do differently next time, etc.

Questions to consider:

What ways of communicating do you find the easiest? Is there a type of communication that you find challenging? What part of that form of communicating is the most difficult for you, and can you think of any ways to become stronger at it?

SUGGESTED ASSESSMENT STRATEGIES (STRUCTURE TO DESIGN ASSIGNMENTS)

PHYS 11 - Conservation of energy; the principle of work and energy
PHYS 11 - Thermal equilibrium and specific heat capacity
PHYS 11 - Power and efficiency

Have students design their experiments to collect the following data. Time water is heated, temperature change, and mass of water. They can find the power (W) of the cartridge heater on the package and look up the specific heat capacity of water. They can then use this data to calculate the efficiency of their heating systems:

efficiency = energy output / energy input x 100 %

Output energy = heat energy (of water) = Q (J) = mcΔT = mass of water (grams) x specific heat capacity of water (J/g/°C) x change in temperature (°C)

Input energy = electrical energy (J) = Pt = Power (W) x time(s)

Conservation of energy: identify any discrepancies between energy in (electrical) and energy out (heat energy of water) - where did energy go? Was it lost? Where? What steps can you think of to mitigate this? Look up the efficiencies of various water heaters – how does your water heater compare?

You may also tie in calculations and data from other projects in this course – for example, they could look back to their mini generators and calculate the electrical energy generated from one drop of the suspended weight on their reversed gear motor. How many times would they need to lift the weight to generate the energy necessary to heat their water mass one degree Celsius in this experiment? How long might that process take? Can they think of another electrical generating contraption that would transform a different type of energy into electricity to power their DC water heater?

You could also have students extrapolate from their data to explore other scenarios. For example, you could have them choose a purpose to heat water (i.e., taking a shower), define the mass of water (look up the average amount of water used in a shower), the temperature change (what is the tap water temperature, and how hot do you want your shower to be?), and calculate the amount of energy the water needs to be given. They can then work backwards through the efficiency calculations to figure out how much electrical energy input is required and calculate how long it would take to heat the shower water using their cartridge heater. Or find a relevant electrical source that they can explore to gain an appreciation of how much input energy they need to make the electricity to heat that amount of water (i.e.,, look up different types of electrical generators people have made based on stationary bikes, etc. Have them write down each energy change happening in that scenario. Then, research to find approximate efficiencies for each energy transformation and backtrack to calculate how long they would have to pedal the bike to heat their shower water and how much they would have to eat to make that happen).

PHYS 11 - Graphical methods in physics

Have students include space on their data tables to record their water temperature at regular intervals during the two different test scenarios to assess the two curves on a time vs temperature graph. They can then analyze the curves and ideate reasons for any differences they observe and think about what the general shapes of the curves indicate about how the water heater works.

What shapes do the curves have? Does the temperature increase in a linear fashion? Does the water heat up quickly and then level off? Does the water heat slowly and increase more quickly as time goes on? How far might you be able to extrapolate your data, and at what point do you think the extrapolation would stop being an accurate estimate of what happens? (i.e., if you left your water heater on for long enough, do you think the water would boil?)

Is the curve a straight line? I.e., is the relationship between time and temperature linear? If so, can you come up with a y=mx + b function that describes each line? How do these functions compare with your classmates' functions, and what might explain why they are different?

FOM 11 - Optimization
FOM 11 - Systems of equations

Students can produce a collaborative temperature vs time for the data of the entire class, then label each line with the general design features of each water heater. Have them assess which water heater works the fastest and discuss the possible reasons why by defining the different variables and looking at how they appear to affect the temperature vs time curves. Where do the curves /lines intersect? What might this indicate about how each heater works?

They can also take what they know from their data and their peers to design the most optimally efficient water heater they can with the supplies available.

FOM 11 - Applications of statistics

Students can perform their tests multiple times and take multiple temperature readings to gain statistical analysis data. They may also want to analyze the class's data from the first tests that they do with their "control" heaters (i.e., the average temperature of the water after 10 mins, etc.). They can calculate the average time it takes to get the water heated 10 degrees, for example, or the average water temperature after 10 minutes of heating, then determine standard deviation, z-scores, and confidence intervals.

SCIENCE CHALLENGE OPPORTUNITY

Invite some grade 4 students up for a science challenge (grade 4s learn about energy transformations and energy conservation). Students can work in pairs or small groups, with the challenge being to make the "best" insulating cover around their water mug to see whose water can get to the highest temperature the fastest. Put the same standard heater design in every water container to keep that variable constant through testing and decide on a time frame to measure the temperature increase. You may choose to have several different awards, including "fastest heating," "most environmentally friendly insulation," "biggest heat-to-mass ratio," etc. You could also have a chemistry teacher make an indicating solution to heat up instead of water that changes colour at a certain temperature and use that as an end goal instead of temperature readings.

TAKE IT FURTHER!

- Research 3 different types of energy transformation "stories" for how 3 other people around the world heat water to enjoy a cup of tea. Write a short story, make an animation, or draw a cartoon about the energy paths, illustrating what energy is lost and the steps people take to conserve their energy (or use "lost" or renewable energy sources to heat their water).

- Take what you now know about insulation and apply it by designing a hypothetical hot water heater for a house. How much do the materials cost? How long do you estimate it would take to build? How much would it be worth when it's finished?

MASTER MATERIALS AND TOOLS LIST

skills READY

"O" = optional, "Y" = yes/needed	1 Magnetizing Metal	2 Lemon Battery	3 Pencil Resistors	4 Simple Electric Motor	5 Doppler Demonstration	6 Solenoid Launcher	7 Ultrason-ic Sensor	8 Electric Acceleration	9 Winch Roller Coaster	10 Mini Generator	11 Simple Machines Mechanism	12 Heat It Up
MATERIALS												
~22 AWG magnet (enamel) wire	1m			25cm		~12m			1m	O ~20cm	O ~20cm	
~14 AWG copper wire		12cm+										
connector wires with alligator clip ends		4+	3	2		2			4+	3+	3+	
assorted wire types / gauges / lengths	Y			Y		O						
9V battery	Y		Y	Y		Y						
9V battery connector	Y		Y									
AA battery								4	4		4	
AA battery 4-battery holder (with switch)								1	1		1	
3V lithium coin battery (eg, 2032)					2				O 4+			
coin battery holder (2 x 2032)					1							
assorted battery types/voltages	O		O	Y		O						
switch (eg, small rocker switch)	O							O			1	
steel nail	Y											
galvanized nail (eg, roofing nail)		3+										
small LED		O							O 4+			
tiny incandescent bulb and base		O	O									
small metal items (pins, paper clips, etc)	20+											
assorted fasteners (nails or screws)									O		O	
1/4" neodimyium disc magnet						1						
assorted magnets (sizes / shapes / strengths / materials)				Y		O						
5V active buzzer					1			O				
assorted small resistors (various Ohmic values)						O						
6V hobby motor								1				
6V 30RPM gear motor (N20)									1	1	1	
gear motor bracket / mount (for N20 gear motor)									O	O	O	
robot wheel / shaft coupler (matching N20 gear motor shaft)										1	1	
USB A-B cable (printer cable)							1					
Arduino Uno microcontroller (# A000066)							1		O	O		
HC-SR04 Ultrasonic sensor							1					
pin-socket cables ("F/M jumpers")							4					
12V 2A AC Adaptor Power Supply (aka "wall wart")												1
24V 40W Ceramic cartridge heater												1
various insulating materials (fabric, bubble wrap, etc)												Y
ball bearings									5 at 1/4" or similar			
lemon		3+										
assorted fruits and vegetables		Y										
graphite and wood pencils			5+									
glass jar or ceramic mug				Y								
binder clips (size medium)				2								
strong string					~1m				~2m		~1.5m	
ribbon (cloth, ~1/4" width)									2m	2m	1.5m	
plastic bottle caps, spools, found cylindrical objects for hubs								1	2+			
fabric craft felt								~2cm x 10cm				
cardboard					~20cm x 20cm	~20cm x 20cm		~ 1 box	1 box +	~20cm x 30cm	1 box +	

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9V battery connector	Y		Y									
AA battery								4	4		4	
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3V lithium coin battery (eg, 2032)					2				O 4+			
coin battery holder (2 x 2032)					1							
assorted battery types/voltages	O		O	Y		O						
switch (eg, small rocker switch)	O							O			1	
steel nail	Y											
galvanized nail (eg, roofing nail)		3+										
small LED		O							O 4+			
tiny incandescent bulb and base		O	O									
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6V hobby motor								1				
6V 30RPM gear motor (N20)									1	1	1	
gear motor bracket / mount (for N20 gear motor)									O	O	O	
robot wheel / shaft coupler (matching N20 gear motor shaft)										1	1	
USB A-B cable (printer cable)							1					
Arduino Uno microcontroller (# A000066)							1		O	O		
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assorted wire types / gauges / lengths	Y			Y		O						
9V battery	Y		Y	Y		Y						
9V battery connector	Y		Y									

CURRICULAR TIES

skills READY

activity title-------->	1 Magnetizing Metal	2 Lemon Battery	3 Pencil Resistors	4 Simple Electric Motor	5 Doppler	6 Solenoid	7 Ultrasonic Sensor	8 Electric Acceleration	9 Winch Roller Coaster	10 Mini Generator	11 Simple Machines Mechanism	12 Heat It Up
PHYSICS GRADE 11												
Content (students are expected to know the following)												
vector and scalar quantities						O		O	O			
horizontal uniform and accelerated motion							O	O				
projectile motion						O	O					
contact forces and the factors that affect magnitude and direction					O		O	O	O	O	O	
mass, force of gravity, and apparent weight	O						O				O	
Newton's laws of motion and free-body diagrams	O						O	O	O	O	O	
balanced and unbalanced forces in systems						O	O	O	O	O	O	
conservation of energy; principle of work and energy									O	O	O	O
power and efficiency		O							O	O	O	O
simple machines and mechanical advantage								O			O	
applications of simple machines by First Peoples											O	
electric circuits (DC), Ohm's law, and Kirchoff's Laws	O	O	O			O						
thermal equilibrium and specific heat capacity			O									O
generation and propagation of waves					O		O					
properties and behaviours of waves					O		O					
characteristics of sound				O	O							
resonance and frequency of sound				O								
graphical methods in physics	O	O	O	O	O	O	O	O	O	O		O
MATHEMATICS - FOUNDATIONS OF MATH GRADE 11												
Content (students are expected to know the following)												
forms of mathematical reasoning	O		O			O					O	
angle relationships						O						
graphical analysis:	O	O		O	O	O	O	O				
linear inequalities				O								
quadratic functions						O	O					
systems of equations				O								O
optimization				O								O
applications of statistics	O	O	O	O			O	O	O	O		O
scale models	O					O	O	O	O		O	
financial literacy: compound interest, investments and loans								O				

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