CLEAN ENERGY BRIGHT FUTURES
A Program of BEF

UNIT OVERVIEW

Wave Attenuator Unit Overview

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DESCRIPTION

Through a series of learning experiences, students will experiment with the basic concepts of motion to electrical energy transformation. Students start by building a series of models that demonstrate the interactions between magnetic and electric fields. Students then apply this background knowledge to convert ocean wave power into electricity. Finally, students design and conduct their own experiments to optimize a design solution for wave energy conversion using a wave attenuator.

GRADE LEVEL(S)

6, 7, 8

SUBJECT AREA(S)

Electromagnetic Induction, Faraday's Law, Electromagnets, Magnetic Properties of Current-carrying Wires, Renewable Energy, Wave Fundamentals, Electricity Generation

LEARNING GOAL(S)

1. Students will demonstrate energy transfer through space using electromagnetic phenomena.
2. Students will design a model that demonstrates that a current-carrying wire can induce magnetism.
3. Students will define and build an electromagnet.
4. Students will demonstrate electromagnetic induction.
5. Students will describe and model the energy transfer and transformation in a wave attenuator.
6. Students will build a wave attenuator using a diagram and selected materials.
7. Students will test the model wave attenuator they built.
8. Students will investigate variables that may affect the output of an energy conversion device (wave attenuator).
9. Students will interpret data to identify which variables increase electrical output for these model wave attenuators.
10. Students will communicate results from scientific inquiry to identify factors that are important to optimizing the design of a wave attenuator.

UNIT LESSON EXPERIENCES

Table 1. Suggested Teaching Time

Lesson/Experience	Time
Engage/Explore	
L1: Introduction to Electromagnetism	50 min x 4 = 200 min (3 hr 20 m)
Explain	
L2: Building a Wave Attenuator	50 min x 3 = 150 min (2 hr 30 m)
Elaborate/Evaluate	
L3: Testing a Wave Attenuator	50 min x 8 = 400 min (6 hr 40 min)
Total	50 min x 15 = 750 min (12 hr 30 min)

NEXT GENERATION SCIENCE STANDARDS

Guiding Phenomenon	Energy transfer via electromagnetic induction

Table 2. Next Generation Science Standards Addressed in This Unit.

Performance Expectation	How is this assessed?
MS-ESS3-3. Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.	Students will learn about tidal wave attenuators and discuss potential advantages and disadvantages of these renewable devices. This knowledge will be used to frame the importance of their design project and will be incorporated into their final presentations.
MS-ETS1-1. Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.	With each of their engineering challenges, students will be required to identify the constraints and criteria for success based on the objectives given to them as well as the materials supplied before they even begin their project. The teacher will explicitly ask for this information in each of these scenarios. Students will also be required to discuss how wave attenuators can affect the environment as well as people.
MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool or process such that an optimal design can be achieved.	While students are completing the initial engineering challenges focusing on magnetism, they will face small challenges to overcome with improving their design simply by making scientific principles more visible in the function of their devices. However, in their later final project, students will be required to identify variables that impacted the success of their design when modified and describe optimal changes made in regards to this variable. They must relate this to the success of their design and its power

	output.
MS-PS2-5. Conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact.	L1: Students will construct models to demonstrate that electricity (a battery circuit) can exert a force on a compass magnet, that electricity can create a magnet that exerts a force on ferromagnetic materials such as paperclips, and that a moving magnet at a (far) distance can influence a compass magnet through the use of coils of wires (electromagnetic induction).
MS-PS3-5. Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.	Students will construct models to show the transfer of energy through magnets and electromagnetic induction.

THREE DIMENSIONAL LINKAGES

NGSS focuses not only on content, but also on process and on building bridges between concepts within and across disciplines. The following tables outline the way in which this unit addresses this three-dimensionality.

Table 3. Three-Dimensional Linkages: Disciplinary Core Ideas

Disciplinary Core Ideas	**Linkage**
ETS1.A: Defining and Delimiting Engineering Problems • The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions.	Students are given multiple engineering challenges where they identify constraints based on the materials provided and the conditions in which they test their models. Students also identify constraints based on their background knowledge of principles of electromagnetism that they build in investigations early in the unit.
ETS1.B: Developing Possible Solutions • A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. • Models of all kinds are important for testing solutions. • The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution.	In each of the investigations and engineering challenges that build in this unit, students are given specific challenges to address with their construction. These begin as very simple, such as generating an electric current or electromagnetic field. Later these build into addressing more complex challenges such as optimizing voltage reached in their design, requiring the testing of different designs and noting the successes and failures of each.

PS3.B: Conservation of Energy and Energy Transfer • When the motion energy of an object changes, there is inevitably some other change in energy at the same time.	Students make connections between the transfer of energy from physical wave motion to electrical energy in their wave attenuator.
ESS3.C: Human Impacts on Earth Systems • Human activities have significantly altered the biosphere, sometimes damaging or destroying natural habitats and causing the extinction of other species. But changes to Earth's environments can have different impacts (negative and positive) for different living things. • Typically as human populations and per-capita consumption of natural resources increase, so do the negative impacts on Earth unless the activities and technologies involved are engineered otherwise.	Students engage in these issues through an overall analysis of the importance of developing new forms of energy. In noting the pros and cons of marine renewables, they discuss the nature of other forms of nonrenewable energy generation we typically use, which have negative impacts on the environment.

Table 4. Three-Dimensional Linkages: Science and Engineering Practices

Science and Engineering Practices	Linkage
Asking questions and defining problems	L1: Students will ask questions about magnetism, electromagnets, and electromagnetic induction. L2: Students will ask questions about the advantages and disadvantages of wave attenuators. L3: Students will ask questions about the effect of manipulating different variables in their attenuator design and define potential difficulties and constraints when changing these variables.
Developing and using models	L2: Students will create a model of the wave attenuator and discuss how this will be used as a control. L3: Students will create a model of the wave attenuator that will be used as a control from which they can make changes and measure impacts.
Planning and carrying out investigations	L1: Students will build three physical models.
Analyzing and interpreting data	
Using mathematics and computational thinking	L3: Students will track data in the form of voltage or current readings and overall energy generated and explain the

	importance of tracking multiple types of data.
Developing explanations and designing solutions	L1: Students will develop explanations and design solutions as they build models demonstrating different basic facets of electromagnetism. L2: Students will develop explanations and design solutions as they build wave attenuators that will support their later engineering design process. L3: Students will develop explanations of how their variable manipulation impacts the effectiveness of their attenuator and design solutions to make these changes.
Engaging in argument from evidence	L1: Students will use evidence to support Faraday's law and electromagnetic induction.
Obtaining, evaluating, and communicating information	L1: Students will have to evaluate and communicate how they know their models work. L2: Students will have to evaluate and communicate how they know their model works. L3: Students will have to evaluate and communicate how they know their model works.

Table 5. Three-Dimensional Linkages: Crosscutting Concepts

Crosscutting Concepts	Linkage
Cause and effect: mechanism and evaluation	L1: Students will use cause and effect as they problem solve through the building of models. L2: Student will identify key components of the wave attenuator that relate to prior electromagnetism lessons, identifying the components needs based on cause and effect relationships in the structure. L3: Student will use cause and effect as they problem solve through the building of the wave attenuator.
Scale, proportion, and quantity	L2: Students will use scale and proportions as they build from the sketch provided and look ahead to advancing this design. L3: Students will use scale and proportion as they build from the sketch provided
Systems and system models	L1: Students will be building a system as they build models. L2: Students will be building a system comprised of numerous parts as they build the wave attenuator. L3: Students will be building a system as they build the wave attenuator.
Energy and matter: Flows, cycle, and conservation	L1: Students will understand how energy travels through wires and magnets. L2: Students will work to identify the transformation of

	mechanical energy from the ocean into electrical energy by the wave attenuator. L3: Students will see how energy can flow through waves.
Structure and function	L1: Students will understand the function of electromagnetic induction. L2: Students will identify the roles of different pieces of the attenuator system based on prior electromagnetism lessons. L3: Students will build a wave attenuator to see how the structure affects the efficiency of its function.

COMMON CORE STATE STANDARDS

- CCSS.ELA-LITERACY.RST.6-8.3: Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks.
- CCSS.ELA-LITERACY.W.6.9: Draw evidence from informational texts to support analysis, reflection, and research.
- CCSS.ELA-LITERACY.6-8.9: Compare and contrast the information gained from experiments, simulations, video or multimedia sources with that gained from text on the same topic.

CONTENT BACKGROUND

STUDENT BACKGROUND

At the start of this unit, students are expected to have some familiarity with the following scientific concepts and practices:

- The engineering design process
- Electricity basics
- Electricity involves electrons flowing through conductors (metals)
- Batteries store energy that can be transformed into electricity using conductors
- Magnetic fields
- (Optional) electricity and magnetism are connected somehow
- (Optional) electric fields

Over the course of the unit, they should gain further insights into electromagnetic induction and its applications (specifically wave power), engineering design, energy transfer, and scientific design and analysis.

EDUCATOR BACKGROUND

ENGINEERING DESIGN CYCLE

Engineering is the field explicitly focused on solving problems by creating solutions. It is a great way to engage students and to help teach teamwork, communication, and the usefulness of “failure” and productive struggle. Students should have some familiarity with this process for this unit. Otherwise, a teacher will need to spend extra time discussing and familiarizing students with this process.

This unit was developed using an engineering design process formalized by Engineering is Elementary for middle school-aged students. It can easily be modified for the specific process that another teacher uses in their classroom. To see the full poster with descriptions, go to http://eie.org and search "Engineering Everywhere Engineering Design Process Poster". The steps for this process are:

- Identify
- Investigate
- Imagine
- Plan
- Create
- Test
- Improve
- Communicate

The steps that this process uses is similar to many other engineering design processes available, but has the additional benefit of calling out the importance of communication in this process. It does include more steps that many of the engineering models, such as:

- Ask (expanded into Identify and Investigate)
- Imagine
- Plan
- Create (expanded into Create and Test)
- Improve (expanded to include Communicate)

Next Generation Science Standards has an engineering model that can be unpacked from the performance expectations, which might lead a teacher to think too narrowly about the process:

- Define Problem
- Develop Solutions (K-5th, HS)
- Test Solutions
- Analyze Solutions
- Optimize Solution using a model

Two of the most critical pieces of the design process, whether for engineering or not, is that failure is a celebrated part of the process ("Fail Early" is a motto of many engineers) and of the importance of improving a design. Even if it an engineered solution functions as desired, it can always be improved, especially by improving performance or reducing costs.

ELECTROMAGNETIC INDUCTION

The key idea for this unit is that kinetic motion energy can be transformed into (kinetic) electrical energy using the phenomenon of electromagnetic induction. For a deeper look into the phenomena making up electromagnetic induction, see Wikipedia entry "Electromagnetic Induction" (https://en.wikipedia.org/wiki/Electromagnetic_induction). For the purposes of this unit, it is important to understand a few key pieces of this concept:

- A circuit generates a magnetic field. More specifically, electric currents generate magnetic fields.
- This magnetic field can be changed in two ways:
- Change the electric current, or
- Change the magnetic field by introducing an object with its own magnetic field.
- Changing magnet fields, in turn, have the ability to change an electric field to induce electrical current flow.

Generating a Magnetic Field

Any circuit will generate a magnetic field. This unit is quite useful for the creation of an electromagnet, or a magnet that can essentially be turned on and off. Unfortunately, the magnetic field generated in a simple circuit (e.g. with wire and a battery) is not very strong, but **can be observed by observing a free-floating magnet (e.g. a compass) near a simple circuit** (see Figure 1 and further description in "Changing Electric Currents").

Some cool physics (Faraday's law of induction and more specifically the Lorentz force) allows us to amplify this effect by taking that wire and looping it into a bunch of coils. With this new circuit (battery connected to coil of wire, perhaps with alligator clips), the magnetic field can be strengthened enough to observe its magnetism directly: the coil of wires will act like a very weak permanent magnet. This effect can be further strengthened by sticking a piece of iron or other ferromagnetic material (pretty much any material that is attracted to a permanent magnet) in the middle. For demonstrations, wire is often wrapped ("coiled") around a nail or screw.

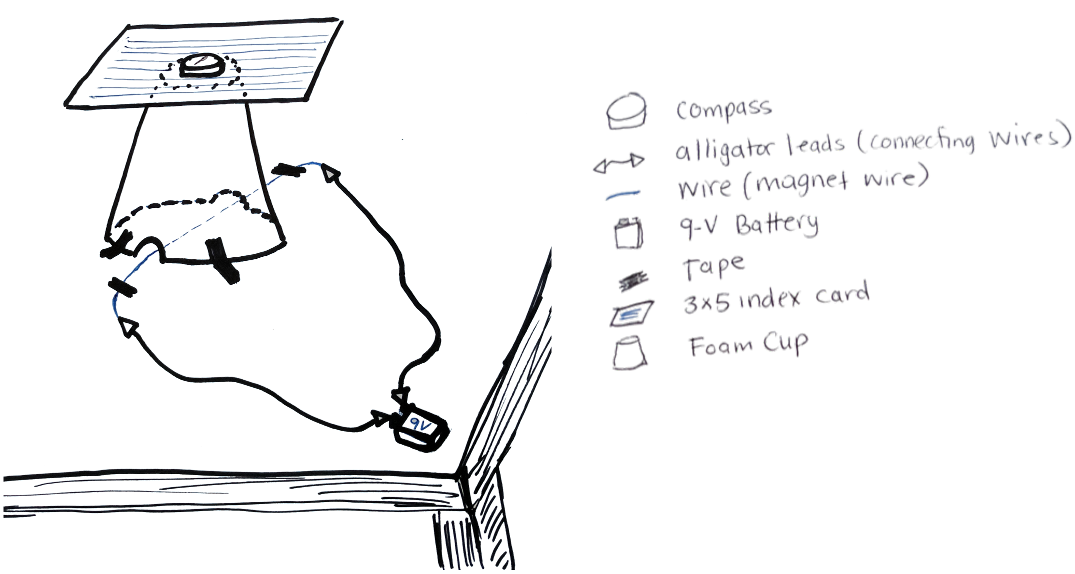

Figure 1. Model of magnetism produced by an electric current

Changing Electric Currents

We can change electric current by having the circuit flow in a non-steady manner. One way to do this is to build a simple circuit and simply connect and disconnect it (change it from a closed to an open circuit and vice versa). The current will change from 0 when the circuit is open to whatever maximum current flows through that circuit when it is closed.

This phenomenon can be observed by placing a magnet near a circuit and then opening and closing the circuit (Figure 1). The magnetic field will not be strong enough in a simple experiment to overcome the resistance of the magnet to movement due to friction, however, so a free-floating magnet is usually used. Make a free-floating magnet by tying a string to a small permanent magnet or simply use a compass.

Though students are not expected to explore much into changing electric currents, it may be useful to think about this concept further. For other DC (direct current) circuits (e.g. any circuit operating directly from a battery or solar panel), the only other way to change the current directly is by changing the resistance in the circuit: think of turning on and off a hose—there are a lot of steps between fully off and fully on. In a simple circuit, this could be accomplished with a device called a variable resistor (real world connection: light dimmer or radio volume knob). *Note: Alternating Current, the electricity that we use in our homes, is a constantly changing current by nature*.

Changing the Magnetic Field

Introducing a permanent magnet to the system will change the magnetic field of the system. If the magnet is moving, then the magnetic field of the system will be changing. Observe this by setting up (closing) a circuit and bringing a free-moving magnet (i.e. compass or magnet-on-a-string) close to the circuit (Figure 1). You will notice that as you bring the magnet closer, it will rotate; when you stop moving, so will the compass. You might notice a time delay between you stopping and the compass stopping if the magnet was rotating with a lot of momentum—you are more likely to notice that with a compass than a more massive magnet-on-a-string. The compass will be aligned in a new direction that indicates the direction of the net magnetic field from your circuit-magnet (and technically Earth) system.

Inducing Current

Electricity, for the purposes of this unit, can be thought of as a moving current. If students will be using a galvanometer to take measurements, they will be measuring this moving current. If, however, you have access to a Vernier Instrumentation Amplifier, then students will be measuring the potential force between the two different locations where the probe is connected. As sitting at the top of a slide supplies the force (due to gravity and your distance away from the center of the

Earth) for you to slide down, voltage provides the push/pull to move electrons around the circuit. This analogy should help clarify the idea that voltage must be measured at two distinct places in the circuit. *Note: do not use the galvanometer in a circuit with a battery unless there is an extremely large resistor in the circuit*.

If, instead of supplying a voltage source (e.g. a battery) to complete a circuit and watching a magnet move, one moves a magnet near a wire without a battery, that effect works in reverse: a moving magnet induces a current in the wire. The direction of the current will depend on which direction you face your portable magnetic field. However, this wire-magnet electrical system is actually too tiny to measure or observe. Faraday's law of induction (the Lorentz force) allows us to amplify this effect by taking that wire and looping it into a bunch of coils. Then, if the magnet is introduced into the coil (north or south pole first), the combined induced current in the wire can be observed and measured. For this, "magnet wire" is used, which is insulated with a thin coating, allowing users to make a huge number of coils in a small space.

The changing-magnetic-field-effect can also be observed by setting up a circuit with a coil of wires rather than a single loop; place the magnet inside, close the circuit, and observe the effects. Student inquiry can include investigate-able questions such as "what happens when the compass isn't placed within the coils?" or a more abstract "does it matter which direction the compass needle is pointing relative to the coil in the circuit?" (Hint: if you line the magnet up parallel with the coil, i.e. both magnet and coil point north, then you shouldn't see much of an effect, as that configuration should just make the magnetic field stronger without changing its direction.

Generating Electricity

An electric generator is simply a coil of wires that move relative to some permanent magnets to induce electric currents in wires that go off to form a circuit with devices to be powered. Note that if you supply electricity to a generator, you can get (rotational) kinetic energy out. In other words, a generator is the same as a motor just like those found in cars, electric bicycles, and anything else you can think of that requires a motor! The only difference is that the energy inputs and outputs have been reversed.

By combining the two concepts of inducing currents and changing a magnetic field, students can observe evidence for kinetic energy transfer through space at a further distance than what you can observe with a magnet (or two magnets) alone. Observe this effect by creating a "circuit" consisting of two

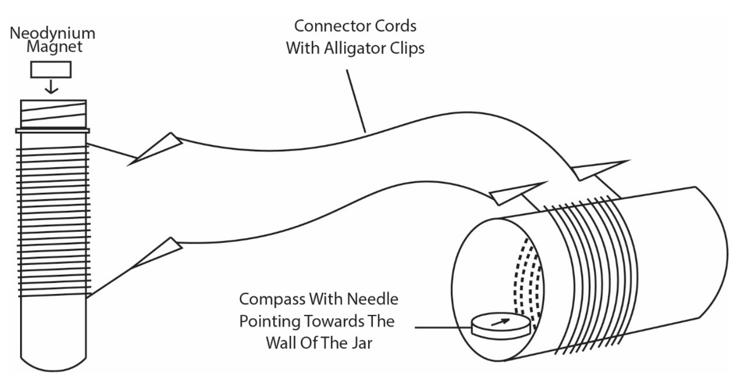

Figure 2. Electromagnetic Induction Model (on the left is the preform and the right is the jar).

coils of wires connected by alligator test leads (no battery). Place a magnet (compass) inside one coil, and move another magnet inside the other coil (Figure 2). *Note: remember to sand the ends of the magnet wire to remove the insulating coating so the alligator connection wires can actually conduct!* Possible extensions or student inquiry could include wondering how far away the two coils could get to still observe a change in the compass—make a bigger circuit with alligator leads or more magnet wire to see!

Under any circumstances in which you want a sustained current (even if it is varying over time), you need a closed loop. Your students should understand this and may have background from making circuits in previous grades. Your students do not need to explore this concept in any depth, but it may be useful to think about why a circuit needs to be "closed": Knowing that electrons move in circuits, consider an open circuit that is simply a wire (no battery) that, for some reason, electrons want to move along (i.e. there is a voltage across it). In instant 0, let's say that 10 electrons want to move from left to right. In instant 1, there are 2 electrons at the right end of the wire, another 3 somewhere along the wire moving to the right, and 5 electrons back at the start. In instant 2, there are 5 electrons at the beginning and 5 at the end. Now, instead of a voltage that makes electrons want to move from right to left, electrons simply want to spread out. This means that 4 of the electrons on the left and 4 of the electrons on the right will travel towards each other until each electron is equidistant from the next one, and almost instantaneously (2 "instants"), there is no longer any current flow and therefore no circuit. Note that the position of the "electrons" in this model are for illustration purposes.

Quick Tips on Galvanometers

To use a galvanometer, set it up in a circuit with any other elements. For the purposes of this lab, this will mean one end will attach to one side of the coil and the other will attach to the other side, the same way that you use a Multimeter or ammeter to measure current. You might also have alligator test leads to connect the circuit. If students get very advanced, they can identify the direction of current flow.

Figure 3. Galvanometer

Note that electrons physically move from the negative side of a voltage source through a circuit towards the positive, but *current* flow follows the convention across many disciplines that things move from positive from negative (or from higher to lower). To do this:

- Determine which direction you need to move the magnet to make the meter needle move to the right (positive direction). This should be either pushing the magnet into the coil or pulling it out of the coil.

- Whichever cable is connected to the positive red plug on the galvanometer is receiving the “current flow” from the coil-magnet system. This means that the *electrons* are passing through the galvanometer entering at the negative terminal and exiting out the positive (red) end.
- Then, when the magnet direction is reversed, the meter should read negative, which means the electrons switched direction and are flowing the other way.

WAVE POWER AND TIDAL POWER

Ocean waves are relatively predictable entities that transfer large volumes of energy towards shore. Like all waves, the energy is transferred without any net movement of matter. In the case of ocean waves, a given column of water will move up and down rhythmically according to the period and amplitude of the waveform. Some of the energy in the wave can be transferred to a device sitting atop the water by the up-and-down motion of a single column of water, the motion of which can be transferred to drive an electrical generator. The model that students will build will involve a fairly direct transfer between water waves and the back-and-forth motion of a magnet through a coil of wires (model generator).

For information on tidal power and additional information on wave power, see:

- Wave Energy- Ocean Energy Council (http://www.oceanenergycouncil.com/ocean-energy/wave-energy/.)
- Tidal Energy- Ocean Energy Council (http://www.oceanenergycouncil.com/ocean-energy/tidal-energy/)
- The Environment – Ducksters Wave and Tidal Energy (http://www.ducksters.com/science/environment/wave_and_tidal_energy.php)
- Wave Power in the UK (2014, https://prezi.com/nw7rxba7vb-c/wave-power-in-the-uk/)

VOCABULARY

Attenuator	A long multi-segment floating structure that is parallel to the directions of the wave. Attenuators contain a converter that creates energy from the movement of the segments *Note: wave attenuators do not usually involve electrical generation, but decrease the power traveling in water like a pool lane line.*
Circuit	A complete and closed path through which a circulating current can flow
Conductor	A material or object that conducts electricity
Electricity	A flow of electrons, often through a circuit
Electromagnet	A circuit with a coil of wire that concentrates and aligns a magnetic field, nearly always with a metal core that acts as the “magnet” that can then be turned on and off
Galvanometer	A device to measure microamps (current)
Magnetic Field	A region of space that surrounds a magnet and affects how magnets interact with their surroundings

Renewable Energy	A naturally occurring source of energy that replenishes itself quickly
Tidal Power	A form of hydropower that is collected by the movement caused by tidal currents or the rise and fall of water levels due to tides *(note: tidal power is not investigated in this unit)*
Wave Power	Power obtained by harnessing the energy produced by waves

REQUIRED MATERIALS

HANDOUTS/PAPER MATERIALS

- Student Science Journals
- Lesson 1: “How Electromagnets Work” Article and Questions Worksheet
- Lesson 1: “The Sticking Power of Electromagnets” Article and Questions Worksheet

CLASSROOM SUPPLIES

- Scissors
- Transparent tape
- Safety goggles
- 100-quart tote
- Enough water to fill tote approximately 5 inches deep
- A 2-liter soda bottle
- 1 galvanometer or Vernier Lab quest 2 and Vernier Instrumentation Amplifier
- Needle nose to cut wire
- Scissors to cut duct tape
- Hot glue gun
- 2-liter bottle (move up and down in the wave tank to create waves)
- Sandpaper
- Metronome (easily found online) (this keeps the wave lengths consistent)
- Laptops or computers for students

ACTIVITY SUPPLIES (PER GROUP OF 3-4 STUDENTS)

- Magnet wire, 3+ gauges (pick middle gauge for general lessons—you will need more of this; about 15 ft per group for all activities; gauges could include 22 AWG, 24 AWG, 28 AWG, 30 AWG)
- Alligator clip test leads (about 20 – minimum of 2 per group for activities that require them)
- Foam cups (one per group)
- 9-volt battery (one per group)
- Rare earth magnets, 9.5 mm thickness, 6.4 mm thickness (one each per group; consider buying some varying types of these for variable changing in final lesson)
- A few sheets of sandpaper (can cut them small for each group – you need to sand off the insulation on the ends of the wire
- Iron nails (1 per group)

- Compass (1 per group)
- Steel paper clips
- 5 ¼ inch soda bottle preform (1 per group)
- 60 milliliter plastic jar (1 per group)
- 1 ¼ inch thick foam cut into 3 ½ x 7 inch rectangles (2 per group)
- 7/8 x ¾ inch acrylic tubes (1 per group)
- ¾ x 3-inch acrylic tube (1 per group)
- Rare Earth magnet (1 per group)
- ¼ 20 4-inch bolt (1 per group)
- ¼ 20 nuts (2 per group)
- 1 ½ inch L bracket (2 per group)
- 1 roll of duct tape (1 per group)
- 1 roll of scotch tape (1 per group)

Figure 4. Picture of group materials for Day 3

UNIT PROGRESSION

PLANNING AND PREP

This unit is designed to cover three distinct lessons that build up to an engineering design problem revolving around designing model wave attenuators. Students build an understanding of the relationship between electricity and magnetism in Lesson 1 and then apply this understanding in Lesson 2 to build a device that converts motion (specifically from waves) into electricity using an example device (or either a precise set of directions or a specific set of materials with no instructions, depending on the level of the class and the teacher's discretion). Finally, in Lesson 3, students identify ways that they can modify their wave attenuators to improve them and design experiments to test the impact of selected variables on the electrical output of this device. Students will be using science notebooks for each day to outline their ideas and document their learning.

LESSON SEQUENCE

LESSON 1: INTRODUCTION TO ELECTROMAGNETISM

This lesson is designed to span 4 days with 50-minute sections. After the introduction day, each day investigates one aspect of electromagnetic phenomena. At this point, a teacher needs to understand about electromagnetism: both how to alter magnetic field and how to generate electricity. As this is an introductory lesson, they do not yet need to feel confident with applying these concepts to using this phenomenon to transform motion to electrical energy.

Students will work in groups for the unit, but they do not need to be in their final groups of 3-4 until Lesson 2. For teachers unsure of effective student grouping based on their current classroom, Lesson 1 offers 4 opportunities to test out different groupings and personalities. That said, teamwork and cooperation is a hugely valuable skill that students can learn through practicing engineering.

- L1 Day 1: Watching videos and reading articles. Students will identify prior knowledge and gain some other background information.
- L1 Day 2: Affecting a magnetic field using electricity. Students will work in groups of 3-4 and each group will build an electromagnet that induces a magnetic field.
- L1 Day 3: Creating a magnet using electricity. Students will watch a video and then create two electromagnets that will each pick up paperclips.
- L1 Day 4: Inducing a changing magnetic field using a magnet. Students will work with a computer simulation that demonstrates interactions between electric and magnetic fields and will then build a circuit that gets its electricity from a coil of wire and a moving magnet.

LESSON 2: BUILDING A WAVE ATTENUATOR

This lesson is designed to span 3 days, building upon previous 4-day lesson that explored electromagnetic energy and will build on this knowledge to understand electromagnetism from an electrical energy perspective.

- L2 Day 1: Background information on wave attenuators. Students will discuss preconceptions about electricity and waves and watch videos for background information.
- L2 Day 2: Wave attenuator diagrams. Students will draw models of wave attenuators that convert energy in water waves to electricity
- L2 Day 3: Building a wave attenuator. Students build a model wave attenuator based on explicit instruction, an example model, and/or through a series of engineering design steps.

LESSON 3: TESTING A WAVE ATTENUATOR

This lesson is designed to span 5 days, building upon previous 3-day lesson in which students built a model wave attenuator, to explore engineering from a rigorous scientific perspective in which students attempt to hold all but one variable constant in their tests.

- L3 Day 1: Wave attenuators and variables. Students will identify different variables that could be modified in the wave attenuator design.
- L3 Days 2-4: Building Days. Students will change their model wave attenuators to test for specific variables that they decide upon and test each iteration in the water tank.

- **Day 5: Group Presentations.** Students prepare and give formal or informal presentations about their projects and findings. Students will get data and ideas for final improvements to their design.
- **Days 6-8: Building and Testing Final Wave Attenuator.** Students will make final modifications to their wave attenuators using data from their or other groups with the goal of improving their models. Then, they will work on project write-up (including graphing and more data analysis) according to the specifications of the rubric.

ASSESSMENT AND EXTENSIONS

FORMATIVE ASSESSMENTS

Teacher should be making observations and notes throughout the investigations and encouraging students to take notes and observations in their science journals. Students can be assessed on their written responses, group responses and teacher observations to check for and correct understandings of content and students should receive feedback throughout the project. As preconceptions and erroneous conclusions develop within the class, determine whether another day of exploration or testing will be necessary (if possible) or ensure that student discussion corrects or at least questions any major misconception.

SUMMATIVE ASSESSMENT

Final assessment will be grading student write-ups that they complete on the last days of Lesson 3 based on the Wave Attenuator Grading Rubric (Table 6, also available as separate Word document for ease of teacher editing and modifying). The first 4 categories in the rubric can also be used as guidelines for the group presentations.

Table 6. Wave Attenuator Grading Rubric.

Category	5 points	4-3 points	2-1 points
Problem / Question	The problem and question are clearly labeled and written.	The problem and question are written but not clearly or labeled	Only a problem or question are written. May or may not be clear and labeled
Variables	Variables including all *independent* and *dependent* variables. Variables are labeled	Variables may or may not be labeled. Some *independent* and *dependent* variables are included.	Only *independent* or *dependent* variables are included. May or may not be clear and labeled.
Hypothesis	The hypothesis for the	The hypothesis is	Hypothesis is written

	group/members are clearly written in the If ________ Then______ because ________. Hypothesis are labeled	written but maybe in the wrong format or not labeled.	but very unclearly.
Observations	A clear, detailed and labeled list/diagrams of students observations during the lab.	Observations are included but they are vague and lack detail. May or may not be labeled.	Observations are extremely vague and provide little to no explanation of student observations.
Table and Graph	A table and Graph are included. Each includes a title and is clearly labeled. Including measurements, units.	A table and Graph are included. Missing important elements such as title, labels, measurements, units.	A table or Graph is included. Missing important elements such as title, labels, measurements, units.
Conclusion	A conclusion includes detailed description of: *What was discovered? *Was your hypothesis correct? * Support finding to science concept	A conclusion is missing one of the following: *What was discovered? *Was your hypothesis correct? * Support finding to science concepts	Conclusion is missing two of the following: *What was discovered? *Was your hypothesis correct? * Support finding to science concepts
Successes, challenges and Next Times	Students include a detailed and clear explanation of successes, challenges and next times. These are labeled.	Students include some successes, challenges and next time. Explanation may be vague or missing factors.	Student include elements of successes, challenges and next times but provides no explanation.
Neatness and Color	The presentation is colorful., neat and easy to read.	The presentation lacks color, neatness and parts are difficult to read.	The presentation has very little color, is unorganized and hard to read

UNIT EXTENSIONS

- Lesson 1: Whether as an assessment or to deepen understanding with real-world connections, students can create a project showing how and where electromagnets are used in real life. This can be done through a poster, book, presentation or song.

- Lesson 2 or 3: Student could write a letter to a local organization such as NNMREC (http://nnmrec.oregonstate.edu/) either promoting or discouraging the use of wave attenuators.
- Lesson 2 or 3: Students could create a brochure comparing wave attenuators to another renewable resource such as wind or solar energy.
- Lesson 2 or 3: Students could create a video promoting or discouraging the use of wave attenuators.
- Lesson 2 or 3: Students could write an argumentative paper supporting or not supporting the use of wave attenuators on the Oregon Coast or another coast more appropriate to their location.
- Lesson 2 or 3: These lessons can easily be expanded to address NGSS Performance Expectation MS-PS4-2 While students do not develop the wave tank system, they can use observations from it to describe and model wave reflection (in addition to wave properties outside of that PE).

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