Introduction to PhysicsQuest Extension Activities

The following extension activities are supplements to the World Year of Physics 2005 activity PhysicsQuest: The Search for Albert Einstein's Hidden Treasure. Each of the four activities within PhysicsQuest has a set of corresponding extension activities.

The most effective way to use these activities is in conjunction with the PhysicsQuest activities as suggested in the section "Using the PhysicsQuest Materials" in the PhysicsQuest Teacher's Guide. While reading though the extension activities you may notice that some activities are more suited as an introduction for the whole class while others are more suited for small group activities. Specific guidelines for implementing extension activities are not included, as the extension activities are provided only as a supplement to the main PhysicsQuest activity.

Materials for extension activities are not included in the PhysicsQuest kit. However, most of the materials are common, inexpensive items such as bubble wands, straws, paperclips, magnets and springs.

We strongly encourage you, the teacher, to perform all of the experiments before attempting to do them with your class. This way you can adapt an activity if you feel that it is too complicated, time consuming, or dangerous for your particular students. Some of the extension activities require close supervision and may work better as demonstrations in less advanced classes.

We hope you find these activities to be helpful and fun supplements to your curriculum. For background information on the concepts they cover, please refer to the background information in the PhysicsQuest Teacher's Guide and the associated references.

Activity 1 Soapy Films

Bubble Sculptures and Regularity

Activity 1

In this activity, students create bubble sculptures. By observing these structures, they will learn about regularities in bubble formation.

Have students experiment with different ways of joining bubbles together and to the surrounding surfaces. It may be easiest to create these structures by blowing bubbles through straws dipped in soapy solution. Challenge your students to:

- Blow bubbles inside of other bubbles.
- Rest bubbles on top of other bubbles.
- Join several hemispherical bubbles side by side on the top of the table.
- Arrange several bubbles in the shape of a square.

After they have experimented with bubbles for a few minutes, encourage students to make careful observations and draw diagrams of their structures. They should look for things like:

- Similarities in the way bubbles combine.
- The number of bubbles that touch at an interface.
- The angles bubbles form with one another.
- The shapes and sizes of the bubbles.

Reconvene as a class and have students discuss their observations about the regularities of bubble formation.

Safety Notes

Students should wear safety goggles when working with bubble solution because the mixture may cause irritation if it gets into students' eyes.

Since the floor will be very slippery if bubble solution spills, be sure that students clean up wet spots on the floor throughout the activities.

Students need to be careful when making wire bubble wands as the ends of the wire may be sharp.

Care should be taken when constructing the device for measuring surface tension as students will be working with pins.

Activity 2

Another great way to observe bubble regularities requires two sheets of clear plastic or plexiglass. Place one sheet in a shallow container of soapy water. Put spacers (e.g. rubber stoppers) approximately 1 cm thick on each corner of the sheet. Then place the other sheet on top of the spacers, forming a "sandwich" with glass or plastic on the top and bottom as shown in Figure 1.1.

Be sure that the sheets are wet and soapy so they do not pop the bubbles. Have students use straws to blow bubbles between the two sheets.

- What do they notice about how these bubbles join?
- How many bubbles join at each point?
- What angles do they form?

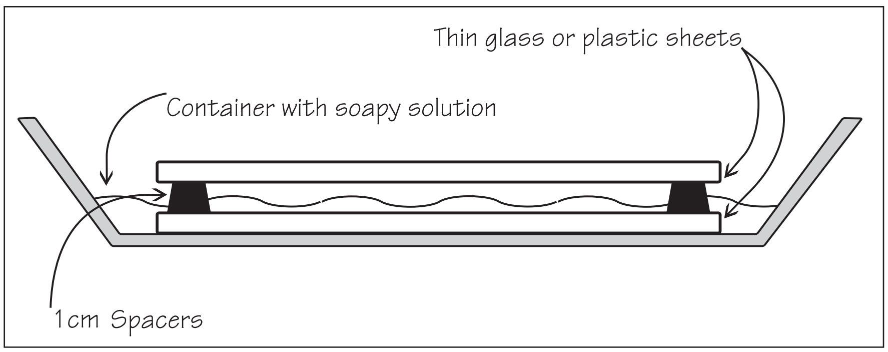

Figure 1.1
Set-up for Bubble Regularity Investigation

After they have blown about 15 bubbles, students should recognize a beehive-like pattern. When bees make their hives, they maximize the amount of honey they can hold while minimizing the amount of wax needed. It turns out the optimum packing shape for enclosing a given volume within the least amount of surface area is 6-sided hexagon tubes. Similarly, the soap bubbles between the sheets arrange to minimize the amount of liquid needed to enclose the largest volume. This is a great example of how the regularity of nature can be explored using bubbles!

Can You Make a Crazy Shaped Bubble?

In this activity, students explore how minimization dictates the shape of soap bubbles.

Have students make several differently shaped wands — including a square, circle, triangle and a non-geometric shape. Ask them to predict the shape of the bubble that each wand will create. Then have them blow bubbles with each wand and record their observations.

Students should discover that bubbles emerge from ALL wands as spheres. This is because spheres minimize the surface area, and therefore the amount of solution, required to enclose a given volume of air. No matter how strangely a wand is shaped, it will only produce spherical bubbles.

You may want to motivate this activity by setting it up as a "which group can make the craziest shaped bubble" contest.

Best Bubble Solution

There are many ways to make bubbles. In this activity, students will attempt to develop a method for making the best bubbles. Two possible measures of the "best" bubbles are how long they last (lifetime) and what size they reach before popping (size). Have groups compete to find the best bubble solution.

The first step to making long-lasting and big bubbles involves finding a soapy solution that balances decreasing surface tension with evaporation prevention. Have students create bubble solution recipes with varying amounts of water, soap (different brands), glycerin (should only be mixed with soap and water), corn syrup, gelatin powder, sugar, Kool-Aid, etc. Students could also explore using hot versus cold water or bottled versus tap water.

Have students make bubbles according to their recipe and record either the lifetime or size of 10 bubbles made with that recipe. All groups should use the same type of wand. Then, have students make logical, incremental changes to their recipes, blow 10 more bubbles, and repeat the process. As a class, discuss the results of these trials.

A variation of this idea is to have each group explore the effect of one of the ingredients. You can then combine the class results and talk about controlling variables.

Another variation is to have half of the groups maximize bubble size and the other half maximize lifetime. Then you can compare the recipes to see if the same method works best for maximizing size and lifetime. Are longer lasting bubbles always the biggest? You can use this opportunity to discuss how trade-offs are assessed in technological development.

Observing Soap Films

Activity 1

In the main PhysicsQuest activity, students create triangular wands and observe features of the resulting soap films. In this activity, students should make several differently shaped wands, including wands with more than three vertices. It may be easier to make these wands out of drinking straws than out of wire.

- Do they notice any patterns in the films?
- Can they predict where the films will intersect for different wands? If so, how?

Have students pop different sections of the film and observe what happens. They should see that the liquid redistributes itself to decrease the path length between points of contact.

Activity 2

The bubble frames students have created thus far have rigid points of contact that cannot be moved. If instead the contact points of the bubble frame are limp, then the need to minimize wall tension in the film will actually pull on the frame in order to decrease surface area. To observe these forces at work, have students build a bubble frame out of two straws and string. They should thread the string through the straws and tie the string into a knot. Then, have students tie several other pieces of string across the main frame to make "holes" in which soap films can form. Have students hold their frames both horizontally and vertically and observe the films.

Have students predict what will happen to the strings when one of the films is popped. Then have them try it and record their observations. When the film on one side of a string is popped, the surface tension in the film on the other side pulls the string in its direction. The liquid pulls on the string to minimize the wall tension, surface area, and energy of the remaining film. Have students hang their wands vertically and pop one of the films on the lower half. The film on top of the popped one will minimize its area so much that the upward pull on the string will be strong enough to overcome the force of gravity — it will actually lift up the string!

Exploring Surface Tension

This set of activities is designed to give students a better understanding of surface tension, how it can be measured, and what phenomena it causes. Have them explore many different liquids such as pure water, soapy water, alcohol, and cooking oil. Robert Gardner's book *Experiments with Bubbles* suggests the following investigations.

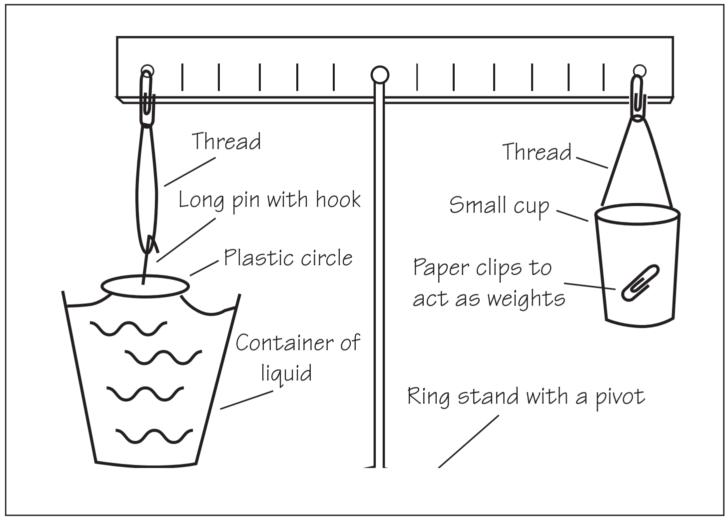

Figure 1.2
Apparatus for Measuring Surface Tension

Activity 1

Have students predict which liquids have the highest surface tension by ranking them from lowest to highest, and have students describe what properties of the liquid they are using to make these predictions. Then, have them use the following apparatus to test their predictions. Students can build the apparatus, but you probably want to build one ahead of time as an example.

The apparatus is a modified "balance" where one end pulls up on the surface of a liquid and the other end pulls down with the weight of paperclips. You will need something to act as a center post and pivot. If you do not have access to a ring stand, a paperclip hanging over the edge of a stack of books can act as a pivot. Attach the center of a ruler to the pivot so that it can rotate freely—most rulers already have holes in the center.

Next, hang a small, lightweight cup on one end of the ruler using thread and a paperclip (see Figure 1.2). On the other end of the ruler, attach a solid plastic circle (cut out of the lid of a yogurt or sour cream container). The circle needs to be small enough to fit inside the container you are using to hold the liquid. Then, push a long pin through the center of the plastic and bend the end of the pin into a hook. Hook the pin and plastic circle onto a loop of thread as shown in Figure 1.2, using a paperclip to attach the thread to the end of the ruler. The plastic circle should hang down and rest lightly on the surface of the liquid in the container underneath. Use modeling clay to add weight on either side of the balance until the ruler is perfectly horizontal.

When students place weights (paperclips) into the cup, the plastic circle on top of the liquid should begin to rise. The surface tension of the liquid will allow the plastic disk (and the liquid) to be pulled up a small amount before the upward force overcomes the downward pull of the other molecules and gravity and the plastic breaks free from the liquid. Have students place paperclips in the cup one at a time and find the maximum number of paperclips each liquid can "balance" before the surface tension breaks. Have them record their measurements and rank the liquids by surface tension.

- Do these rankings match their predictions?
- Were there any surprises?
- What other variables might affect surface tension? Depth? Temperature? Size of the plastic circle?

Have them explore these possibilities as well. Students should find that soapy water has less surface tension that pure water.

Activity 2

Have students use eyedroppers filled with pure water to put drops of several different sizes on a piece of wax paper. Have them describe the shape of the drops, especially noticing how the shape changes as the drops get bigger. The drops "flatten out" because gravity starts to overcome the surface tension that holds the drops together. Eventually they will fall apart! Now have students put drops of soapy water next to the pure water drops.

- What differences do they see between the two types of drops?
- Which liquid holds its shape better?
- Have them make observations about droplet shapes for the liquids whose surface tension they investigated previously.
- How can they use surface tension to explain why the drops behave this way?

Liquids with lower surface tension do not hold their rounded shapes very well in large drops because the weight of the water overcomes the forces holding the drops together.

Integration with Other Curricular Elements

Mathematics

Minimizing the surface area needed to enclose a given volume can also be explored mathematically. Have students find the ratio of surface area to volume for various three-dimensional shapes – spheres, cubes, cylinders, etc. They will find that a sphere always has the minimum surface area associated with a given volume.

Students can also use "dome" bubbles blown on flat surfaces to practice their graphing skills. Have students blow domes of several sizes and then measure and plot the width and height of the bubbles.

- Encourage them to think about the best scale for their graph. How should they choose the axes?
- Ask them to draw a straight line through their data points. What does the line tell them?
- Is a straight line the best fit for the data or would a curved line fit better?
- What does the line say about the proportions of bubbles?
- Can they use their graph to predict the height of a bubble given its width, or vice-versa?

Language Arts

Once the students have completed the bubble activities in small groups, you can have them give presentations about one aspect of their investigation. Have students create posters or other graphics to display their data and results.

Students could also give presentations/speeches or write research papers about related topics like the colors we see in bubbles, other things you can learn from soapy solutions, and the history of bubble toys.

You may want to have students engage in debates with their peers who came to different conclusions about the starting point of the search. Have them discuss how they can resolve these differences.

Activity 2 Seeing Spots

Adding Waves

In this set of activities, students will use a variety of methods to explore how waves of different sizes add together.

Activity 1

Have five students (or more, as long as it is an odd number) stand side-by-side and link arms tightly. Instruct the students to move only when they feel the person beside them pull on them. Then, have a student at one end of the line lean forward and back upright. This action will cause the next person in line to lean forward also, and the pulse will continue down the line until it reaches the other end.

Encourage students to watch the wave as it moves down the line. Ask them to predict what will happen to the person in the middle if the students at both ends lean forward at the same time. Try it out – the person in the middle will be thrust forward because the two pulses add together. Ask students what will happen to the person in the middle if a student at one end leans forward and the student at the other end leans backward. Try it out — the person in the middle will remain still because the two waves will cancel each other.

Activity 2

If you have access to slinkies or long, tight springs, have students work in pairs to reproduce these same phenomena. Have each pair hold a spring stretched out along the floor. After warning them that letting go of the spring may hurt their partner or others in the room, one of the students should create a single pulse by move the spring quickly to the right and back to the middle.

- What happens to the pulse?
- What happens if both students start a pulse at the same time in the same direction?
- What happens if both students start a pulse at the same time in opposite directions?

Safety Notes

Students should be careful not to let go of the end of a taut spring because it will snap back and may hurt someone.

Remind students that they should NEVER look directly at the sun, even if looking through a diffraction grating. The grating will not protect their eyes. Similarly, they should never look directly at a bright light bulb.

Activity 3

Draw waves of different sizes and shapes on the board and ask students what happens if they overlap. Encourage them to use their intuition about water waves to help make predictions. Throughout this activity, students will probably be using words such as “bigger” and “flatter” to describe the resultant waves. Talk with them about what those words mean in terms of light waves (amplitude/brightness).

Homemade Diffraction Gratings

The Exploratorium website gives suggestions for how students can observe diffraction using common household items.

Activity 1

Have each student wrap a layer of tape around the top of a pencil just below the eraser. Then, they should hold the pencil right next to another pencil so that the tape creates a small slit between the two pencils. Have the students hold the pencils right in front of their eyes and look at various light sources through the slit (works best with flashlights or candles). Ask the students what they see. If they make the slit smaller by squeezing the pencils together, they should see a different diffraction pattern.

You can also have students rotate the pencils and discuss how the patterns change.

Activity 2

You can observe diffraction from light waves bending around very small objects. Have students hold a piece of their hair taut about 1 inch away from their eyes. Have them look at different light sources “through” the hair – they may have to squint to reduce the amount of light coming toward them. Have them record their observations as they rotate the hair and as they look at different light sources.

Light Spectra

A rainbow is a spectrum of all the colors of visible light. In this activity, students explore the "rainbows" made by different sources of light passing through a diffraction grating.

Ask students to predict whether all sources of light are composed of a full rainbow of colors.

- Will the colors always appear in the same order?
- Will they always touch one another as they do in rainbows?
- Will the colors always have the same brightness?

Once they have discussed these ideas with each other, have students use a diffraction grating to investigate the spectra for different sources of light. Have them record what colors they see in a table like the one below, taken from the NASA Quest website. You could also have them draw the spectra using colored pencils.

Light Source	Red	Orange	Yellow	Green	Blue	Purple
Sunlight						
Fluorescent Light						
150-200 Watt Light Bulb						
20-60 Watt Light Bulb						
Flashlight						
Colored Light Bulb						

WARNING: Do not look directly at the sun, even through a diffraction grating.

Students should notice that different types of light sources have different spectra. In fact, every element has a unique spectrum—they act like fingerprints that astronomers and other scientists use to study galaxies and to identify unknown gases.

Other Properties of Light Waves

Although the wave nature of light might seem irrelevant to everyday life, it actually explains phenomena people encounter daily. Use this extension to discuss some additional properties of waves. If you have access to computers and Internet stations, have students look up the answers to these questions and discuss them with one another.

1. Scattering: Why is the sky blue?

The sky is blue because of the wave nature of light. The sun emits light across the entire range of visible light (and far beyond), and when all of these colors mix together they make white light. When white light from the sun comes through the earth's atmosphere and into the sky, the air molecules scatter the incoming light. Blue light has a shorter wavelength and is therefore scattered more by the air molecules than light with longer wavelengths. Since blue light is scattered across the sky more than any other color, we see blue light coming toward us from all areas of the sky.

Using this reasoning we can also determine why a sunset looks bright red or orange. When the sun sets, its light passes through more of the Earth's atmosphere than when it is directly overhead. As mentioned above, air molecules in the atmosphere scatter blue light most and red light least. When we look toward the sun at sunset we see mostly red light since it is scattered least along our line of sight. The blue light is scattered out higher in the atmosphere. In addition, since the light has to travel through more of the atmosphere it also encounters more dust and moisture molecules. These molecules are larger than air molecules and scatter mostly longer wavelengths of light (red/orange/yellow); making those colors dominate the sky.

2. Refraction: What makes a rainbow?

After a rainstorm, or when there is a lot of moisture in the air, we sometimes see rainbows in the sky. We see these rainbows because of refraction, the bending of light when it passes through a material with different optical properties than air. The angle by which light is bent depends on two things: the properties of the material and the wavelength of the light. Light hitting a water molecule splits into its component colors because each wavelength bends by a different amount.

Students may note that they cannot see a rainbow after every storm. This is because you can only see rainbows when the sunlight is coming from behind the moisture in the air, through the water, and toward you.

If light did not have a wave nature, the world would be much different. Discuss with your students what it might be like.

Integration with Other Curricular Elements

History and Social Sciences

Since the discovery of the wave nature of light, people have studied and exploited all different frequencies. Ask students to research the ways that we use waves from all portions of the electromagnetic spectrum. They may already be familiar with the use of x-rays and microwaves, but encourage them to look for less common applications. Have them identify the advantages and disadvantages of using specific wavelengths for these particular applications.

Mathematics

Students will be measuring angles using protractors in the corresponding PhysicsQuest activity. You can use this activity to motivate the definitions of sine, cosine, and tangent. Using these mathematical tools can help students see why groups using different set-up distances still get the same angles. Consider adding the following portion to their lab write-up.

> Draw a diagram of your experimental set-up, being sure to label all the distances.
>
> - How far is your laser from the grating? ________________________
> - How far is your grating from the wall? ________________________
>
> Will groups with different set-up distances measure different angles? Why or why not?

Language Arts

Once students have completed the diffraction activity in small groups, have them write an account of their investigation. Since they are already familiar with diffraction and may have done some background historical research, students can focus on writing for a particular audience – the school paper, a science magazine, or their parents. Students can also give presentations about their investigations or engage in formal debates with peers who obtained different results.

Other Sciences

We can't observe most of the universe with the naked eye, or even with the most powerful optical telescopes. Many clues to the origin of the universe, its expansion and composition, and its evolution result from investigating other light waves in the electromagnetic spectrum. Have students research other ways that astronomers study space. Then, have them explain the technology that helps astronomers gather and analyze data in their pursuit of understanding the universe.

Activity 3 As the Washer Swings

Pendulum Races

This activity is a good way to introduce periodic motion and demonstrate the properties of a pendulum. Begin with two large pendulums set up in front of the class (they do not need to be identical). After demonstrating their swinging motion several times, tell the students that you are going to "race" the pendulums by releasing them at the same time. The "winning" pendulum will be the one that returns to its starting position the fastest. Have the students discuss what factors might increase/decrease the time it takes the weight to return to its original position. Possible answers include length, amount of weight, height of release, and type of string. Encourage students to explain their hypotheses.

Now perform several "races" for the students by varying features of the pendulums. Have students record the results of each race. Encourage them to think about how to keep track of the data so that at the end of the demonstration they can create a speed-optimized pendulum. If you have enough equipment, let each group create a pendulum to "race" against their peers.

- Which design wins? Why?
- What are the limitations in design?

Safety Notes

Groups working with pendulums should keep a safe distance from one another and watch where they are going so that no one is hit by a swinging weight.

Catching Up with the Pendulum

Students may be able to predict the path of a pendulum, but may not know how to describe it in terms of position, direction, or speed. This activity introduces that terminology.

Set up a large pendulum in the classroom. If you can, hang the string from the ceiling and tie the weight just above the floor. Pull the pendulum back from its equilibrium position and have one of your students stand beside it. When you let go of the pendulum, have the student run back and forth with the pendulum — matching his/her speed to its motion.

Ask the other students to comment on when he/she is running the fastest, when he/she is moving the slowest, and when he/she turns around.

- Where is the runner's speed maximum?
- What effect does changing direction have on speed?

What Matters Other Than String Length?

The PhysicsQuest activity only has students explore how the length of the pendulum affects its period. However, students may have intuitive ideas about whether the weight of the washer and height of release play a role in the outcome. Have small groups test such variables.

- Why is it important for each group to test only one variable at a time?

Let each group decide which variable to test, what data to collect, how much data to collect, and the method of collection. Have each group record their data in tables and graphs similar to the one provided for the PhysicsQuest activity. After all groups have completed their investigations, bring the class together to discuss the results.

- What variables affect the period of a pendulum?
- Why might these variables have an influence while the others do not?

If there is time, have each group present their data collection and analysis method along with their results. Encourage them to spend time planning the presentations as it is an important part of scientific progress. Write their results on the board so that everyone can see them in one place.

- Are there any discrepancies between what different groups found?
- What could account for these differences?
- Do any of the data collection methods seem more/less reliable than others?

Repeated Motion

Activity 1

Pendulum motion is just one of many predictable cycles found in our natural world. Have students brainstorm other examples of repeated motion such as the day and night cycle, circadian rhythms, springs, the rock cycle, and the phases of the moon. Write their examples on the board for discussion. Consider the similarities and differences between each of the examples and pendulum motion.

- Do all the cycles have regular time scales?
- Can they be used as a measure of time? How?

Activity 2

Have students repeat the PhysicsQuest activity using several different spring-and-weight systems instead of pendulums. Students should use the set-up shown in Figure 3.1. Rulers held horizontally off of a tabletop or a stack of books can be substituted for ring stands.

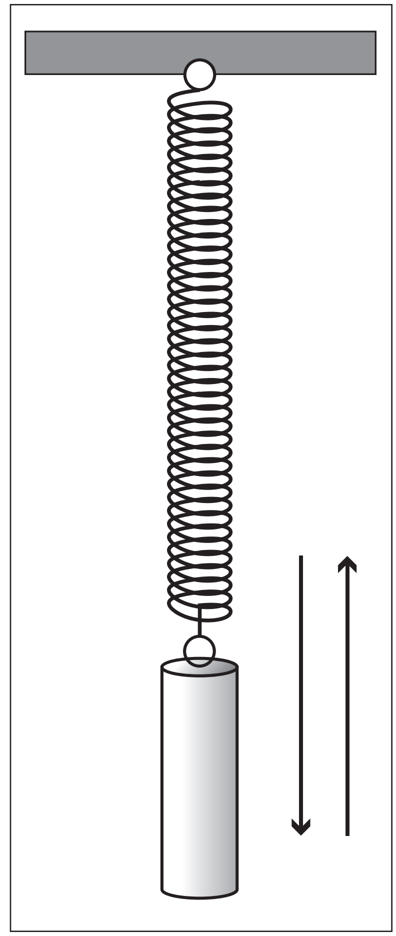

Figure 3.1

The Period of a Spring-and-Weight System

In the PhysicsQuest activity, the period of a pendulum was measured by holding the weight out to one side, letting go, and measuring the time it took the weight to return to its starting position. Similarly, the period of a spring-and-weight system is measured by pulling down vertically on the weight, letting go, and measuring the time it takes the weight to return to its starting position.

Springs with different spring constants should be provided so that students can investigate how the "stretchiness" of a spring affects its period. Also provide several different masses—it may surprise students that mass *does* affect the period of springs even though it *does not* affect the period of pendulums. Have each group choose one variable to investigate—give them one spring with several masses or one mass and several springs. Students can copy the format of the PhysicsQuest data table when recording their data. For reflection, have them answer questions such as:

- What features affect the period of a spring?
- What variables that affect a spring are the same as/different from those that affect the pendulum?
- What forces affect the motion of a spring?
- Was it easier to measure the motion of a spring or a pendulum? Why?

Integration with Other Curricular Elements

History

Using a pendulum to measure time was one of Galileo's major achievements. Students can research the history of chronology (the measure of time) and how discovery of the pendulum's periodic motion fit into its evolution. Pendulum technology also played a significant role in the search for a way to measure longitude at sea. Dava Sobel's book *Longitude* gives an excellent account of this story, students may enjoy reading excerpts of this.

Mathematics

Without knowledge of how to transform raw data into meaningful results, researchers would not be able to draw conclusions. Students can use data from this activity to learn about graphing, measures of central tendency, uncertainty, data transformation, trend line fitting and prediction, as well as sample size.

Language Arts and Social Sciences

Once students have completed the pendulum activities, they can write an account of their investigation or give a presentation to a particular type of audience about pendulums, clocks, Galileo, etc. Students can also give presentations about their investigation that include demonstrations or graphic representations of their work.

You may want to have students read historical accounts about measuring time and write book reports, or make timelines of progress in time measurement.

Other Sciences

The periodicity of motion is a common phenomenon in many physical, chemical, biological, and astronomical systems. Students can investigate repeated motion in other fields of science and compare those motions to pendulum motion. Students can also explore how engineers use knowledge of the physical world to solve real-life problems such as measuring time.

Activity 4 Furry Magnets

Mapping Magnetic Fields

Activity 1

A three-dimensional model of the magnetic field students saw in PhysicsQuest Activity 4 can be created using a plastic bottle. Pour vegetable oil and iron filings into the bottle and close the lid tightly. Shake the liquid so that the iron filings are spread evenly throughout the bottle. Then, hold a magnet up to the side of the bottle. The iron filings will disperse throughout the oil in the shape of the magnetic field. For other interesting results use magnets of different shapes or even multiple magnets on different sides of the bottle.

Safety Notes

It may be best to make the bottle for the first Mapping Magnetic Fields activity ahead of time so that you do not have to worry about students getting filings into their eyes or spilling slippery oil on the floor.

When students make magnets they will be working with nails, hammers, wire, and batteries. Use of these tools requires close supervision

Activity 2

In addition to using iron filings, students can also map the magnetic field of a bar magnet with a compass. Have students place a magnet on top of a piece of white paper in the middle of a non-metal table. Then, have them hold the compass at set distances around the magnet and mark the direction of the compass arrow at each point.

- How do the arrows vary with distance from the magnet?
- What factors affect the direction in which the arrow points?
- What pattern do the arrows create?
- Does this match what you saw with the filings?

Activity 3

The final exercise for mapping magnetic fields may be more appropriate for advanced students. Have students place a compass on the table with the needle pointing north. Then, have them place a ruler on each side of the compass so that the ends reading 0 cm are touching the compass.

Next have them put a bar magnet on each ruler and notice the orientation of the north and south poles.

- What happens to the needle when the magnets are the same distance from the compass? How does this depend on the orientation of the magnets?
- If the north ends of the magnets both face the compass, what happens when one magnet is closer to the compass?
- What about if the two south ends are used?
- How do things change when one north end and one south end are used?

In doing this, the students are observing the direction of the combined magnetic field from both magnets. These fields add and cancel depending on their relative orientations. Have students record their observations in a table similar to the one below or by drawing pictures of their set-up and results.

Pole of left magnet facing compass	Distance of left magnet from compass	Pole of right magnet facing compass	Distance of right magnet from compass	Approximate angle of compass needle
N	3.0 cm	N	5.0 cm	
N	5.0 cm	N	5.0 cm	
N	7.0 cm	N	5.0 cm	
S	3.0 cm	S	5.0 cm	
S	5.0 cm	S	5.0 cm	
S	7.0 cm	S	5.0 cm	
N	3.0 cm	S	5.0 cm	
N	5.0 cm	S	5.0 cm	
N	7.0 cm	S	5.0 cm	

Testing Magnetic Field Strength

In these activities, students will make quantitative observations abut magnetic fields.

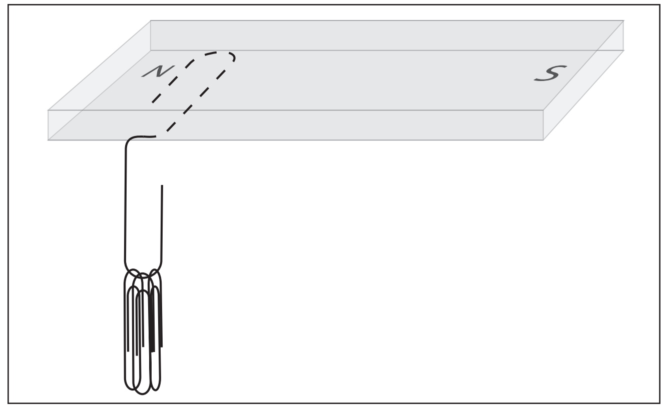

Figure 4.1
Testing the Strength of a Magnetic Field

Activity 1

Have an assortment of materials and a bar magnet on a non-metal desk. Ask students to predict which of the objects the magnet will be able to pick up from the table. Be sure they articulate the reasons for their predictions. Then have students test each of the objects.

- Are some of the objects easier to pick up than others? Why?

For objects that the magnet does pick up, have students try to pick up the object with different parts of the magnet.

- Is it easier to pick up objects with the end of the magnet or the middle of the magnet?
- Does it matter whether they use the north end or the south end of the magnet?

Have them record their observations and make a qualitative conclusion about which portion of the magnet exerts the strongest magnetic force. Students should find that the ends of a magnet exert a stronger magnetic force than the center.

Activity 2

Have students perform the following experiment to test their conclusion quantitatively. Bend a paperclip halfway open in the shape of an "L." Have students place this paperclip on the underside of the north end of a strong bar magnet so that the hook hangs down and the paperclip is supported by the magnetic force only (note — a long bar magnet works best for this). Then, students should slowly place other paperclips on the hook until the base paperclip falls off the magnet — this will be when the force of gravity overcomes the magnetic force. See Figure 4.1 for an illustration of this.

Once they have measured and recorded the number of paperclips that can be added before the hook falls off, for three different trials, have students move the hook 1.0 cm in toward the middle and repeat the exercise. They should continue down the magnet at 1.0 cm intervals until they reach the other end. They can record their observations in a table like the one below.

Distance from north end of magnet	Number of paperclips on hook		
	Trial One	Trial Two	Trial Three
0.0 cm			
1.0 cm			
2.0 cm			
3.0 cm			
4.0 cm			
5.0 cm			
6.0 cm			

Have your students plot their values on a graph with "Distance from the end of the magnet in cm" on the x-axis and "Number of paperclips" on the y-axis.

- Do they notice a pattern?
- Is the graph symmetric?
- What does this tell them about magnetic force?
- Do the results agree with the qualitative observations from the previous activity?

If you have access to other magnets, students can repeat these exercises for horseshoe magnets, circular magnets, and other shapes.

Activity 3

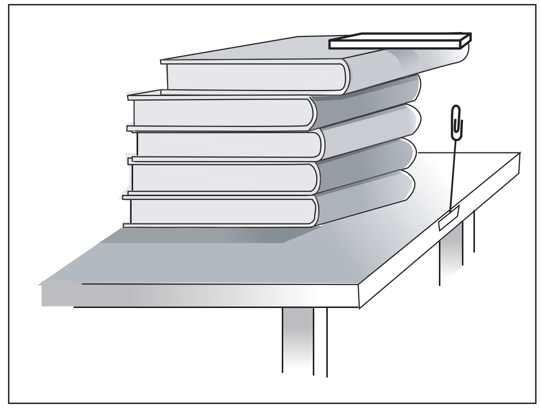

Figure 4.2

Have students explore what happens when various objects "shield" the magnetic force. They should cut a piece of string around 20 cm long, tape one end of the string to the table and attach a paperclip to the other end. Next to the string, have them make a pile of books on the table and tape a bar magnet to the top so that the edge of the magnet sticks out over the book. The magnet should be high enough so that it can hold the paperclip up in the air without touching it. There should be at least 5 cm between the magnet and the paperclip. See Figure 4.2.

The magnet holds the paperclip in the air because the force it exerts on the paperclip is larger than the force of gravity. Have several different materials - paper, cardboard, Styrofoam, a book, plastic wrap, aluminum foil, a metal sheet, a glass dish with water, wooden blocks, etc. - for students to place in the space between the magnet and the paperclip. Have students observe and record what happens to the paperclip when each material is inserted in the empty space.

- What materials "shield" the paperclip from the magnetic force the most? How can you tell?
- Why might it be important to know which materials block magnetic force?
- What properties of the materials seem to affect shielding capability?

Magnetizing and Demagnetizing Objects

In this activity, students make their own magnets and compare the strength of magnets made by different methods.

Activity 1

Give each student a long, thin nail and a bar magnet. After laying the nail on a non-metal table, have them stroke the nail IN ONE DIRECTION with the end of a bar magnet. After about 20 strokes, each student should try to pick up paperclips with their nail (by magnetic force, not by hooking them on the nail!) and record how many their nail can hold. Have students stroke another nail 30 times and record how many paperclips that nail can pick up.

Have students record their observations in a table like the one shown. They can also plot these data on a graph.

Number of strokes with the bar magnet	Number of paperclips picked up		
	Trial One	Trial Two	Trial Three
10			
20			
30			
40			
50			
60			
70			

- Is there a limit to the strength of a magnet made with this method — are there a maximum number of paperclips that can be picked up?

Activity 2

Students can also magnetize a nail by striking it lightly with a hammer. Have them lay a nail on the table pointing north. Using a small hammer, students should lightly tap the nail several times. This action will force loose dipoles to arrange themselves in the same direction. Again, have students test the strength of the magnets they made and organize their observations in a table similar to the one used previously.

- Does hitting the nail more times cause the magnet to become stronger or weaker?

Activity 3

Students can also make magnets with un-insulated wire using the method described above. After they do this, ask them to predict what will happen when they cut their wire in half.

- Will the magnetic properties be lost?
- Will you end up with two magnets?

- If two magnets are made, will they both be as strong as the original magnet?

Using wire cutters, help the students cut their magnets in half. They should find that cutting a magnet in half makes two magnets. Have them test the strength of these magnets.

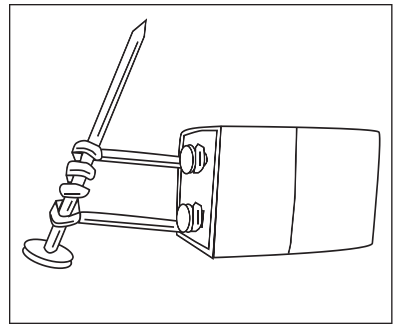

Figure 4.3

Activity 4

As a brief introduction to the relationship between electricity and magnetism, have your students build an electromagnet by wrapping insulated wire around a nail several times in the same direction. Then have them connect the free ends of the wire to a 9-volt battery as shown in Figure 4.4. Note: these batteries drain fairly quickly so have a good supply available.

When current goes through the wire, the moving charges create a magnetic field similar to that from a bar magnet. That field forces the domains to align in the nail, turning it into a magnet.

- Is the nail strong enough to pick up any paperclips?
- What happens if you wind more wire around the nail? Does the magnet get stronger or weaker?

Activity 5

When magnets are dropped, shaken, hit, or heated, they tend to lose their magnetic properties. Have students use the nail or wire magnets they made to investigate this process.

- How many shakes does it take before your magnet can no longer support a paperclip?
- How many times can you hit your magnet before it can no longer support a paperclip?
- How long do you have to heat a magnet before it can no longer support a paperclip?

Again, have students record their results in a table or on a graph.

Integration with Other Curricular Elements

History and Social Sciences

Societies have taken advantage of the magnetic properties of materials for years. Have students research how this field of study began and the evolution of applications of magnetic fields. They may already be familiar with compasses and metal detectors, but encourage them to look for other common applications like credit cards. In what other ways are magnetic properties used to solve technological problems?

Language Arts

Once the students have completed the magnetic field activities, they can write an account or give a presentation on their investigation with accompanying graphics. Encourage them to talk about how they used the scientific method throughout the investigation.

You could also have students research how people have used magnets over time and make a timeline of important developments in magnet use.

Biological Sciences and Technology

Magnetic fields are used in many medical diagnostic procedures. Ask students to research areas of medicine where magnetic fields are used, paying special attention to how different cells, tissues, and muscles react to these treatments.

- What properties of biological structures respond to magnetic fields?
- How can doctors take advantage of this in diagnosing patients?

Some companies claim that magnetic fields can have healing effects for people with chronic pain. Encourage students to research this claim and either support or refute the effectiveness of such products.

Astronomers use the magnetic fields that exist around astronomical bodies to learn more about the universe. Have students identify astronomical sources of magnetic fields and the type of information that such fields give scientists.

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