Sixth Through Twelfth Grade:
Physical Science and Earth Science

Case of the Falling Gargoyles

News Flash! Historical gargoyles tumble down in rain! In today's news, several landmark gargoyles on top of an old church in the historical center of town toppled from their perches. Fortunately, there were no injuries from the falling statues since they came down at night. The marble gargoyles have occupied the top of the old church for over 150 years. Archaeologists are unsure as to why the gargoyles fell.

Local historians are calling this a great loss to the city, as it is impossible to replace the amazing statues that were hand carved by artisans more than 150 years ago. An inspection of the remaining gargoyles shows great damage with more ready to fall. One inspector remarked, "They look like they're melting in the rain." City officials want answers before any more gargoyles are lost and someone is hurt. Why are the gargoyles falling?

Investigation

As an intern at the City Building and Safety Department, you have been assigned to help investigate this case. Your research has produced many historical images of the gargoyles and the old church. The photos show that the gargoyles appeared to be in good condition with much of the damage only becoming visible recently. Your first inclination is that something was wrong with the original design. But at the city museum, an examination of two gargoyles that were never mounted outside reveals that they are well made and show no signs of degradation over time. Your investigation reveals that many outside statues in the center of town and even headstones in local graveyards are dissolving. This leads you to consider rain as a possible cause.

You are equipped with a ProScope to gather microscopic evidence from building materials used throughout the city, including marble, limestone, and granite. Each of the materials has been exposed to different types of "rain" over a period of time. You will use a Vernier pH Sensor and a Conductivity Probe to test differences in the rain. These differences include the acidity level of the rain and the Total Dissolved Solids (TDS) in the rain before and after coming in contact with the building materials. By analyzing the data, you will be able to determine the relationship between the rain and damage to the gargoyles. To explain your findings to the city council and the local TV news station, you will use iMovie and iPhoto to present the case of the falling gargoyles.

Objectives

In this experiment, you will:

- Use a pH Sensor to measure the acidity of simulated rain and runoff
- Use a Conductivity Probe to measure the Total Dissolved Solids (TDS) of simulated rain and runoff
- Use a ProScope digital USB microscope to document detailed images of common building materials
- Determine the relationship between increased acidic precipitation and the potential damage to common building materials over time
- Communicate conclusions of scientific investigation in a multimedia format using iPhoto and iMovie software

Materials

- Macintosh computer with Mac OS X
- iMovie software
- iPhoto software
- Bodelin ProScope with 50X lens
- Bodelin USB Shot software
- Vernier pH Sensor
- Vernier Conductivity Probe
- Vernier Go! Link interface
- Vernier Logger Lite software
- 300 mL beakers
- 100 mL graduated cylinder
- Rock samples (marble, granite, limestone)
- Ice pick
- Clear 9-ounce plastic cups
- Distilled white vinegar
- Distilled water
- Tap water

Procedure

1 In your science journal, write down your hypothesis as to why you think the rain is causing the gargoyles to fall. Make sure you explain why.

2 Obtain and wear goggles.

3 To set up the samples, follow these steps:

a Using a pair of scissors or an ice pick, carefully punch four or five holes in the bottom of nine 9-ounce plastic cups.

b Label three of the cups "Marble," then place a sample of the marble rock in each of those cups.

c Label one of the Marble cups "Vinegar," one "1:4 Solution," and one "Tap Water."

4 Repeat step 3 with the other rock samples, then place each of the labeled cups inside one of the 300 mL beakers.

5 Set up the ProScope.

a Open the USB Shot application. The ProScope should now be active.

b Select one of the marble samples. Touch the tip of the ProScope with the 50X lens to the marble sample to view an image. Then, press the button on the ProScope to snap a still image. Repeat this step for each of the remaining rock samples.

6 Create four data tables like the ones in the "Data" section. Insert appropriate material images into the "Day One" column of Table 4, and write a description of each image.

7 Prepare the computer to collect pH data:

a Connect the pH Sensor to Go! Link.

b Make sure the Go! Link is connected to the computer.

c Open the Logger Lite application.

d Choose Data Collection from the Experiment menu and set the experiment length to 15 seconds.

e Click Done. You are now ready to collect pH data.

8 For the pH measurement, follow these steps:

a Place 50 mL of tap water in one of the 300 mL beakers.

b Remove the pH Sensor from the storage bottle. Rinse the tip of the sensor thoroughly with distilled water.

c Place the tip of the sensor into the sample. Submerge the sensor tip to a depth of 3-4 cm.

Important: Hold the pH Sensor so that the cup does not tip over.

9 If the pH value displayed in the meter is fluctuating, determine the mean (or average) value. To do this, follow these steps:

a Click the Collect button  to begin a 15 second sampling run.

Important: Leave the sensor tip submerged while data is being collected.

b When the sampling run is complete, click the Statistics button to display the statistics box on the graph.

c Record the mean pH value on your sheet or in your science journal and record it in the "pH" row and "Tap Water" column.

d Disconnect the pH Sensor from the Go! Link.

e Rinse the pH Sensor in distilled water and return it to the storage solution, tightening the cap on the bottle.

10 Prepare the computer to collect conductivity data:

a Set the conductivity setting switch to 0 to 2000.

b Connect the Conductivity Probe to Go! Link.

c Make sure the Go! Link is connected to the computer.

d Click the NEW button on the toolbar.

e Choose Data Collection from the Experiment menu and set the experiment length to 15 seconds.

f Click Done.

g Click Experiment on the toolbar, then choose Set Up Sensors.

h Click the icon of the Conductivity Probe and choose "TDS 1000/mg/L <computer>" from the drop-down menu.

11 Place the Conductivity Probe into the tap water sample.

a When the reading has stabilized, click Collect  .

b After data collection ends, click the Statistics button. Find the mean for the total dissolved solids (TDS) and record your result in the "TDS" row and "Tap Water" column.

12 Repeat steps 7 through 11 with the 1:4 solution and vinegar. In this experiment, tap water represents normal rain, the 1:4 solution of vinegar and tap water represents weak acid rain, and the vinegar represents a moderately strong acid rain.

13 Measure 50 mL of the tap water, then drizzle it over the marble sample in the cup labeled "Tap Water," allowing the water to run off into the beaker.

14 Repeat step 13 with the 1:4 solution and vinegar.

15 Repeat steps 13 and 14 with the granite and limestone.

16 The next day, use the ProScope to snap new images of each of the samples.

a Insert the images into the Day 2 column of Table 4.

b Write a description of each of the samples, noting any changes from the day before.

17 Repeat the entire procedure every day for a period of four days. Make sure to place your data in the data sheet every day.

18 On the fifth day, make final observations of the materials and use the ProScope to snap final images.

19 On the fifth day, measure the runoff from each material for pH and TDS. Record your measurements in Table 2.

20 Compare the runoff data to the rain data. Calculate the changes and record them in Table 3.

21 Within your Applications folder, find the Snap folder created by USB Shot. Import this folder or specific images into iPhoto for captioning, organization, and presentation.

22 Prepare an iPhoto slideshow of the microscopic examination, to support an oral presentation of your findings.

23 Combine the pH and TDS data, material images, and information you collected from your research in a creative and informative iMovie project. Use the rubric, storyboard form, and brainstorm form to plan your iMovie project.

Data

Table 1

Rain Data (Measure and record this data prior to the experiment.)

	Tap Water	1:4 Solution	Vinegar
pH			
TDS			

Table 2

Runoff Data (Measure and record this data *after* the experiment.)

	Tap Water	1:4 Solution	Vinegar
pH–Marble			
TDS–Marble			
pH–Limestone			
TDS–Limestone			
pH–Granite			
TDS–Granite			

Table 3

Change in pH and TDS From Rain to Runoff (What changes were noticed in pH and TDS values as "rain" became runoff?)

	Tap Water	1:4 Solution	Vinegar
pH–Marble			
TDS–Marble			
pH–Limestone			
TDS–Limestone			
pH–Granite			
TDS–Granite			

Table 4

	Day One (Original condition)	**Day Two**	**Day Three**	**Day Four**	**Day Five**
Marble– Tap Water					
Marble– 1:4 Solution					
Marble– Vinegar					
Limestone– Tap Water					
Limestone– 1:4 Solution					
Limestone– Vinegar					
Granite– Tap Water					
Granite– 1:4 Solution					
Granite– Vinegar					

Case of the Falling Gargoyles: Rubric

As you conduct your experiment on the falling gargoyles and the effects of acid rain on building materials, use the Internet and print resources to investigate this topic. Your assignment is to create an entertaining and informative iMovie project about acid rain. Your movie should include all the following:

- What causes acid rain?
- What are the common effects of acid rain on building materials and on the environment?
- Which materials are most vulnerable to acid rain and why?
- What can humans do to minimize the formation of acid rain?
- Results of your experiment

Use the brainstorm and storyboard forms to collect and organize your research. Guide your own progress using the rubric provided below. The class will share projects with each other on _____.

Criteria	Excellent 20	Good 15	Needs Improvement 10	Self-Assessment	Teacher Assessment
Accuracy of Information	All aspects are accurately represented.	Most aspects are accurately represented.	Few aspects are accurately represented.		
Audio Soundtrack	Soundtrack provides pertinent information and enhances production.	Soundtrack provides minimal information.	Soundtrack inaccurate and/or distracting.		
Requirements	All requirements are met and exceeded.	All requirements are met.	Some requirements not completely met.		
Organization	Content is well organized using titles/headings.	Uses titles/ headings to organize, but the overall organization is flawed.	Content lacks logical organization; uses no titles/headings.		
Storyboard	Detailed storyboard, with explicit narrative.	Shows very good planning, with limited narrative.	Shows basic understanding through illustrations, but no narrative.		
			Total Score		

Name _____

Case of the Falling Gargoyles: Storyboard

Name _____

Scene #____ Visual (location/set)	Script/Voiceover Music/Sound Effects:
Scene #____ Visual (location/set)	Script/Voiceover Music/Sound Effects:
Scene #____ Visual (location/set)	Script/Voiceover Music/Sound Effects:

Case of the Falling Gargoyles: Brainstorm

Name _____

Causes

Vulnerable Materials

Effects

Who will stop the acid rain?

Processing the data

Compare before and after images of each of the materials, and record any changes that you observe. Use Table 3 to record differences in the pH level and TDS for each type of "rain" as it becomes runoff for each of the samples.

Analyze your data

1 What changes did you notice in each of the materials?

2 What effect, if any, did the decrease in the pH of rain have on the damage to each material?

3 What did the change in pH from rain to runoff indicate?

4 What did the change in TDS from rain to runoff indicate?

5 How do you think your experiment differs from the real world?

6 Why does the degradation of building materials due to acid rain cause concern?

7 How can the information you gained be applied to the real world?

8 Based on your data and observations, what do you think the rain is doing to the gargoyles?

9 Do you think the gargoyles will survive? Be sure to support your answer with your findings.

10 How are statues like these protected? Research your answer on the Internet.

Teacher Information

Hypothesis

This experiment is designed to promote student observation, questioning, and presenting possible explanations. The identification of the problem is something that students may have observed in many parts of the country or world. The problem is common in most industrialized countries. In this experiment, allow students to form their own questions as part of the investigation and develop possible explanations or a hypothesis. Here is an example of a question and hypothesis.

Question: What changes occur to building materials that use marble, limestone, and granite when they are exposed to normal rain (tap water), a weak acid rain (1/4 vinegar, 3/4 tap water), and a moderately strong acid rain (vinegar)?

Hypothesis: Rain that is acidic in nature attacks building materials that use marble, limestone, and granite, causing damage to materials. The more acidic the rain, the more damage is caused.

Science concepts

Acid rain refers to rainfall with a pH of less than 5.6. Students may expect normal rain to have a pH of 7, which is neutral on the pH scale and is the pH of pure water. However, the traces of carbon dioxide present in Earth's atmosphere dissolve into precipitation, forming a weak carbonic acid (pH 5.6). In this experiment, students will be using tap water as their control, simulating regular rain. They should realize that normal rain is slightly more acidic than their control.

The primary causes of acid rain are emissions of sulfur dioxide (SO2) and nitrogen oxides (NOx). The burning of fossil fuels for generating electricity is responsible for about two thirds of all SO2 and one fourth of all NOx released into our atmosphere. Burning of fossil fuels for transportation is responsible for the largest proportion of NOx. When these substances are released into the air, they undergo chemical changes that result in the formation of sulfuric acid and nitric acid which significantly lower the pH level of precipitation.

The mass of the solids dissolved in a water sample is referred to as the total dissolved solids (TDS). One method of determining TDS is by using a Conductivity Probe. The probe measures how well electric current is conducted due to dissolved salts and their resulting ions. Conductivity can then be converted to TDS, since there is a nearly linear relationship between the two values. Limestone, sandstone, and marble are prevalent building materials for many statues, monuments, and buildings. The effects of acid rain can often cause serious damage to structures made from these materials.

Additional online resources

- http://www.epa.gov/airmarkets/acidrain/ (Environmental Protection Agency)
- http://pubs.usgs.gov/gip/acidrain/2.html (USGS)
- http://www.ec.gc.ca/acidrain/ (Environment Canada)
- http://macservcart.uncc.edu/faculty/haas/geol3190/termpap/earwood/ (Acid Rain's Monumental Effect)
- http://www.scienceshorts.com/articles/Acid%20Rain.htm (Dr. Humphreys)
- http://nadp.sws.uiuc.edu/ (National Atmospheric Deposition Program)

Facilitation tips

This experiment requires a considerable amount of data collection. You may opt to divide the class into groups, giving each group one material to investigate. Groups can then share data to draw conclusions. Additionally, other building materials such as sandstone can be investigated. Various degrees of acid concentration and resulting pH may also be used.

You will need to prepare the weak acid rain solution prior to beginning this experiment by combining vinegar and tap water in a 1:4 proportion.

Expected outcomes

In this experiment, you should expect to see evidence of corrosion on the limestone and marble. The stronger the acid, the more damage will be observed. There should be no noticeable change in any of the substances receiving water, though over an extended period of time, water alone will cause weathering. Granite is a combination of minerals, so you may see the acetic acid react with some minerals containing calcium within the granite. However, the damage to the granite rock will be minimal, especially to the naked eye. When observed under the ProScope, some damage to the granite should be evident. Students should also gain an understanding of the chemical reaction that takes place when an acid meets a basic material such as limestone.

Sample results

Table 1

Rain Data (Measure and record this data prior to the experiment.)

	Tap Water	1:4 Solution	Vinegar
pH	8.3	2.1	1.9
TDS	53.84	389.2	660.5

Table 2

Runoff Data (Measure and record this data *after* the experiment.)

	Tap Water	1:4 Solution	Vinegar
pH–Marble	7.0	2.7	2.6
TDS–Marble	60.37	519.4	733.1
pH–Limestone	7.7	2.7	2.9
TDS–Limestone	88.45	526.2	1462
pH–Granite	7.5	2.4	2,4
TDS–Granite	60.2	396.7	691.7

Table 3

Change in pH and TDS From Rain to Runoff (What changes were noticed in pH and TDS values as "rain" became runoff?)

	Tap Water	1:4 Solution	Vinegar
pH–Marble	-1.3	+.6	+.7
TDS–Marble	+6.53	+130.2	+72.6
pH–Limestone	-.6	+.6	+1.0
TDS–Limestone	+34.61	+137	+801.5
pH–Granite	-.8	+.3	+.5
TDS–Granite	+6.36	+7.5	+31.2

Table 4

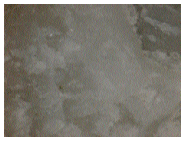
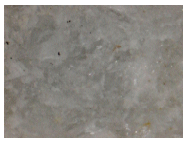
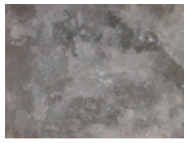
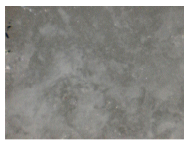
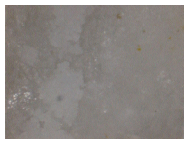
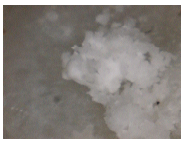
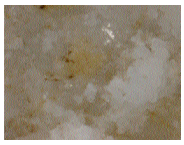
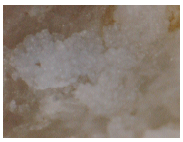
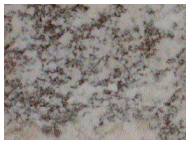
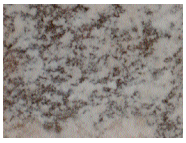
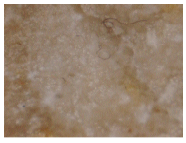
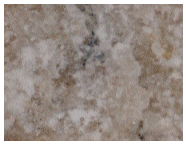
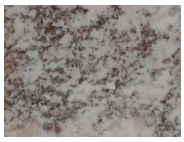
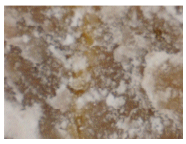
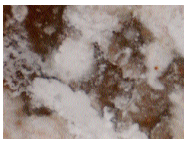
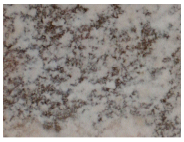
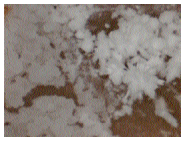
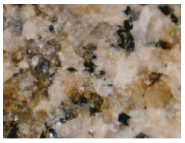
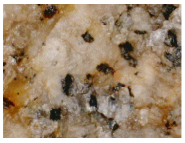
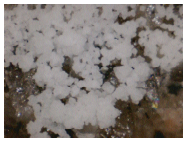
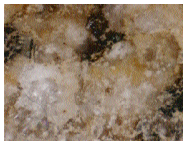
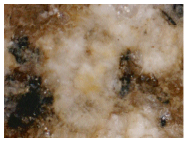
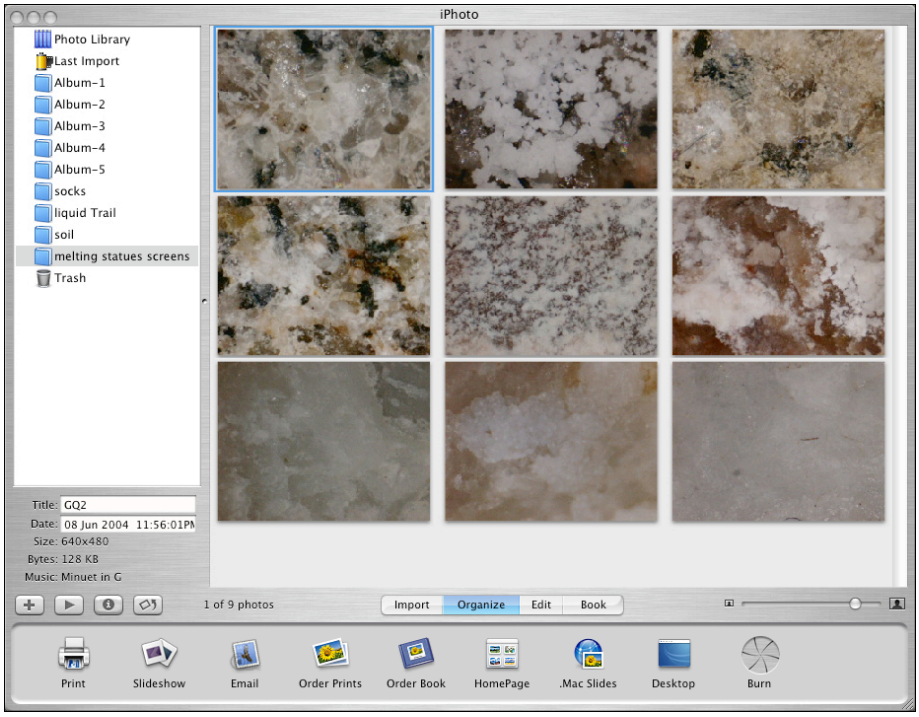
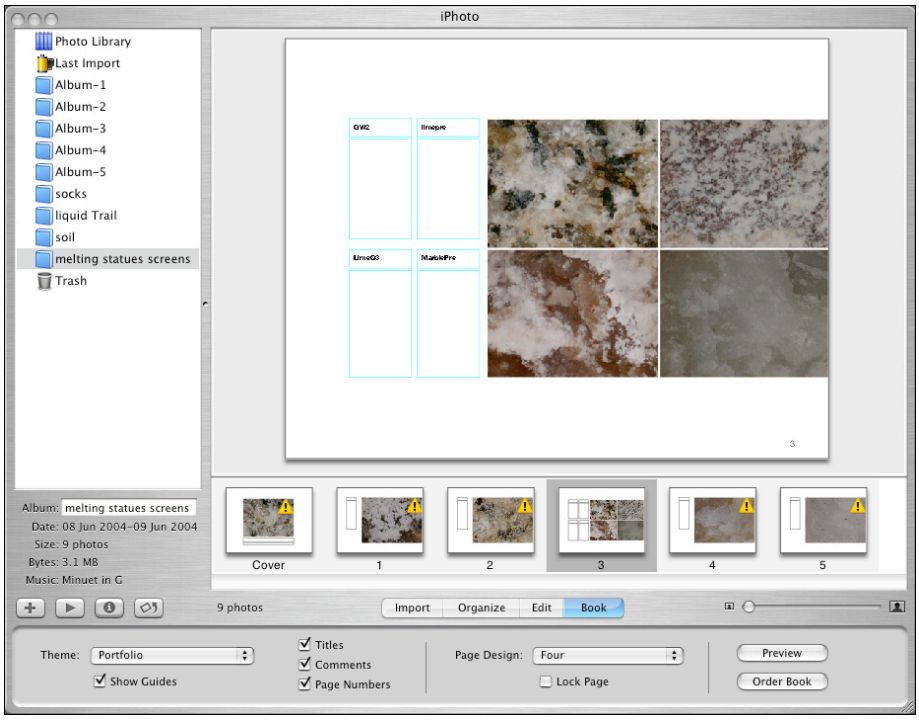
	Day One (Original condition)	**Day Two**	**Day Three**	**Day Four**	**Day Five**
Marble–Tap Water	 Large, clear, and white crystals	 No noticeable changes	 No changes	 No changes	 No changes
Marble–1:4 Solution	 Large, clear, and white crystals	 No noticeable changes	 Patch of small surface crystals	 Several patches of crystals on surface of rock	 Patches of white crystals, some quite large
Marble–Vinegar	 Large, clear, and white crystals	 The marble has turned yellowish. There are sugary looking crystals on top of the marble.	 Layer of fine crystals on surface	 Large crystals on surface of rock; layer of loosened particles	 White sugary crystals cover much of surface.
Limestone–Tap Water	 Small crystals, white and black	 No apparent change	 Color change	 No changes	 No changes
Limestone–1:4 Solution	 Small crystals, white and black	 Sugary crystals forming on surface; yellow tint	 White crystals on surface	 Large crystals on surface	 Overall lighter color of rock; white surface crystals in patches

Table 4 (continued)

	Day One (Original condition)	**Day Two**	**Day Three**	**Day Four**	**Day Five**
Limestone–Vinegar	 Small crystals, white and black	 Large, spiky crystals on surface; yellowish	 Numerous, large spiky white crystals on surface	 Large, white spiky crystals cover surface of rock.	 Overall smooth appearance. Much of surface is covered with sugary looking crystals.
Granite–Tap Water	 Multicolored crystals	 No changes evident	 No changes	 No changes	 No changes
Granite–1:4 Solution	 Multicolored crystals	 Slight discoloration	 Small patch of white crystals on surface	 Small patch of sugary crystals on surface	 Tiny patch of small crystals on surface.
Granite–Vinegar	 Multicolored crystals	 Definite discoloration; brownish tint to white specks	 Few small surface crystals observed	 Crystals of quartz appear broken.	 Rock appears to be darker.





Extensions

- Science. In addition to damage to building materials they have investigated, students can study the effect of acid rain on metals. They can try this experiment with copper pennies.
- Ecology/biology. What effect does acid rain have on the living environment? Students can test the effects of acid rain on plant growth by watering bean plants of the same size with various degrees of acid rain.
- Science. Prolonged periods of acid rain make a difference. Make this a long-term experiment.
- Mathematics. How do students think the mass of the materials might change when exposed to acid rain? Measure the mass before and after this experiment. Based on your calculations, how long would your sample last before it disappeared?
- Does your community have a problem with acid rain? Have students monitor rainfall in your area over a period of time. They can investigate the source of acid precipitation in your community if there is a problem.
- Internet research. Many of the ancient cities had entire buildings that used marble. This is especially true in places like Rome and Greece. Students can explore how these incredible sites are protected.
- History. Have students address these questions: Why is marble used as both a building material and an art material? Where does it come from?

Answers to analyzing your data questions

1 Students should notice definite changes in the limestone and marble. Marble is a metamorphic rock formed from limestone. Both limestone and marble contain calcium carbonate (CaCO3). The acetic acid of vinegar reacts with the calcium carbonate to accelerate the decaying process. The loosened crystals that appear on the stones are easily washed away by the next rain.

2 The lower the pH value of the rain (the more acidic), the more damage is observed.

3 The change in pH in the limestone and marble indicates that the acid has been slightly neutralized by the basic calcium carbonate in those materials.

4 The increase in TDS indicates that there has been an increase of dissolved solids in the runoff resulting from the wearing away of the stones.

5 In the real world, acid rain can come in the form of any type of precipitation. Additionally, dry deposits of acidic compounds can cause damage. It is also important to realize that harmful SO2 and NOx are carried by winds, making emission problems more than just a local concern.

6 Acid rain has caused costly damage to bridges and cultural artifacts. Additionally, there are health and environmental concerns associated with acid rain.

7 Granite could be a better building material in areas where acid precipitation is a problem since it can better withstand acid rain due to its chemical makeup. Granite is an intrusive igneous rock composed of several different minerals. Unlike marble and limestone, granite is not primarily composed of calcium.

8 The acid rain is dissolving the marble that the gargoyles are made out of.

9 No, the acid rain is clearly attacking the surface and surrrounding structure. Unless the pH moves more toward the neutral reading, the gargoyles are doomed!

10 In some instances, a clear polymer or plastic-like material is painted on the surface to protect the material from the acid.

Science standards alignment

This experiment provides direct alignment to national standards by allowing students to actually see and measure changes in the physical properties of matter that is interacting. In this case, they examine the acid rain and the marble, granite, and limestone. The experiment also emphasizes alignment with measurement, inquiry, and investigative standards by having students use technology to practice and gain insight to these skills. In addition, the experiment exposes students to hazards that are man-made in origin and affect the environment which in turn affects society.

National Science Standards

Unifying Concepts and Processes

1 Evidence, models, and explanation.

2 Change, constancy, and measurement.

Science as Inquiry

Content Standard A

As a result of activities, students should develop

1 Abilities necessary to do scientific inquiry.

2 Understandings about scientific inquiry.

National Content Standards

Level 5-8. Physical Science Standards

Content Standard B. Properties and changes of Properties in matter.

Substances react chemically in characteristics ways with other substances to form new substances with different characteristic properties.

Level 5-8 Science in Personal and Social Perspectives.

Content Standard F. Populations, Resources and Environments.

Causes of environmental degradation and resource depletion vary from region to region and from country to country.

National Educational Technology Standards. (ISTE)

Standards Categories

1 Basic operations and concepts

3 Technology productivity tools

4 Technology communication tools

5 Technology research tools

6 Technology problem-solving and decision-making tools

Performance Indicators

1 Use content-specific tools, software, and simulations (e.g., environmental probes, graphing calculators, exploratory environments, Web tools) to support learning and research.

2 Apply productivity/multimedia tools and peripherals to support personal productivity, group collaboration, and learning throughout the curriculum.

3 Design, develop, publish, and present products (e.g. Web pages, videotapes) using technology resources that demonstrate and communicate curriculum concepts to audiences inside and outside the classroom.

4 Collaborate with peers, experts and others using telecommunications and collaborative tools to investigate curriculum-related problems, issues and information, and to develop solutions or products for audiences inside and outside the classroom.

5 Select and use appropriate tools and technology resources to accomplish an variety of tasks to solve problems.

Learn more

If you enjoyed this hands-on science experiment, learn more about the Science CSI Kit and additional curriculum lessons that can be used for concentrated science investigations at: http://www.apple.com/education/sciencecsikit.

Special thanks

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